European Science Review 2026, No 3–4
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 7. Pedagogy

DOI:10.29013/ESR-26-3.4-64-67

DEVELOPMENT OF STUDENTS' RESEARCH SKILLS IN STUDYING GENETICS THROUGH DIGITAL MODELING AND CASE STUDY METHODS

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Cite: *Shakhmurova G.A., Mirkhamidova P. (2026). Development of Students' Research Skills in Studying Genetics Through Digital Modeling and Case Study Methods. European Science Review 2026, No 3–4.* https://doi.org/10.29013/ESR-26-3.4-64-67

Abstract

The article addresses the development of students' research skills during the study of the "Genetics" section in the school biology course. It highlights the transition from a knowledge-centric paradigm to a system-activity approach. The author describes a methodology integrating project-based learning, case technologies, and digital modeling (using the Virtual Genetics Lab as an example). The results of a pedagogical experiment conducted at Secondary School No. 350 in Tashkent are presented. It was established that the use of active learning methods and virtual simulators contributes to a 22% increase in academic performance and significantly enhances students' ability to independently formulate scientific hypotheses. The study confirms the effectiveness of the digital transformation of the educational process in forming scientific thinking and functional literacy among graduates.

Keywords: *education, biology teaching methodology, genetics, research skills, system-activity approach, project-based learning, case study, digital educational simulators, functional literacy*

Introduction

The modern transformation of the general education system is marked by a fundamental transition from a knowledge-centric paradigm to a system-activity approach (Vygotsky, L.S., 1999; Lerner, I.Ya., 1974). Within this model, the priority is no longer the mere transmission of ready-made knowledge, but the formation of students' universal action methods. In the context of the rapid progress of biomedical and convergent technologies, biological literacy ceases to be a highly specialized characteristic and transforms into an integral component of the functional literacy of a modern individual. This developmental vector is embedded in the requirements of the state educational standards for secondary education (Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated April 6, 2017). In this regard, one of the key tasks of secondary school is to prepare a graduate who is proficient in the methodology of scientific inquiry, possesses skills for analyzing multifactorial biological processes, and is capable of formulating evidence-based conclusions derived from empirical data.

Despite the high significance of the discipline, the "Genetics" section is traditionally classified as one of the most challenging to master in the school biology course. Students' cognitive difficulties are caused by a high degree of abstraction of genetic patterns and the complexity of interpreting microbiological processes. In pedagogical practice, there is often a dominance of reproductive teaching methods, which are reduced to the mechanical interiorization of Mendel's laws. Such an approach levels the research potential of the discipline. At the same time, it is genetics that possesses a unique didactic resource for developing research competencies through the study of phenotypic trait variability, genealogical analysis, and mutagenesis modeling.

Materials and Methods

The methodological framework of this research is grounded in the core tenets of the system-activity approach and the concept of problem-based learning (Makhmutov, M. I., 1977). The study was conducted at General Secondary School No. 350 in the Sergeli district of Tashkent.

The study sample comprised 40 ninth-grade students, who were divided into two groups of 20 participants each:

1. Experimental Group (9-"A"): Instruction was based on the integration of project-based methods, case technologies, and digital modeling. Particular emphasis was placed on working with virtual genetic simulators, specifically the *Virtual Genetics Lab*, which enabled students to model cross-breeding processes and perform real-time statistical data analysis (Virtual Genetics Lab (VGL II)).
2. Control Group (9-"B"): The educational process followed traditional methodology, focusing on the reproductive acquisition of theoretical material and the solution of standardized problems.

The set of research methods included a theoretical analysis of State Educational Standards (SES) and pedagogical literature, participant observation, the case study method (analysis of real-world genetic scenarios and pathologies), and methods of mathematical statistics to evaluate the significance of differences between the groups.

Results of the research and their discussion

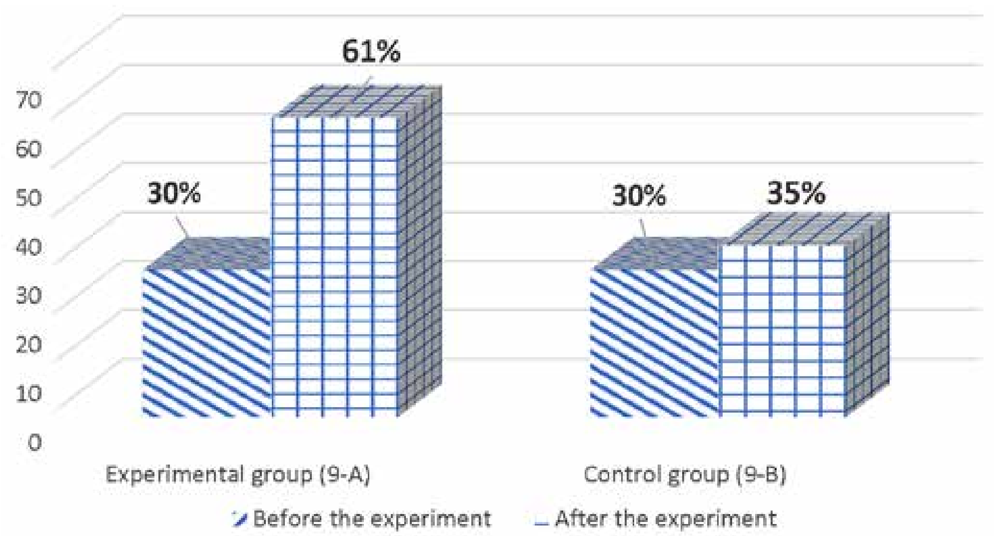
The testing of the developed methodological system within the educational process at Secondary School No. 350 in Tashkent confirmed the hypothesis regarding the high efficiency of integrating active learning methods. A comparative analysis of academic performance revealed a significant correlation between the forms of instructional organization and the quality of material acquisition. Based on the results of the assessment tests for the "Genetics" section, the average score in the experimental class (9-"A") was 22% higher than that in the control class (9-"B").

A qualitative analysis of the educational outcomes allowed for the identification of the following significant indicators:

- Improvement in operational skills: Students in the experimental group demonstrated a high degree of cognitive skill development when solving genetic problems of advanced complexity (including dihybrid crossing and sex-linked inheritance). While students in the control group frequently made algorithmic errors, the 9-"A" class exhibited the ability to make conscious strategic choices in their problem-solving approaches;
- Transformation of cognitive activity: The implementation of digital simulators (*Virtual Genetics Lab*) facilitated a transition from the mechanical internalization of Mendel's laws to a profound understanding of the dynamic mechanisms of heredity. Visualization and repeated virtual experimentation enabled students to "internalize" the statistical nature of genetics, as evidenced by their successful performance in tasks requiring the prediction of trait segregation in offspring;

- Development of research competencies: Students in group 9-»A» exhibited a high level of autonomy in formulating scientific hypotheses and interpreting mutagenesis modeling results. While participants initially experienced difficulties in establishing cause-and-effect relationships, by the final stage, 61% of them were able to provide reasoned explanations for discrepancies between modeling results and expected theoretical data;
- Project productivity: The effectiveness of the methodology is further evidenced by the fact that all 20 students in the experimental group successfully defended their individual mini-projects. An analysis of these projects revealed that the students learned not only to operate with biological terminology but also to apply it in analyzing real-world medico-genetic scenarios and pedigrees, indicating the successful formation of functional literacy.

Figure 1. *Dynamics of the ability to independently formulate a hypothesis*



The interpretation of the obtained quantitative data confirms the hypothesis that the integration of active learning methods into the study of genetics radically changes the quality of educational outcomes. A significant indicator of effectiveness was the 100% success rate in the implementation of individual research projects within the experimental group. In contrast to the control group, where student activity was limited to textbook-based learning, the students of group 9-"A" transitioned into the role of active subjects of scientific inquiry.

The key factor in intensifying the learning process was the use of digital modeling. The opportunity to conduct virtual "crosses" – the volume of which exceeded standard curriculum requirements by fourfold – helped overcome one of the primary challenges in school genetics: its abstract nature. Under a traditional approach, statistical patterns (Mendel's laws) are often perceived by students as dogmas. However, working with large datasets in a digital environment allowed students to practically observe the stochastic (probabilistic) nature of heredity. This contributed to the formation of a scientific understanding that biological laws are realized not as rigid prescriptions, but as statistical trends.

The qualitative transformation of cognitive skills deserves particular attention. The increase in the ability to independently formulate hypotheses from 30% to 61% in the experimental group indicates a transition of thinking to a productive level. In the control group (9-"B"), where reproductive methods dominated, the stagnation of this indicator (an increase of only 5%) confirms that the traditional lecture-seminar system lacks sufficient resources to develop a researcher's methodological apparatus.

The psycho-pedagogical effect of the methodology was reflected in a sharp rise in academic motivation. The subjective assessment of 85% of students in the experimental group, who confirmed the practical significance of case technologies, indicates a solution to a fundamental problem in school education – the alienation of knowledge. Through solving problem-based situations (analyzing real genetic pathologies, predicting traits), abstract biological knowledge was transformed into personally meaningful experience. Thus, problem-based learning, coupled with digital tools, not only improves academic performance but also forms the foundation of scientific literacy required in the context of modern technological progress.

Conclusion

The study conducted at Secondary School No. 350 in Tashkent confirms that the "Genetics" section possesses exceptional potential for developing students' research competencies. Based on the data obtained, the following conclusions can be drawn:

1. The formation of research skills occurs most effectively through problem-solving and project-based work, where the student assumes the role of an active subject of inquiry.

2. The integration of digital simulators helps to overcome the limitations of school laboratory infrastructure and facilitates a transition to evidence-based learning through repeated modeling of biological processes.

3. The developed methodology fosters the growth of critical analysis and scientific thinking skills, which fully aligns with the requirements of modern educational standards and prepares graduates to function effectively in a high-tech society.

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submitted 13.04.2026;
accepted for publication 27.04.2026;
published 30.04.2026
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