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Organizing and Conducting Experimental Research on Improving Integrative Technologies for Teaching Biology in Academic Lyceums

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Abstract: This article presents the methodology used to organize and conduct experimental-testing (pedagogical experiment) work aimed at improving the integrative technologies of teaching biology in academic lyceums. The study is grounded in a comprehensive analysis of theoretical and applied pedagogical literature, together with an examination of the experience of countries that have achieved high educational outcomes, in order to justify the practical relevance of testing integrative approaches within the national education system. A set of scientific-methodological materials was developed, including textbooks, laboratory and practical manuals, and the original web-based educational platform integrative-biology.uz, which hosts theoretical materials, presentation resources, integrated video lessons, a glossary, tests, and a bank of didactically structured practical assignments for every topic of the school biology curriculum. The pedagogical experiment was carried out in three consecutive stages — ascertaining (2022–2023), formative (2023–2024), and final/summative (2023–2024) — across four academic lyceums located in Tashkent city, Navoi region, and Fergana region (Kokand), involving a total of 581 first- and second-year students divided into experimental (n = 283) and control (n = 298) groups. Learning outcomes were assessed through questionnaires, classroom observation, testing, and independent assignments, and the resulting data were processed using mathematical-statistical methods, including the χ^2 criterion, standard error, confidence intervals, and t-test-based reliability estimates. The mathematical-statistical analysis confirmed a statistically significant improvement in learning outcomes in the experimental groups, with an overall teaching-effectiveness coefficient of 12.5% ($\chi^2 = 50.87$, $p < 0.05$) across all four lyceums, and individual effectiveness values ranging from 11.4% to 13.6% per institution. The findings demonstrate that the integrative approach, implemented through the integrative-biology.uz platform and supported by digitally adapted, competency-oriented instructional materials, significantly enhances students' natural-science literacy, practical competencies, and learning motivation compared with traditional instruction.

Keywords: Integrative approach; biology education; academic lyceum; pedagogical experiment; digital educational platform; teaching effectiveness; competency-based learning; natural-science literacy.

Introduction: Improving the quality of biology education in academic lyceums requires not only the renewal of curricular content but also the introduction of pedagogical technologies capable of integrating disparate fields of knowledge into a coherent, competency-oriented learning experience. A broad analysis of the theoretical and applied pedagogical literature, combined with an examination of the results already achieved in this direction, revealed that testing the methodological and scientific experience of countries with high educational outcomes within the framework of the national education system holds substantial practical value. On this basis, the present study was designed to organize and empirically verify experimental-testing work devoted to improving the integrative technologies used in teaching biology in academic lyceums.

To support the pedagogical experiment, a series of

scientific-methodological materials was developed. These include the textbooks "Biology (Part 1)" and "Biology (Part 2)", prepared for academic-lyceum students in the natural-sciences track [10, 11]; the methodological textbook "Biology: Methodology of Teaching Based on Integrative Technologies" [12]; a dedicated study on organizing students' independent work with information resources during biology laboratory exercises [13]; and the specially designed web-based platform "Improving the Integrative Technologies of Teaching Biology in Academic Lyceums" (https://integrative-biology.uz/), officially registered with the Ministry of Justice of the Republic of Uzbekistan [14]. The theoretical and methodological foundations of the approach were further elaborated in the monograph "Improving the Integrative Technologies of Teaching Biology in Academic Lyceums" [15] and in a series of research articles addressing the methodical system for applying integrative technologies in academic-lyceum biology instruction [16], the theoretical grounding of this methodology , the methodological conditions for forming integratively oriented knowledge through cooperative learning , the conceptual foundations of the integrative approach its broader methodological and theoretical basis and the didactic model of integrative biology instruction .

The integrative approach adopted in this study is grounded in a set of well-established didactic frameworks: Bloom's taxonomy of educational objectives, which underlies the graded design of the contextual assignments [1]; Vygotsky's sociocultural theory of learning, which informs the scaffolded, socially mediated character of the tasks [2]; the 5E instructional model (Engage–Explore–Explain–Elaborate–Evaluate), which structures the sequencing of lessons on the platform [3]; the TPACK framework for integrating technology, pedagogy, and content knowledge, which guided the design of the digital resources [4]; cooperative-learning strategies such as Jigsaw, Think-Pair-Share, and the Student Teams-Achievement Divisions (STAD) technique, which shaped the collaborative formats of classroom activities [5–7]; and the broader framework of twenty-first-century (4C) skills — critical thinking, communication, collaboration, and creativity — which informed the competency orientation of the assignment bank [8, 9].

METHODS

Purpose and Organization of the Experimental Work the purpose of the experimental-testing work was to determine, under real classroom conditions, the pedagogical effectiveness of integrative technologies for teaching biology in academic lyceums, and to verify the practical value of the instructional materials, tasks, and digital resources developed for this purpose. The experimental work was organized around first- and second-year students of academic lyceums, since it is at this stage that the pedagogical level of integrative-approach research can be most directly assessed through direct engagement with learners. The theoretical foundations of the results obtained during the study were analyzed for their practical significance, and the resulting conclusions were evaluated objectively.

To achieve these aims, the following action plan was implemented:

1- a bank of didactically structured electronic assignments was compiled and analyzed in terms of content and scope, drawing on the theoretical materials, presentation resources, integrated video lessons, glossary, and practical tasks available on the integrative-biology.uz platform for every topic of the biology curriculum, and the didactic factors that increase the effectiveness of independent assignments were identified and scientifically substantiated;

2- scientific-methodological materials were developed on the basis of tasks used in biology lessons with first- and second-year students, in order to analyze the level of their theoretical knowledge, and instructional recommendations were selected for developing competencies in working with information tools, applying innovative methods that foster creativity, and using didactic tasks that promote critical thinking;

3- the scope of didactic support for developing students' competence in working with contextual tasks was expanded;

4-the results of the experimental work were analyzed against established criteria for research on integrative biology instruction, confirming the validity and effectiveness of the proposed ideas, after which systematic conclusions were formulated and applied in practice.

The methodology for the experimental-testing work was developed through the identification and

resolution of organizational problems, systematic analysis and observation of first- and second-year biology lessons, questionnaires, surveys and interviews with students, a review of advanced pedagogical experience, and the pilot testing of experimental materials directly in biology lessons. Specially developed assignments aimed at improving integrative pedagogical technologies were used throughout the instructional process, and the practical exercises hosted on the integrative-biology.uz platform were actively employed. Information resources of varied content and form were analyzed and used to enrich and systematize the instructional materials, contributing to the development of students' natural-science literacy. Throughout the experiment, changes in students' mastery of content, analytical thinking, and learning dynamics were monitored on a regular basis, and learning outcomes were evaluated using control assessments and practical assignments.

Stages of Preparing Students and Teachers Preparing students to master and apply the improved methodological support was organized in three stages. In the preparatory stage, students' existing knowledge, skills, and gaps were identified through diagnostic questionnaires, which were then methodologically analyzed, and explanatory and awareness-raising work was carried out regarding the practical significance of the newly developed materials. In the practical-preparation stage, specialized training courses were planned and conducted for biology teachers in the participating academic lyceums; the instructional materials and methodological support were revised on a scientific basis using the results obtained in the preparatory stage, and teachers' lessons were observed and analyzed in light of the revised materials. In the correction and implementation stage, additional questionnaires were administered and analyzed, lessons were conducted by teachers on the basis of the revised materials and methodological support, and methodological recommendations were provided as necessary to correct shortcomings identified in the teachers' instructional practice.

The integrative-biology.uz Platform Effective use of the electronic assignment bank hosted on the integrative-biology.uz platform was found to be closely linked to students' thorough mastery of theoretical knowledge, their deep understanding of its content and essence, and its reinforcement through practical assignments. The combination of classroom lessons, extracurricular and out-of-class activities, and the electronic assignment bank available on the platform enabled the effective formation of students' biological competencies and practical skills through integrative technologies. Within the framework of the experimental work, materials and recommendations for creating electronic assignments on the platform were developed on the basis of the standard biology curricula and textbooks, reorganized around an integrative-pragmatic approach to adapting content to the digital environment, combined with digital and simulation-based technologies, and oriented toward developing practice-based competencies through virtual modeling and digital restructuring.

In the experimental groups, the effectiveness of the integrative approach was implemented and assessed continuously, transparently, and diagnostically through the application of the integrative-biology.uz platform in the instructional process, scientific-theoretical analysis and evaluation of practical experience, and a metacognitive-navigation approach designed to stimulate cognitive activity and the rapid dissemination and transformation of knowledge in the digital environment. In the control groups, the same tasks and tests were administered according to the traditional lesson plan, without recourse to the platform or the integrative approach.

Sample and Experimental Design Experimental and control groups were formed using the parallel-group method. Respondents were randomly selected from among first- and second-year students of four academic lyceums and randomly assigned to the experimental or control group. The experimental-testing work engaged a total of 581 respondents: 156 students of Academic Lyceum No. 2 of the Tashkent State Medical University, 304 students of the academic lyceum of the Tashkent Pharmaceutical Institute, 70 students of the academic lyceum of Kokand State University, and 51 students of the academic lyceum of Navoi State University. Of these, 283 students were assigned to the experimental groups and 298 to the control groups.

The experimental work was organized into three consecutive and logically sequential stages. In the ascertaining stage (2022–2023), the theoretical and organizational-methodological foundations of the

pedagogical experiment were developed. The existing level of students' competence in working with contextual biology assignments was diagnostically analyzed, directions for modernizing the instructional-methodological support were identified, and normative-legal documents, pedagogical and methodological literature, current textbooks, and scientific information sources were systematically reviewed to ensure the scientific-methodological reliability of the study. A bank of contextual tasks and test items oriented toward developing students' practical competencies was developed on the basis of the integrative approach and introduced into the pedagogical experiment through the integrative-biology.uz platform. In the formative stage (2023–2024), students engaged with the integrative approach and the platform in practice, while teachers observed the degree to which students mastered the assignments, and the lessons conducted were methodologically analyzed and their conclusions systematically summarized. In the final/summative stage (2024–2025), the results of the experimental-testing work were systematically generalized and analyzed; the findings were critically evaluated, and the validity of the research hypothesis and the practical effectiveness of the newly developed methodology in educational institutions were scientifically demonstrated.

The following research hypotheses guided the experimental work: that students would more effectively master the educational information delivered through the integrative approach and the integrative-biology.uz platform; that skills in working with assignments and interactive materials during biology lessons, analyzed through specialized methods, would improve through the use of specially developed lesson plans addressing identified problems; that monitoring learning outcomes would inform the correct methodological application of didactic tools for forming competence in working with educational information; and that the content and scope of students' competence in working with information, together with the improved integrative technologies, would be applied effectively in the instructional process.

Statistical Analysis the data collected during the experiment were processed using mathematical-statistical methods. For each participating lyceum and for the combined sample, the χ^2 criterion, mean values, standard error (SE), 95% confidence intervals, and reliability indices (t-test / χ^2) were calculated, and the pedagogical effectiveness of the integrative approach was expressed as a percentage difference between the experimental and control groups.

RESULTS

The statistical analysis confirmed a positive and statistically significant increase in learning outcomes among students of the experimental groups relative to the control groups at every participating lyceum. Across all four academic lyceums combined, the teaching-effectiveness coefficient of the integrative methodology was found to be 12.5% ($\chi^2 = 50.87$, $p < 0.05$), with effectiveness values for individual institutions ranging from 11.4% to 13.6% (Table 1).

Table 1.

Statistical indicators of the experimental-testing work across the participating academic lyceums.

Lyceum	Group	n	χ^2	Mean	SE	95% CI	t / χ^2	Effectiveness
Navoi SU AL	Experimental	51	6.34	4.27	0.17	4.08–4.46	3.0	13.6%
	Control	—	—	3.76	—	3.50–4.02	—	—
TSMU AL No.2	Experimental	156	11.5	4.11	0.12	4.06–4.36	3.5	11.4%
	Control	—	—	3.69	—	3.51–3.87	—	—

Lyceum	Group	n	χ^2	Mean	SE	95% CI	t / χ^2	Effectiveness
TPI AL	Experimental	304	28.82	4.15	0.06	4.06–4.24	7.8	12.8%
	Control	—	—	3.68	—	3.58–3.78	—	—
QSU AL	Experimental	70	8.04	—	0.15	3.91–4.31	2.93	11.9%
	Control	—	—	—	—	3.47–3.87	—	—
All four lyceums (combined)	Experimental	283	50.87	4.15	0.045	4.08–4.22	10.2	12.5%
	Control	298	—	3.69	—	3.62–3.76	—	—

The dispersion-spectral range and effectiveness of the results obtained were further optimized through algorithmic visualization and modeling, which illustrated the distribution of achievement levels among the experimental- and control-group students at the conclusion of the experimental-testing work (Figures 1–2). These visualizations confirmed that students in the experimental groups consistently achieved higher and more stable levels of mastery than their counterparts in the control groups across all four participating institutions.

Figure 1. Achievement indicators of experimental-group students at the end of the experimental-testing work

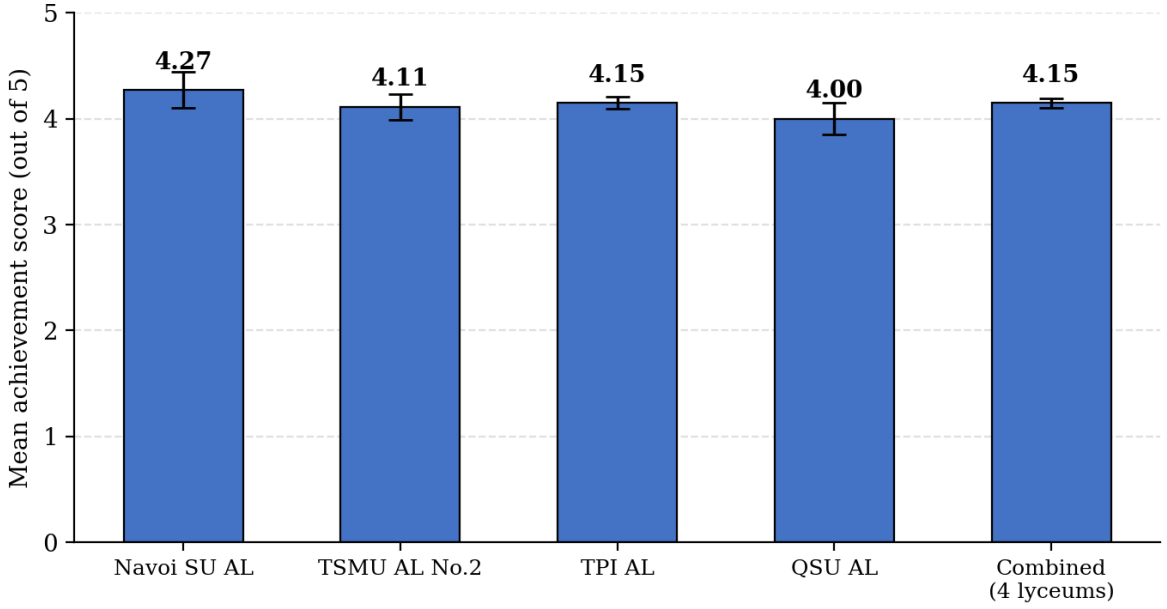

Figure 1. Diagram of experimental-group students' achievement indicators at the end of the experimental-testing work.

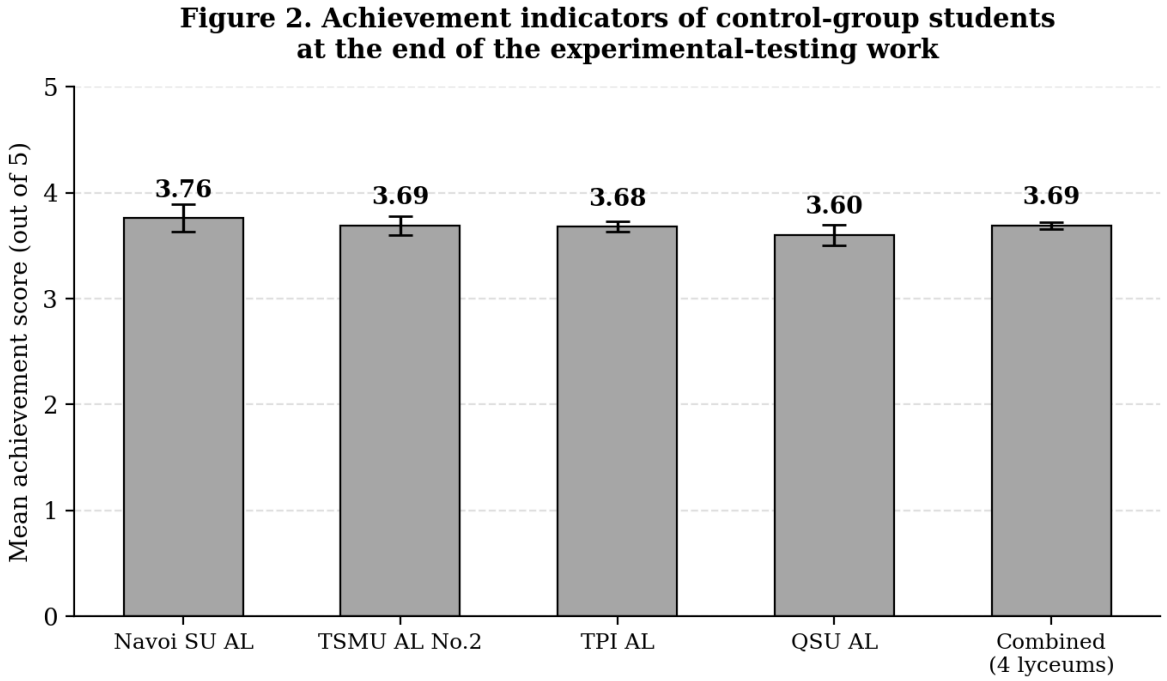

Figure 2. Diagram of control-group students' achievement indicators at the end of the experimental-testing work.

Overall, the results demonstrate that the integrative approach to teaching biology, implemented through the integrative-biology.uz platform and the accompanying didactic materials, produced a measurable and statistically reliable improvement in students' academic achievement, confirming that the goals of the experimental-testing work were successfully achieved.

DISCUSSION

The results of the experimental-testing work indicate that organizing biology instruction in academic lyceums around an integrative approach — supported by a dedicated digital platform, a structured bank of contextual assignments grounded in Bloom's taxonomy [1] and the 5E model [3], and teacher training aligned with the TPACK framework [4] and the new methodological materials — meaningfully strengthens students' natural-science literacy and practical competencies. The stepwise implementation of virtual construction and digital restructuring within the instructional process appears to activate students' reflective thinking and to strengthen mechanisms of learning motivation, consistent with the sociocultural, scaffolded model of learning described by Vygotsky [2] and with the collaborative gains reported for Jigsaw- and STAD-based instruction [5–7]; these effects are reflected in the consistently positive effectiveness values observed across all four lyceums.

The consistency of the effect across institutions with markedly different sample sizes — ranging from 51 to 304 students — together with the high overall χ^2 value for the combined sample, lends additional confidence to the reliability of the observed effect and suggests that the integrative methodology is robust across varying institutional contexts within the national education system. At the same time, the moderate variation in effectiveness across lyceums (11.4%–13.6%) points to the potential influence of local implementation conditions, teacher preparedness, and student baseline competencies, which merit further investigation in subsequent studies.

CONCLUSION

The experimental-testing work carried out within the framework of this study confirms that the improvement of integrative technologies for teaching biology in academic lyceums — implemented through the integrative-biology.uz platform, a structured bank of contextual and practical assignments, and a three-stage (ascertaining, formative, and final) pedagogical experiment — produces a statistically significant increase in student learning outcomes. Across a combined sample of 581 respondents from four academic lyceums, the methodology yielded an overall teaching-effectiveness coefficient of 12.5% ($\chi^2 = 50.87$, $p < 0.05$). These findings validate the research

hypotheses advanced at the outset of the study and demonstrate that adapting instructional content to the digital environment through an integrative-pragmatic approach, combined with simulation-based technologies and competency-oriented tasks, is an effective means of strengthening the systematicity and interdisciplinary coherence of biological knowledge among academic-lyceum students.

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