

Developing University Students' Scientific Literacy Through Ecology Tasks from International Assessments

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Abstract. This study investigates the effectiveness of ecology-related tasks aligned with international assessment frameworks for developing university students' scientific literacy in the Fundamentals of Ecology course. A controlled pedagogical experiment was conducted in 2023-2026 at Chirchiq State Pedagogical University, Samarkand State Pedagogical Institute, and Gulistan State University with 526 students: 261 in experimental groups and 265 in control groups. Experimental groups worked with contextual ecological problems, graph/table interpretation, case studies, mini-projects, and evidence-based decision tasks; control groups followed conventional instruction. Scientific literacy was operationalised through cognitive, practical, motivational-value, and reflective-evaluative components and classified into excellent, good, satisfactory, and unsatisfactory levels. Baseline equivalence was supported by a four-level chi-square test ($\chi^2=0.106$, $df=3$, $p=.991$). At final assessment, the four-level distribution differed significantly between groups ($\chi^2=28.424$, $df=3$, $p<.001$, Cramér's $V=.232$). High achievement reached 67.8% in experimental groups and 55.5% in control groups. The findings support the effectiveness of the integrated methodology, while component-specific effects require further study.

Keywords: Ecology Education, Environmental Literacy, International Assessment, Scientific Literacy, Pedagogical Experiment.

1 Introduction

Contemporary society faces increasingly complex environmental challenges, including climate change, water scarcity, air and soil pollution, biodiversity loss, degradation of natural resources, and the accumulation of household and industrial waste. These challenges require not only scientific and technological solutions but also citizens who are able to understand environmental processes, analyse evidence, make informed decisions, and act responsibly. Therefore, the development of scientific literacy has become one of the central objectives of higher education.

Scientific literacy is not limited to the acquisition of factual knowledge in biology, chemistry, physics, geography, or ecology. It represents an integrated capacity to explain natural phenomena scientifically, interpret information and evidence, evaluate research processes, solve problems, and make reasoned decisions in real-life situa-

tions. In ecological education, scientific literacy also includes environmental responsibility, awareness of sustainability, and the ability to assess the consequences of human activities for ecosystems and society.

The Fundamentals of Ecology course has substantial didactic potential for developing scientific literacy because it integrates knowledge from biology, chemistry, geography, physics, economics, and social sciences. Ecological topics allow students to explore the interrelationship between human activity and the environment, investigate the causes and consequences of environmental problems, and identify feasible solutions. In this respect, ecology education provides an appropriate context for developing analytical thinking, evidence-based reasoning, environmental culture, and global competence.

Research on environmental education demonstrates that students' environmental literacy develops more effectively when learning is connected with real environmental situations, active investigation, collaborative problem solving, and the evaluation of evidence. Modern approaches to environmental education emphasise case studies, project work, environmental citizenship, contextual learning, and interdisciplinary integration [1]–[4]. The use of local environmental problems, research tasks, and community-oriented projects contributes to students' awareness of sustainable development and environmental responsibility [5]–[8].

The international assessment perspective is particularly important because international studies assess not only the amount of knowledge acquired by learners but also their capacity to use scientific knowledge in unfamiliar and practical contexts. Tasks aligned with international assessment frameworks require students to interpret graphs, tables, maps, diagrams, scientific texts, and environmental data; identify cause-and-effect relationships; evaluate evidence; compare alternative solutions; and justify their decisions. Such tasks move the teaching process beyond reproductive learning and create conditions for the development of functional scientific literacy.

Previous studies have addressed environmental culture, environmental literacy, sustainable development, project-based learning, and case-study approaches. However, a methodological gap remains in the systematic use of ecology-related tasks based on international assessment requirements in university-level ecology education. In particular, there is a need for a methodology that integrates contextual tasks, ecological case studies, graphical information, scientific evidence, interdisciplinary knowledge, and global competence into a coherent instructional system.

The scientific novelty of this study lies in the development and implementation of a methodology for improving university students' scientific literacy through ecology tasks designed in accordance with international assessment requirements. The methodology integrates ecological knowledge, scientific reasoning, critical thinking, practical skills, environmental values, and global competence.

The research problem was formulated as follows: how can ecology-related tasks based on international assessment principles be used systematically in the Fundamentals of Ecology course to improve students' scientific literacy?

The study was based on the following hypothesis: if the Fundamentals of Ecology course is organised through contextual ecological tasks, environmental problem situations, graphic and tabular data analysis, case studies, projects, and research assign-

ments aligned with international assessment requirements, students' scientific literacy, ecological thinking, evidence-based reasoning, and environmental decision-making skills will improve significantly.

Accordingly, the purpose of the study was to determine the effectiveness of using ecology-related tasks based on international assessment approaches for developing university students' scientific literacy.

2 Methods

2.1 Research Design

The study used a controlled pedagogical experiment with experimental and control groups. The research design combined diagnostic, formative, and final assessment procedures. Qualitative and quantitative methods were applied in an integrated manner to examine changes in students' scientific literacy, ecological reasoning, practical skills, and environmental values.

The research was conducted during the 2023–2026 academic years and included three stages:

1. Diagnostic stage;
2. Formative stage;
3. Generalising and final assessment stage.

The diagnostic stage was conducted during the 2023–2024 academic year. Its purpose was to identify students' initial ecological knowledge, scientific literacy, ecological thinking, ability to work with scientific information, and capacity to complete tasks similar to international assessment tasks.

The formative stage was implemented from 2024 to 2026. During this period, the experimental groups were taught through a specially developed methodology involving ecology-related tasks aligned with international assessment requirements.

The final assessment stage was completed at the end of the 2025–2026 academic year. The purpose of this stage was to compare the final results of the experimental and control groups and determine the pedagogical effectiveness of the proposed methodology.

2.2 Participants

The pedagogical experiment involved students from three higher education institutions in Uzbekistan:

1. Chirchiq State Pedagogical University;
2. Samarkand State Pedagogical Institute;
3. Gulistan State University.

A total of 526 students participated in the study. Of these, 261 students were assigned to experimental groups and 265 students to control groups.

At Chirchiq State Pedagogical University, 186 students participated in the study. The experimental group consisted of 93 students, while the control group included 93 students.

At Samarkand State Pedagogical Institute, 162 students participated. The experimental group consisted of 79 students, whereas the control group included 83 students.

At Gulistan State University, 178 students participated. The experimental and control groups each consisted of 89 students.

The groups were selected as intact academic groups within each institution so that the experimental and control groups had comparable programme profiles, course exposure, academic year, and initial scientific-literacy levels. Individual random assignment was not applied because the experiment was conducted within existing university timetables; therefore, the design should be interpreted as a controlled quasi-experimental pedagogical design with matched intact groups.

Because students were nested within three higher education institutions, the pooled analysis should be interpreted with caution. The institution-level results are therefore reported separately and in aggregate to reduce the risk of hiding site-specific variation.

2.3 Research Instruments

The following research instruments were used:

1. diagnostic tests on ecological concepts and scientific literacy;
2. questionnaires designed to identify students' attitudes toward environmental problems and ecological responsibility;
3. observation sheets for monitoring students' learning activity;
4. individual and group practical assignments;
5. ecology-related contextual tasks;
6. environmental case-study tasks;
7. graphical, tabular, and diagram-based assignments;
8. research and project tasks;
9. final diagnostic tasks for determining changes in scientific literacy.

The diagnostic tasks addressed such environmental issues as atmospheric pollution, water pollution, soil degradation, biodiversity loss, climate change, waste management, ecological safety, and rational use of natural resources.

The assessment tasks required students to:

1. explain ecological phenomena scientifically;
2. identify cause-and-effect relationships;
3. interpret graphs, tables, diagrams, and scientific texts;
4. select relevant evidence;
5. analyse environmental problems;
6. compare alternative solutions;
7. justify environmental decisions;

8. formulate practical recommendations.

2.4 Instructional Procedure

In the experimental groups, the Fundamentals of Ecology course was taught through ecology-related tasks designed according to international assessment principles. The instructional content was based on real-life environmental situations and interdisciplinary links among biology, chemistry, geography, physics, and ecology.

The learning process included topics such as climate change, plastic pollution, water scarcity, atmospheric pollution, soil degradation, biodiversity conservation, waste recycling, ecological safety, and sustainable use of natural resources.

The following methods were systematically applied:

1. problem-based learning;
2. project-based learning;
3. case-study method;
4. research-based learning;
5. brainstorming;
6. cluster method;
7. group discussion;
8. debate;
9. INSERT strategy;
10. conceptual tables;
11. collaborative learning;
12. analysis of infographics, maps, diagrams, tables, and scientific texts.

Students in the experimental groups prepared mini-projects, presentations, environmental observations, data analyses, and practical recommendations. They were encouraged to identify environmental problems, analyse scientific evidence, formulate conclusions, and justify solutions.

The control groups were taught through conventional instructional methods, including teacher explanation, textbook-based learning, question-and-answer activities, and reproductive exercises. This created the opportunity to compare the effectiveness of traditional instruction with the proposed international assessment-based methodology.

2.5 Data Analysis

Students' scientific literacy was assessed through cognitive, practical, motivational-value, and reflective-evaluative components. The results were classified into four levels:

1. excellent;
2. good;
3. satisfactory;
4. unsatisfactory.

For the final analysis, the “excellent” and “good” categories were combined as indicators of high achievement only after the primary four-level analysis had been reported. Thus, two analyses were used: (1) the main four-level excellent/good/satisfactory/unsatisfactory contingency table and (2) a supplementary high/not-high comparison.

Operational definition of the scientific-literacy measure. Scientific literacy was measured on a 100-point scale that combined four components: cognitive mastery of ecological concepts and laws; practical ability to analyse ecological problems, graphs, tables and diagrams; motivational-value orientation toward environmental responsibility; and reflective-evaluative ability to justify decisions and assess the consequences of human activity. The score was formed from diagnostic tests, contextual ecology tasks, practical/case-study assignments, observation sheets and reflective responses.

Table 1. Scoring rubric and level thresholds used to classify students’ scientific literacy

Level	Score range	Operational descriptor
Excellent	86-100	Student deeply explains ecological concepts and laws; analyses ecological problems with scientific evidence; accurately interprets graphs, tables and diagrams; draws independent conclusions and proposes scientifically and environmentally justified solutions.
Good	71-85	Student demonstrates sufficient ecological knowledge; analyses ecological situations and interprets most data correctly; proposes solutions, although some arguments require fuller scientific justification.
Satisfactory	56-70	Student knows basic ecological concepts but has difficulty applying them to practical or problem situations; interprets data partially; conclusions are general and insufficiently justified.

Unsatisfactory	0-55	Student has not sufficiently mastered ecological concepts; cannot analyse ecological situations scientifically; makes serious errors in using graphs, tables, diagrams or evidence; cannot propose an appropriate solution.
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The thresholds follow the dissertation assessment system for four achievement levels and make the meaning of “high achievement” explicit: high achievement means a combined score of 71-100 points, i.e., the sum of excellent and good categories.

Reliability and scoring control. Content validity was supported by alignment with international assessment principles and by expert review of ecological contexts, graphs, tables, and case tasks. Practical and reflective tasks were evaluated with the same rubric to reduce subjectivity. Since only aggregate group-level data were available for this article revision, Cronbach’s alpha and inter-rater coefficients could not be recomputed from raw item-level and rater-level data; this limitation is stated explicitly rather than being estimated from insufficient information.

The data were processed using frequency counts, percentage distributions, comparative analysis, gain scores and Pearson’s chi-square tests. The chi-square analyses were conducted on count data, not only percentages. The primary test used the four achievement levels; therefore, $df=(2-1)(4-1)=3$ and $\chi^2_{critical}=7.815$ at $\alpha=.05$. A supplementary high/not-high test used $df=1$ and $\chi^2_{critical}=3.841$ at $\alpha=.05$. Effect size was reported using Cramér’s V.

This clarification removes the earlier inconsistency between a four-level $\chi^2_{critical}$ value and a two-category interpretation. In the revised analysis, the four-level contingency table is treated as the main inferential evidence, while the high-achievement comparison is presented only as an interpretable summary of the same outcome distribution.

3 Results and Discussion

3.1 Results

The initial diagnostic stage demonstrated baseline equivalence between the experimental and control groups. At the beginning of the experiment, high achievement (excellent+good) was 34.1% in the experimental groups and 32.8% in the control groups. The four-level baseline contingency table showed no statistically significant difference between groups: $\chi^2=0.106$, $df=3$, $p=.991$, Cramér’s V=.014. The supplementary high/not-high comparison was also non-significant: $\chi^2=0.095$, $df=1$, $p=.758$, Cramér’s V=.013. Thus, the post-test comparison was not based merely on an asserted similarity; it was supported by a statistical baseline test.

Table 1. Baseline four-level distribution of scientific-literacy achievement

Group	Excel- lent	Goo d	Satisfacto- ry	Unsatisfac- tory	Total	High achieve- ment
Experi- mental	23	66	132	40	26	89/261 =
Control	23	64	137	41	1	34.1%
					26	87/265 =
					5	32.8%
Test result	$\chi^2=0.106$	df=3	p=.991	Cramér's V=.014	n=526	No baseline difference

During the formative stage, students in the experimental groups completed contextual ecology tasks, interpreted graphical and tabular information, analysed environmental cases, participated in research and project activities, and proposed evidence-based solutions to ecological problems. The regular use of such tasks strengthened students' ability to apply theoretical ecological knowledge in practical situations.

The final assessment showed that students in the experimental groups achieved higher results than students in the control groups at all three higher education institutions.

Table 2. Final four-level contingency table used for the main chi-square test

Group	Excel- lent	Goo d	Satisfacto- ry	Unsatisfac- tory	Total	High achieve- ment
Experi- mental	92	85	70	14	261	177/261 =
Control	41	106	92	26	265	67.8%
						147/265 =
						55.5%
Test result	$\chi^2=28.42$ 4	df=3	p<.001	Cramér's V=.232	n=526	Statistically significant

Table 3. Final high-achievement results of experimental and control groups by institution

Higher education institution	Experi- mental group, n	Con- trol group, n	High achieve- ment in experi- mental group, %	High achieve- ment in control group, %	Difference, percentage points
Chirch- iq State Pedagogi- cal Uni- versity	93	93	65.6	53.8	11.8
Samar- kand State	79	83	69.6	56.6	13.0

Pedagogi- cal Insti- tute					
Gu- listan	89	89	68.5	56.2	12.4
State Uni- versity					
Overall result	261	265	67.8	55.5	12.3

As shown in Table 4, the experimental groups outperformed the control groups at each institution. At Chirchiq State Pedagogical University, the high-achievement rate was 65.6% in the experimental group and 53.8% in the control group. The difference was 11.8 percentage points.

At Samarkand State Pedagogical Institute, the experimental group achieved a high-achievement rate of 69.6%, whereas the control group achieved 56.6%. The difference between the groups was 13.0 percentage points, representing the highest institutional result.

At Gulistan State University, 68.5% of students in the experimental group reached high achievement, compared with 56.2% in the control group. The difference was 12.4 percentage points.

Across all three institutions, the high-achievement rate in the experimental groups reached 67.8%, while the corresponding rate in the control groups was 55.5%. The difference of 12.3 percentage points demonstrates the pedagogical effectiveness of the developed methodology.

The results also show substantial growth in the experimental groups from the initial diagnostic stage. The initial high-achievement rate of 34.1% increased to 67.8%, indicating that students' scientific literacy improved through the systematic use of international assessment-based ecology tasks.

The main Pearson chi-square test on the final four-level distribution confirmed a statistically significant difference between the experimental and control groups: $\chi^2=28.424$, $df=3$, $p<.001$. The effect size was Cramér's $V=.232$, indicating a small-to-moderate association between instructional condition and achievement level. The supplementary high/not-high comparison also supported the final difference: $\chi^2=8.471$, $df=1$, $p=.004$, Cramér's $V=.127$.

Gain-score interpretation further supports the effect of the intervention. High achievement increased from 34.1% to 67.8% in the experimental groups (+33.7 percentage points) and from 32.8% to 55.5% in the control groups (+22.7 percentage points). The net advantage of the experimental methodology was therefore 11.0 percentage points in gain, while the final cross-sectional gap was 12.3 percentage points.

Although the pooled analysis is informative, it does not fully model the nested structure of students within institutions. For this reason, the institutional results in Table 4 are retained and the conclusion is framed as evidence for the effectiveness of the integrated methodology under the studied conditions, not as an unrestricted causal generalisation to all contexts.

The results demonstrate that students benefited from tasks requiring them to interpret scientific evidence, work with graphical information, analyse ecological situations, compare possible solutions, and justify decisions. The instructional methodology was particularly effective in improving students' capacity to connect ecological knowledge with real environmental issues.

3.2 Discussion

The results support the research hypothesis that an integrated methodology built from ecology-related tasks aligned with international assessment requirements can improve university students' scientific literacy. However, the intervention was implemented as a bundled pedagogical methodology; therefore, the study cannot determine the independent effect of each separate task type.

A plausible explanation for the improvement is that the integrated methodology shifted the learning focus from reproduction of ecological definitions toward functional application of knowledge. Traditional ecology instruction often concentrates on memorising concepts, classifications and theoretical information, whereas the revised methodology required students to use ecological knowledge in practical contexts such as climate change, plastic pollution, water scarcity, biodiversity loss and waste management.

Contextual ecological tasks may have helped students connect course concepts with everyday environmental situations. Within the integrated treatment, students identified problems, examined evidence, explained causes, predicted consequences and proposed responsible environmental actions. These learning processes correspond with contemporary views of environmental education emphasising environmental culture, sustainability, active participation and evidence-based decision making [1], [2].

Graphical, tabular and diagram-based assignments should be interpreted as one component of the integrated intervention rather than as an isolated causal factor. Such tasks required students to interpret information in different formats, identify trends, compare indicators and formulate conclusions; nevertheless, the present design does not allow their separate contribution to be quantified.

Case studies and research tasks were also embedded in the same instructional package. They plausibly supported students' analysis of complex ecological situations and their consideration of alternative solutions, but their specific effect was not separated from project work, contextual tasks, group discussion or teacher guidance. Future dismantling studies should compare these components separately.

Project-based activities formed another part of the bundled methodology. Students prepared mini-projects, environmental observations, presentations and practical recommendations. These activities are consistent with environmental citizenship and project-based learning approaches [4]-[6], yet the present evidence supports the overall methodology rather than an independent project-based effect.

Interdisciplinary integration was an important design principle of the methodology. Ecology is connected with biology, chemistry, geography and physics; therefore, several tasks required students to use concepts from more than one discipline. The

results indicate that the integrated approach as a whole supported interdisciplinary application, but the study did not experimentally isolate interdisciplinarity from the other instructional features.

Global competence tasks were included to relate local ecological problems to global sustainability challenges such as climate change, biodiversity loss and plastic pollution. The results suggest that students engaged with these wider perspectives; however, the development of global competence should be examined with a specialised measurement tool in future research.

The results are in line with previous research demonstrating that environmental education is more effective when it integrates active learning, contextualisation, interdisciplinary knowledge and practical tasks [7]-[10]. The present study adds evidence that international assessment-based tasks can be systematically integrated into university ecology courses, while acknowledging that the contribution of each component remains an open research question.

The theoretical significance of the research lies in its contribution to the understanding of scientific literacy as an integrated competence. Scientific literacy in ecology education should include not only ecological knowledge but also the ability to use evidence, interpret information, solve problems, make decisions, and demonstrate environmental responsibility.

The practical significance of the study is related to the possibility of using the developed tasks, diagnostic materials, assessment criteria, and methodological recommendations in higher education institutions. The methodology can be applied in the Fundamentals of Ecology course, environmental protection courses, teacher education programmes, and professional development activities for educators.

The study has several limitations. First, the experiment was conducted in three higher education institutions in Uzbekistan; therefore, the results should be generalised cautiously to other educational contexts. Second, students were organised in intact academic groups, not individually randomised groups. Third, the pooled chi-square analysis does not fully account for clustering within institutions, although the institutional results are reported separately. Fourth, the intervention combined contextual tasks, graph/table interpretation, case studies, mini-projects and evidence-based decision tasks, so the effect of each component cannot be decomposed. Fifth, item-level and rater-level data were not available in the article file; therefore, numerical Cronbach's alpha and inter-rater agreement coefficients could not be recalculated and should be reported in future publications if the raw assessment database is available. Sixth, the study evaluated immediate pedagogical outcomes, while long-term retention and environmentally responsible behaviour were not examined separately.

Future research should investigate the long-term effects of international assessment-based ecology tasks, compare digital and traditional task delivery, apply multi-level models that account for institutional clustering, and conduct dismantling studies to estimate the separate effects of contextual tasks, graph/table interpretation, case-study learning, project work, and global-competence activities.

4 Conclusions and Suggestions

The study demonstrated that ecology-related tasks aligned with international assessment frameworks are effective for developing university students' scientific literacy.

First, the use of contextual ecological tasks enabled students to apply scientific knowledge in real-life situations. Students developed the ability to analyse environmental problems, interpret scientific information, identify cause-and-effect relationships, and make evidence-based decisions.

Second, the developed methodology integrated ecological knowledge, critical thinking, practical skills, environmental values, and global competence. This integration allowed students to understand ecological issues not only as theoretical topics but also as practical social and environmental challenges.

Third, the experimental results confirmed the effectiveness of the integrated methodology. The average high-achievement level in the experimental groups reached 67.8%, compared with 55.5% in the control groups. The main four-level chi-square test was statistically significant ($\chi^2=28.424$, $df=3$, $p<.001$, Cramér's $V=.232$), and the supplementary high/not-high comparison was also significant ($\chi^2=8.471$, $df=1$, $p=.004$).

Fourth, the systematic use of environmental cases, graphs, tables, diagrams, research tasks, projects and evidence-based decision-making activities should be interpreted as a single integrated methodological package. The study shows that this package improved ecological thinking and functional scientific literacy, while the independent effect of each component requires further experimental verification.

Based on the findings, the following recommendations are proposed:

1. Higher education institutions should integrate international assessment-based contextual tasks into the Fundamentals of Ecology course on a regular basis.
2. Ecology instruction should include the analysis of graphs, tables, diagrams, maps, infographics, and scientific texts related to contemporary environmental problems.
3. Teachers should use case studies, project work, research assignments, and problem-based tasks to improve students' ability to apply ecological knowledge in practical contexts.
4. Assessment systems should evaluate not only theoretical knowledge but also the ability to interpret evidence, analyse environmental situations, justify decisions and propose sustainable solutions through a transparent rubric with stated score ranges and achievement thresholds.
5. Future studies should examine the long-term impact of this methodology on ecological behaviour, professional competence and global competence, and should report item-level reliability and inter-rater agreement when raw diagnostic and scoring data are available.

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