

DEVELOPING STUDENTS' PRACTICAL COMPETENCIES THROUGH VIRTUAL LABORATORIES AND INTERACTIVE SIMULATIONS IN TEACHING ECOLOGY

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Abstract

This article analyzes the pedagogical potential of using virtual laboratories and interactive simulations in teaching ecology, as well as their methodological significance in developing students' practical competencies. It highlights opportunities for modeling ecological processes, assessing the impact of anthropogenic factors, analyzing environmental monitoring results, and drawing scientifically grounded conclusions using digital educational tools. Furthermore, the article proposes stages for organizing virtual laboratory sessions, methods for integrating interactive simulations into the educational process, and criteria for assessing practical competencies.

Keywords: Environmental education, virtual laboratory, interactive simulation, practical competence, environmental monitoring, digital technology, ecological modeling, innovative pedagogical technologies.

Introduction

EKOLOGIYA FANINI O'QITISHDA VIRTUAL LABORATORIYALAR VA INTERFAOL SIMULYATSIYALAR ORQALI TALABALARNING AMALIY KOMPETENSIYALARINI RIVOJLANTIRISH

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ANNOTATSIYA

Mazkur maqolada ekologiya fanini o'qitishda virtual laboratoriyalar va interfaol simulyatsiyalardan foydalanishning pedagogik imkoniyatlari hamda talabalarning amaliy kompetensiyalarini rivojlantirishdagi metodik ahamiyati

tahlil qilinadi. Raqamli ta'lim vositalari orqali ekologik jarayonlarni modellashtirish, antropogen omillar ta'sirini baholash, ekologik monitoring natijalarini tahlil qilish va ilmiy asoslangan xulosalar chiqarish imkoniyatlari yoritiladi. Shuningdek, virtual laboratoriya mashg'ulotlarini tashkil etish bosqichlari, interfaol simulyatsiyalarni o'quv jarayoniga integratsiyalash usullari va amaliy kompetensiyalarni baholash mezonlari taklif etiladi.

Kalit so'zlar: ekologik ta'lim, virtual laboratoriya, interfaol simulyatsiya, amaliy kompetensiya, ekologik monitoring, raqamli texnologiya, ekologik modellashtirish, innovatsion pedagogik texnologiyalar.

INTRODUCTION

The global escalation of environmental problems today necessitates the improvement of the content and methodology of teaching ecology within the higher education system. In particular, modern digital technologies are becoming increasingly important for the scientific study of processes such as climate change, the loss of biodiversity, the depletion of natural resources, and environmental pollution.

The digital transformation of environmental education is closely linked to regulatory documents adopted in recent years. Specifically, Presidential decrees and resolutions covering the 2023–2026 period outline tasks aimed at raising environmental awareness, training specialists, and applying environmental knowledge in practice [1–5]. These priorities underscore the relevance of utilizing virtual laboratories as didactic tools.

The use of virtual laboratories in teaching ecology enables the visualization of complex environmental phenomena, the replication of experiments, and the analysis of interrelationships between various environmental factors. However, the effectiveness of these tools depends not only on their technical capabilities but also on their application in alignment with didactic objectives. The aim of the study is to provide a scientific basis for methodological approaches focused on developing students' practical competencies in teaching ecology through virtual laboratories and interactive simulations.

Based on an analysis of these documents, the following didactic sequence is proposed: translating regulatory requirements into learning outcomes →

modeling ecological situations → analyzing digital data → justifying ecological solutions → reflection and criterion-based assessment. This is an original methodological proposal and should not be interpreted as the verbatim text of regulatory documents.

Law No. ORQ-1036 "On Environmental Expertise, Environmental Impact Assessment, and Strategic Environmental Assessment," dated February 24, 2025 [5], defines the professional context regarding environmental assessment. Assigning students tasks that involve comparing alternative project scenarios, analyzing impact indicators, and substantiating conclusions with evidence aligns with this context.

Resolution No. PQ-110, dated March 25, 2026, envisages the intensification of environmental education, science, and advocacy within the framework of the "Eco-Culture" nationwide project [4]. The resolution focuses on training qualified specialists and developing the education system. Instructional activities combining virtual experiments, interactive simulations, and field studies are proposed as methodological solutions suited to these objectives; the document itself does not explicitly mandate the introduction of virtual laboratories in all higher education courses.

The Concept for Raising the Population's Environmental Culture through 2030 was approved by the President's Resolution No. PQ-184, dated May 15, 2025 [3]. This document aims to develop environmental education and strengthen the role of educational institutions. Its pedagogical interpretation requires linking students' environmental knowledge with their behavior and informed decision-making.

The state program associated with Decree No. PF-16, dated January 30, 2025, outlines priority tasks regarding environmental protection and the "green economy" [2]. Therefore, it is advisable to study practical aspects—such as resource efficiency, carbon footprint, and environmental risk assessment—through digital models within ecology courses.

Decree No. PF-81 of the President of the Republic of Uzbekistan, dated May 31, 2023, defines tasks for transforming the sphere of ecology and environmental protection [1]. This initiative highlights the practical importance of developing skills in environmental monitoring, data analysis, and environmental status

assessment. Modeling pollution scenarios in a virtual laboratory can facilitate the development of these competencies within an educational setting.

LITERATURE REVIEW AND METHODOLOGY

The use of virtual laboratories in the educational process has been extensively studied in international research. T. de Jong, M. C. Linn, and Z. C. Zacharia (2013) viewed virtual and traditional laboratories as complementary educational tools and substantiated the pedagogical significance of integrating them. Research by G. Makransky and colleagues reveals the complex relationships between the sense of presence, motivation, and learning outcomes in virtual learning environments. This implies that the technological appeal of a virtual environment does not always guarantee deep mastery of knowledge.

This article is based on a theoretical-methodological analysis employing methods such as the comparative study of scientific literature, pedagogical modeling, a systems approach, and competency analysis. The methodological potential of virtual laboratories in teaching ecology is evident in the dynamic modeling of ecological processes, the study of the impact of abiotic and biotic factors on organisms, the analysis of population sizes and ecosystem stability, the processing of ecological monitoring data, and the making of scientifically grounded decisions.

ANALYSIS AND DISCUSSION OF RESULTS

Virtual laboratories expand the opportunities to link theoretical concepts in ecology with practical activities. They are of particular didactic importance when modeling ecological processes that are long-term, hazardous, or require significant material resources.

A four-stage methodological model is proposed to develop students' practical competencies.

Stage	Educational activities	Expected Competence
Diagnostic	Assessing environmental knowledge and practical preparation	Understanding the problem
Modeling	Conducting environmental experiments in a virtual environment	Inquisitiveness
Analytical	Comparing and interpreting the obtained results	Analytical thinking
Reflective	Drawing conclusions and evaluating solutions	Environmentally conscious decision-making

For instance, in a virtual laboratory session focused on "the impact of pollution factors on aquatic ecosystems," students can model the relationships between water temperature, dissolved oxygen levels, nutrient concentrations, and the living conditions of aquatic organisms. In this process, students first formulate a research hypothesis, then modify factor values within the virtual environment and represent the results in tables and graphs. In the final stage, they identify the probable causes of ecological changes and develop recommendations to address the issue. Such activities are aimed at developing competencies in research, data processing, identifying cause-and-effect relationships, and assessing ecological situations.

It is advisable to integrate virtual laboratories with traditional field observations and hands-on laboratory sessions, as digital models cannot fully replicate all the complex processes occurring in natural ecosystems. As a methodological proposal, it is recommended to evaluate the effectiveness of virtual laboratory sessions based on four criteria: identifying the ecological problem, designing the research process, scientifically analyzing the results, and substantiating ecological solutions. This model constitutes a theoretical-methodological proposal; to determine its pedagogical effectiveness, empirical testing involving experimental and control groups is required in future research.

CONCLUSION

The use of virtual laboratories and interactive simulations in teaching ecology expands opportunities for students to apply their ecological knowledge to practical activities. These technologies facilitate the organization of educational

activities focused on modeling ecological processes, analyzing experimental data, and developing scientifically grounded solutions to environmental problems.

Based on the theoretical-methodological analysis of the study, it is proposed that virtual laboratory sessions be structured around the stages of diagnosis, modeling, analysis, and reflection. Aligned with the objectives of regulatory documents, these virtual sessions enrich the content of students' practical assignments regarding elements of environmental assessment, monitoring, and sustainable development.

Integrating virtual laboratories with traditional practical sessions can strengthen the competency-based approach to environmental education. In this context, the teacher's methodological preparedness, the scientific reliability of digital resources, and the clarity of assessment criteria are considered crucial pedagogical prerequisites.

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