European International Journal of Pedagogics (ISSN: 2751-OOOX)

Received: 12 April 2026 | Accepted: 05 May 2026 | Published: 31 May 2026

DOI: 10.55640/eijp-06-05-74

RESEARCH ARTICLE

Effectiveness of An Integrative Model Aimed at Developing Systemic Thinking in Future Biology Teachers

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VOLUME: Vol.06 Issue05 2026

PAGE: 348-355

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Abstract

This article aims to evaluate the structure and practical effectiveness of an integrative pedagogical model designed to form systemic thinking in future biology teachers. Methods. A quasi-experimental study with non-random group distribution, including initial and final assessments, was conducted in three higher education institutions in Uzbekistan in the 2022-2025 academic years. According to the dissertation, the sample consisted of 619 students, of whom 315 were included in the experimental group and 304 in the control group. The experimental group combined problem-based lectures, case studies, conceptual mapping, systematic modeling, project activities, numerical simulation, independent research, and reflexive assessment. Systemic thinking was determined through tests, graphic and situational tasks, project results, observation, and expert assessment. Results. The average score of the experimental group increased from 3.3693 to 3.8920, and that of the control group increased from 3.3621 to 3.6034. The average increase was 0.5227 and 0.2413, respectively; the difference in increases was 0.2814 points. The source provided a value of t = 6.71 for the final comparison, which was analyzed to be above the critical value at the 0.05 significance level.

KEYWORDS

Systems thinking; future biology teacher; biological education; integrative pedagogical model; conceptual map; modeling; problem-based learning; quasi-experiment.

INTRODUCTION

Biology studies living nature at various organizational levels: from molecules and cells to organisms, populations, ecosystems, and biospheres. Therefore, a complete understanding of biological phenomena depends not only on knowing individual facts, but also on interpreting parts, functions, time factors, and cause-and-effect relationships within the framework of a whole system. Systems and their models allow us to unify the scattered topics of the biology course into a single conceptual direction (Momsen et al., 2022; National Research Council, 2012). In the literature, systems thinking is described as a set of abilities to define the boundaries of an object, identify its elements and the interactions between them, relate structure to function, think in hierarchical levels, take into account dynamic change and feedback, and explain or predict the development of processes using a model (Verhoeff et al., 2018). Therefore, this competency is not limited to counting the parts of a system; The student must be able to make connections between a specific biological example and a generalized model and transform individual actions into a coherent thinking strategy (Boersma et al., 2011; Verhoeff et al., 2008).

Previous studies have shown that this competency develops when system properties are directly taught and students are regularly engaged in model building, simulation, conceptual

representation, and reflection. For example, step-by-step modeling has integrated concepts in cell biology (Verhoeff et al., 2008), and the use of system categories in conjunction with computer simulation has improved the analysis of ecological processes (Riess and Mischo, 2010). Conceptual representations have also helped to explain the structure, mechanism, and outcome of an ecosystem (Hmelo-Silver et al., 2017). However, the term "system" alone does not guarantee deep systems thinking unless the concepts of system boundaries, hierarchy, feedback, dynamics, and emergence are taught based on clear criteria (Gilissen et al., 2020a; Verhoeff et al., 2018).

The issue is even more relevant at the stage of teacher training. The future biology teacher, while understanding complex biological processes himself, must design a lesson that takes the student from retelling facts to explaining, justifying, and predicting relationships. It has been found that these skills are not formed equally in future teachers; in particular, conceptual mapping, mechanistic communication, hierarchical transitions, and meaningful ecological tasks are important tools (Schmäing et al., 2026). Therefore, it is necessary to develop systems thinking not as a separate theoretical topic, but through a holistic methodology that connects content, method, digital tools, evaluation, and reflection. In the dissertation that formed the basis of this study, an integrative model for the course "Biology Teaching Methods" was developed and tested in pedagogical experience. The model aims to develop the student not as a receiver of ready-made information, but as an active subject who can analyze the biological system in parts, show connections, create explanations and models based on evidence, design pedagogical solutions and evaluate their possible consequences. The study seeks answers to two questions: what components are included in the integrative model, and how did the indicators of systematic thinking of the experimental and control groups change after its application?

Theoretical basis and integrative model. In the research concept, systems thinking is considered in the unity of cognitive and metacognitive actions. It includes analysis, model creation, development of new solutions, reflection and interpretation of a biological phenomenon from the point of view of several disciplines. Analysis serves to separate the parts and functions of an object, and then restore a holistic explanation based on the relationships between them. Modeling represents a process that cannot be directly observed with the eye through a diagram, graphic or mental image. Creative activity provides solutions to non-standard biological and pedagogical tasks, and reflection controls the justification and completeness of the conclusion. Multidirectional analysis allows you to connect genetic, evolutionary, ecological, chemical, physical and social factors within the framework of a single phenomenon.

Such an interpretation corresponds to the holistic approach, which is based on studying the biological system not as a collection of components, but as their dynamic cooperation at different hierarchical levels (Verhoeff et al., 2018). It also supports the developmental logic proposed for undergraduate biology: the student first describes the structure of the system, then moves on to explain the internal connections, overall functioning, and relationship with other systems (Momsen et al., 2022).

The integrative model consists of five interconnected links: goal-oriented, content-oriented, process-oriented, methodological and result-oriented blocks. It is based on the principles of activity, continuity, integrity, psychologically favorable environment, variability, creativity, causality and systematic organization. The open nature of the structure allows updating the topic, tasks and digital tools while maintaining the general didactic logic.

PURPOSE	CONTENT	PROCESS	METHODOLOGY	RESULT
To prepare teachers with systematic thinking who can explain biological phenomena holistically and	Integrity, hierarchy, openness, dynamics, feedback and interdisciplinary integration; analysis,	Knowledge activation → structuring connections → problem and research → visual model → project →	Problem-based lecture, case, concept map, system model, laboratory observation, project, numerical simulation,	Integrated knowledge, structural-functional analysis, model building, forecasting and reflexive

at different levels.	modeling, creativity and reflection.	reflection and evaluation.	discussion, and individual research.	management; high, medium and low levels.

Figure 1. Structural blocks of the integrative model for developing systems thinking.

The target block determines the need of society and the educational system for a teacher who can comprehensively explain complex biological phenomena. The content block transforms the general concepts of systems theory into educational practices of biological science. Integrity, hierarchy, openness, dynamics, feedback, and interdisciplinary connections are translated into practical competence through analysis, model building, creative solutions, reflection, and multifactorial interpretation.

The process block organizes the gradual formation of competence. First, existing knowledge is activated, system elements are identified; in the next stage, relationships are classified and information is structured. In problem-based research activities, a question and hypothesis are developed, and an explanation is given based on evidence. A conceptual map, flowchart, and other visual models make relationships visible. An independent project requires the application of knowledge to a real biological or methodological task, and the final reflection re-evaluates the logic, completeness, and possible consequences of the thinking process.

The methodological block covers the tools that implement the above steps. It combines the "element-structure-function-relationship" algorithm, problem questions and situations, system mapping, case studies, discussions, laboratory observations, numerical simulations, and project tasks. Studies that have shown that it is effective to clearly name system categories, represent the same phenomenon in different ways, and build a directed model form the theoretical basis of this selection (Gilissen et al., 2020b; Hmelo-Silver et al., 2017; Lankers et al., 2023).

The result block covers not only factual knowledge, but also indicators such as correctly defining the boundaries of the system, justifying the relationship between elements, creating a model, predicting the consequences of change, combining different scientific approaches, and controlling personal thinking. The result is determined through tests, case studies, project defense, and descriptions appropriate to the level of activity.

METHODS

The study was organized as a quasi-experimental study, covering initial and final measurements, conducted in several educational institutions; the experimental and control groups were not randomized. Urgench State University named after Abu Rayhon Beruni, Jizzakh State Pedagogical University named after Abdulla Qodiri, and Navoi State Pedagogical University were selected as the test bases. The work was conducted in the 2022-2023, 2023-2024, and 2024-2025 academic years. The intervention was integrated into the course "Biology Teaching Methods" in the Biology education direction 60110900.

The source document records the participation of 619 students: 315 in the experimental group and 304 in the control group. The experimental groups were trained based on the author's model and methodological materials, while the control groups continued with their traditional training. Since the individual observation database and the group allocation protocol were not available at the time of writing, the analysis retained the generalized values published in the dissertation, and the design was described as an experiment without random assignment.

The learning process in the experimental group was composed of the following interconnected activities:

• Lectures that begin with a contradiction, problem, or system-wide question, rather than presenting biological content in the form of a ready-made conclusion.

• Analysis and synthesis along the "element → structure → function → relationship" sequence, supplemented by the identification of system boundaries, input-output flows, and hierarchical connections.

• Conceptual maps, clusters, cause-and-effect diagrams, block diagrams, and other types of visual models that represent the structure of the process and its change over time.

• Biological and pedagogical cases that require the comparison of several causes, effects, stakeholders, and alternative solutions.

• Individual and group projects and small studies focused on a practical biological, ecological, or educational problem.

• Purposeful use of laboratory observations, electronic resources, virtual experiments, multimedia materials, and

educational platforms.

• Group discussion, series of questions, debate, peer evaluation, and reflective self-assessment.

In a sample lesson on photosynthesis, the process is not limited to the mechanism within the cell, but is linked to the functioning of the organism, oxygen in the atmosphere, the food chain, and the stability of the biosphere. Students discussed the consequences of a process failure, created a mind map, defended the group's solution with evidence, and finally completed reflective and numerical assessment tasks. This format combined content integration, causal analysis, visualization, collaboration, and knowledge transfer into real situations within one lesson.

The formation of systematic thinking was assessed on the basis of tests, logical questions, cases, graphic tasks, project products, observations, questionnaires, and expert opinions. In the source, student activity is divided into three levels, and to calculate the generalized average indicators, 3 points are given to the low level, 4 to the medium level, and 5 to the high level.

Criteria for determining levels of systematic thinking.

Table 1.

Level	Mazmuniy tavsif	Baholashda kuzatiladigan belgilar
High (creative)	Systematic thinking capable of creating independent, integrated and innovative solutions.	Justifies the internal structure of the system and inter-level relationships; creates an original model; provides an evidence-based solution; predicts the outcome; critically reevaluates one's own thinking.
Medium (variable)	Partially systematic thinking that is manifested based on a familiar situation or guiding aid.	Identifies key relationships; compares options; performs simple analysis and modeling, but has difficulty with complex forecasting or fully independent solutions.
Low (reproductive)	Fragmented, fact-based, and algorithm-based thinking.	Retells information, but has difficulty establishing causal relationships, integrating parts, creating models, and solving unfamiliar tasks without help.

The number and proportions, arithmetic mean, efficiency coefficient, dispersion index, confidence interval and Student's test were used in the research. The null hypothesis stated that the average values of the experimental and control groups were equal, and the alternative hypothesis was that there was a statistical difference between them. In the two-sided test, $\alpha = 0.05$ and the critical value was taken as 1.96.

The initial and final mean values in the article were taken directly from the source. Based on them, the growth indicators were recalculated: in the experimental group 3.8920 – 3.3693 = 0.5227; in the control group 3.6034 – 3.3621 = 0.2413; the difference between the two increases was 0.2814 points. Due to the lack of individual data, the effect size, the effect of covariates, the paired observation model, and the reliability coefficients of the diagnostic tools were not calculated independently.

The source notes that a pedagogical test and anonymous online surveys were conducted. However, the decision of the ethics committee, informed consent of the participant, and the procedure for protecting personal data are not indicated. The

copy sent to the journal must clearly state the name of the relevant organization, the permit number, the consent form, and confidentiality measures.

RESULTS

After the model was implemented, the learning activity was brought into a sequence that began with the identification of a biological fact, continued to the discovery of relationships and the creation of a system-wide explanation. Analysis, visualization, research, project and reflection were organized not as separate methods, but as complementary stages. The criterion for high results was considered to be the ability to think in a way that connects levels from the molecule to the biosphere, build a structural-functional model, justify a causal chain, predict the subsequent impact of change and transfer this competence to the lesson project.

The content of the assessment has also expanded. The student's response is assessed not only for factual accuracy, but also for the ability to define the boundaries of the system, justify the relationship between parts, describe the dynamics of the process, justify a possible outcome, and revise their initial opinion in the light of new evidence. This distinction is important because memorizing a fact is not in itself considered systemic competence.

Summary of indicators for the experimental and control groups.

Table 2.

Indicator	Experimental group (n = 176)	Control group (n = 174)	Comment
Initial GPA	3,3693	3,3621	The initial values are very close to each other.
Final grade point average	3,8920	3,6034	The experimental group performed better on the final measure.
Average growth	0,5227	0,2413	The increase in the experimental group is 0.2814 points higher than that in the control group.
Student criterion	Final comparison: t = 6.71	Critical value: 1,96	According to the interpretation in the source, the null hypothesis is rejected at α = 0.05.

At baseline, the difference between the groups was 0.0072 points, and the indicators were almost the same. At the final assessment, the experimental group showed a result 0.2886 points higher than the control group. The increase in the experimental group was 0.5227 points, and in the control group the increase was 0.2413 points; the difference between the growth indicators is 0.2814 points.

The source gives a value of t = 1.23 for the initial comparison, which is interpreted as not rejecting the null hypothesis of group equality. In the post-intervention comparison, t = 6.71, which is above the critical threshold of 1.96. Also, a 14.5% pedagogical efficiency advantage in favor of the experimental group was noted. These results support the research hypothesis within the framework of the author's calculations. However, since participant-level data are not provided, statistical conclusions need to be re-confirmed using the initial data.

DISCUSSION

The results suggest that systems thinking should be used as a

general didactic principle that guides learning content, activities, and assessment, rather than limiting it to a single method or topic. In the experimental model, system features are repeatedly linked to analysis, modeling, problem solving, design, and reflection. This approach addresses a fundamental dilemma in biology education: students may know many facts but may not be able to integrate them hierarchically or use them to explain dynamic phenomena. The emphasis on hierarchical linkage and visual models is consistent with the scientific consensus that specific pedagogical support is needed to transition between a concrete biological object and an abstract system representation. Verhoeff et al. (2008) have shown that sequential modeling can help to develop a coherent understanding of cell biology. This study extended this logic to pre-service teacher education, incorporating a biological model as well as lesson, case, and project development tasks.

Problem situations and cases provided a natural context for causal and multifactorial analysis. Rather than retelling a process, students were asked to explain how changes in a particular part of the system would affect the rest of the system. This approach is consistent with research that has shown that simulations, system-wide tasks, and conceptual representations can enhance connections between elements, mechanisms, behaviors, and future states (Hmelo-Silver et al., 2017; Lankers et al., 2023; Riess and Mischo, 2010).

Reflection was not a final addition to the model, but rather an internal mechanism to guide the systematic thinking. Students checked that the analysis did not leave out a necessary connection, that an important hierarchical level was not missing in the model, and that the proposed solution did not produce an unexpected negative result. Such metacognitive control is necessary because systematic thinking is not a list of independent skills; it is a holistic way of thinking that requires conscious transitions between concepts, models, and contexts (Boersma et al., 2011; Verhoeff et al., 2018).

The quantitative results also favored the model. While both groups were expected to show growth over the course, the average growth in the experimental group was more than twice that of the control group. The closeness of the baseline values increases the likelihood that the subsequent difference is attributable to the intervention. However, since the groups were not randomly assigned and other influencing factors were not controlled for, firm causal inferences cannot be drawn.

The value of the study for teacher training is that most work on systems thinking has focused on schoolchildren, and the combined scientific and pedagogical competence of the future teacher has been analyzed less. In addition to understanding the biological system itself, the teacher must be able to organize the boundaries, levels, interactions, feedback and dynamics in a way that is visible to the student. It has been noted that the structure of the conceptual map and the connections between levels serve to identify the strengths and weaknesses of future biology teachers (Schmäing et al., 2026). The proposed model can be adapted to the topics of genetics, physiology, ecology, evolution and environmental education.

The five-block structure serves as an algorithm for redesigning a course in practice: the goal block defines the expected competencies, the content block defines the system features to be studied, the process block defines the sequence of activities, the methodological block defines the tasks and tools, and the outcome block defines the evaluation criteria. These elements must be compatible with each other; if the final control only measures memorization, the systematic thinking formed through active learning will not be fully reflected.

Study limitations. A number of limitations should be considered when interpreting the results. The groups were not randomly assigned; their demographic composition, prior achievement level, teacher influence, and adherence to the intervention protocol were not fully reported. In addition, although low, medium, and high scores are ordinal categories, they are coded as interval scales in the source report. When initial data are available, it is appropriate to repeat the analysis using ordinal regression, chi-square, or mixed models that account for institution and group factors, with effect sizes and 95% confidence intervals. The content and construct validity, internal reliability, inter-rater consistency, and rubric descriptions of the assessment tools are not adequately reported. Therefore, full specifications of the tests, cases, and project tasks should be provided separately. The number of participants also needs to be verified: although the dissertation states that the total sample size was 350, the sum of the sub-tables from some HEIs does not fully correspond to this number. Only general indicators were used in the article; the final publication should reconstruct the sample table based on the initial records. The lack of a delayed final assessment is another limitation. The available indicators represent

immediate changes after the intervention, but do not prove the long-term maintenance of competence or the transfer of it to the school lesson in pedagogical practice. Further research should plan to include repeated measurements, the quality of lesson development, observation during the practice period, and repeated testing of the model in different biology subjects and institutions.

CONCLUSION

The proposed integrative model combines biological systems concepts with active learning, visual and numerical models, real-world problems, independent projects, and reflection. The growth observed in the experimental group was higher than in the control group, indicating the model's potential to develop systems thinking in prospective biology teachers. The results should be interpreted with caution because the analysis was based on generalized data and the groups were not randomly formed. It is not enough to include systems thinking in the curriculum as a single lecture topic. It must become a guiding principle for selecting, describing, investigating, teaching, and evaluating biological content. When a prospective teacher is able to see the relationships between elements, construct explanations at hierarchical levels, create models, predict consequences, and check the completeness of his or her explanation, he or she will be prepared to teach biology as a holistic science about living systems.

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