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Research Article

Integrating Online Laboratories into Secondary Biology Education: A Focus on Invertebrate Animals in Kazakhstan

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Abstract

This study explores the integration of online laboratories into secondary biology education in Kazakhstan, focusing on invertebrate animals such as earthworms. A localized, interactive lab was developed and piloted with seventh-grade students. Using a mixed-methods approach, the study compared academic performance and engagement between experimental (digital lab) and control (textbook) groups. Results showed a statistically significant improvement in learning outcomes and student motivation for the digital lab group. The study highlights the potential of localized digital tools that enhance science learning, promote equity, and modernize biology instruction in Kazakhstani schools.

Introduction

The role of digital technologies in transforming traditional educational methods has become increasingly prominent over the past decade, especially in STEM subjects such as biology. As educational systems around the world adapt to 21st-century learning needs, the use of online laboratories has emerged as a powerful tool to enrich the teaching and learning of science. These platforms provide students with opportunities for experiential learning, visual engagement, and self-directed inquiry—all of which are crucial for developing scientific literacy. In Kazakhstan, the integration of online laboratories remains relatively limited, with limited resources available in Kazakh and even fewer aligned with national curricular standards.

One of the most challenging topics in secondary biology is the study of invertebrate animals. These organisms, while fundamental to understanding biodiversity and evolutionary biology, often lack the physical representation or dissection opportunities in classrooms due to ethical, logistical, or financial constraints. This study explores the development and implementation of a contextually adapted online laboratory designed to teach invertebrate anatomy and locomotion—specifically earthworms—to Grade 7 students. Through a controlled experiment and detailed feedback analysis, the study evaluates how digital labs can serve as both a pedagogical innovation and a tool for educational equity in Kazakhstani schools.

Methodology

The study followed a mixed-methods design, combining quantitative assessments with qualitative feedback to obtain a comprehensive understanding of the online laboratory's impact. Fifty Grade 7 students from a private secondary school in Kazakhstan were selected to participate in the experiment. These students were divided into two equal groups:

- **Experimental Group (Class 7A):** Used the online laboratory, which included a 3D earthworm model, animation of internal systems, interactive labeling tasks, video explanations and integrated quizzes.
- **Control Group (Class 7B):** Followed the standard biology textbook and classroom instruction without access to any digital tools.

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Both groups were taught the same two lessons focusing on earthworm anatomy and locomotion. Pre-tests and post-tests were administered to assess students' prior knowledge and learning gains. Each test consisted of 10 multiple-choice questions aligned with core objectives from the national biology curriculum.

In addition to testing, students in the experimental group completed a Likert-scale survey with five key questions about the usability, clarity, interactivity, and perceived value of the online lab. This qualitative component helped to assess not only cognitive but also affective outcomes of the digital intervention.

Statistical analyses were performed using Microsoft Excel and SPSS software. A paired-sample t-test measured the significance of within-group learning improvements, while an independent-sample t-test compared the final performance between the two groups. Descriptive statistics were also used to interpret survey results.

Results

The results showed clear differences in learning outcomes between the experimental and control groups. The control group, which followed a traditional teaching approach, improved from a pre-test mean score of 5.2 to a post-test score of 6.3—representing a modest gain of 1.1 points. In contrast, the experimental group's mean score rose from 5.4 to 8.4, indicating a substantial gain of 3.0 points. A t-test confirmed that this difference was statistically significant at $p < 0.01$, suggesting that the digital intervention had a meaningful effect on learning outcomes (Figure 1).

The bar chart shows the average scores before and after the intervention for both groups. The experimental group's markedly higher post-test scores underscore the pedagogical benefits of visual interactivity and digital scaffolding in complex biology topics.

In the survey, the majority of students reported positive experiences with the online laboratory. Specifically, 92% agreed that the lab was easy to use, 88% felt that it helped them understand the material better, and 85% expressed a preference for learning through online labs rather than relying solely on textbooks. Students identified clear animations, self-paced review options, and interactive assessments as primary benefits. These findings support the assertion that interactive tools enhance both student motivation and scientific comprehension.

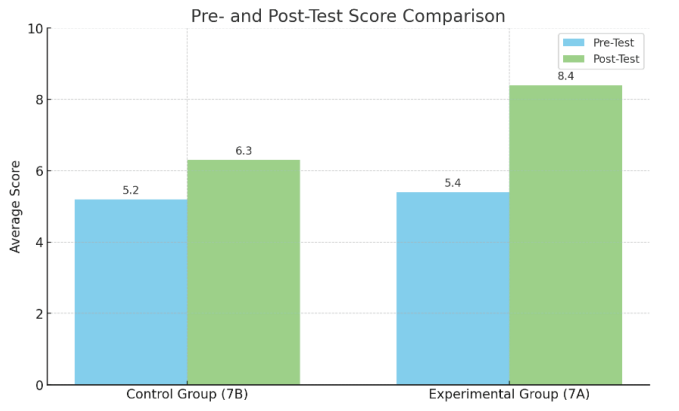

Figure 1: Pre-Test and Post-Test Score Comparison.

Discussion

The results of this study are consistent with international research findings about the impact of online laboratories on science education. As Smetana and Bell [1] argue, digital simulations can make abstract concepts more tangible and accessible, especially when physical laboratories are unavailable. In this case, the significant improvement in student performance highlights the potential of localized online labs to bridge gaps in science education caused by a lack of resources or instructional time.

Pedagogically, the online laboratory design reflects alignment with established educational theories. The visual design aligns with Mayer's [2] cognitive theory of multimedia learning, which emphasizes the value of dual coding through both visual and verbal content. The interactive elements reflected Bruner's [3] notion of discovery learning, while the scaffolded structure and pacing enabled student learning within the framework of Vygotsky's [4] zone of proximal development.

Furthermore, the study provides evidence that digital laboratories can support differentiated instruction and universal design principles. Because students were able to explore the material at their own pace, review sections independently, and choose the order of content engagement, the platform accommodated various learning styles. This finding aligns with Rose and Meyer's [5] argument that educational tools should be flexible and inclusive by design.

The positive student feedback also underscores the importance of engagement and motivation in learning science. Through the use of familiar digital formats and interactive components, the online lab aligned with students' digital literacy and expectations. This is particularly relevant in the Kazakhstani context, where the the education system is transitioning to digital platforms yet still lacks localized content aligned with cultural and linguistic contexts with students' cultural and linguistic realities.

However, challenges remain. The study was conducted in a private school with stable internet access and modern devices, conditions that are not universally available across Kazakhstan. Ethical considerations such as equitable access, student data privacy, and screen time management should be addressed prior to broader implementation. The online lab was built using open-source tools (GitHub, Netlify) to minimize cost, but broader deployment would require infrastructure support from the Ministry of Education and teacher training initiatives [6,7].

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Conclusion

This study demonstrates that integrating online laboratories into secondary biology instruction can significantly enhance both learning outcomes and student engagement. By developing and evaluating a digital platform tailored to the national curriculum and local language, the research highlights the pedagogical and practical benefits of educational technologies in Kazakhstan. The findings suggest these tools can enhance conceptual understanding of invertebrate animals but also foster greater student motivation and participation in science learning.

As the country advances toward digital modernization in education, it is essential to prioritize the development of accessible, curriculum-aligned digital resources. Future research should include longitudinal studies to evaluate long-term knowledge retention, extend implementation to rural and public schools, and explore additional biological content areas using similar platforms. Moreover, policy efforts should promote the expansion of digital pedagogy, investments in infrastructure, and the development of localized content to ensure equitable access to high-quality science education for all students in Kazakhstan.

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