2025; 2-1 | pp.15-23

Academians Journal of Biology

ISSN: 3121-6404

Volume 2, Issue 1, March, 2026

(An Academians Publishers of Research & Academic Resources)

Review Article

OPEN ACCESS

Received: 22-01-2026 Accepted: 16-02-2026 Published: 25-03-2026

Developing Ecological-Pedagogical Competence in Biology Teacher Education: A Review of Integration Challenges and Innovative Approaches

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Abstract: The escalating global environmental crisis, characterized by biodiversity loss, climate change, and accelerating ecological degradation, has intensified demands for educational systems to produce environmentally literate citizens capable of sustainable decision-making. Central to this imperative is the preparation of biology teachers who possess not only disciplinary expertise but also robust ecological-pedagogical competence—the capacity to facilitate learning that fosters holistic environmental perception, conservation awareness, and responsible natural resource stewardship among students. This review synthesizes contemporary research on the formation of ecological-pedagogical competence in university-based biology teacher preparation programs, with particular attention to the Kazakhstani higher education context. Drawing on mixed-methods empirical studies, curriculum analyses, and international comparative scholarship, this review examines: (1) the conceptual foundations and structural components of ecological-pedagogical competence; (2) the current state of environmental education integration in biology teacher training curricula; (3) student perceptions, self-assessments, and pedagogical preferences regarding ecological preparation; and (4) evidence-based recommendations for curriculum reform, innovative pedagogical strategies, and digital technology integration. The analysis reveals significant gaps between the theoretical importance of ecological-pedagogical competence and its practical implementation in teacher education programs. Students demonstrate increasing competence across academic progression yet consistently report insufficient ecological content integration, particularly at early stages of training. Active and interactive learning modalities—practical exercises, project-based learning, and field research—are strongly preferred over passive lecture formats. The review concludes with a comprehensive framework of seven strategic recommendations for transforming biology teacher education to meet twenty-first-century environmental challenges.

Keywords: *ecological-pedagogical competence, biology teacher education, environmental education, curriculum integration, higher education, sustainable development, digital technologies, Kazakhstan*

1. Introduction

The twenty-first century has witnessed an unprecedented convergence of environmental crises that threaten planetary sustainability. Climate change, biodiversity collapse, pollution, and resource depletion constitute existential challenges requiring immediate and coordinated responses from all sectors of society, including education (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2021). The United Nations Sustainable Development Goals (SDGs), particularly Goal 4 (Quality Education) and Goal 13 (Climate Action), explicitly mandate the integration of environmental sustainability into educational systems at all levels (United Nations, 2015). Within this global framework, the preparation of teachers—especially biology teachers—who can effectively cultivate ecological literacy and environmental responsibility among future generations has become strategically imperative (Ponomarenko et al., 2016; Stevenson et al., 2017).

Biology teachers occupy a unique position in environmental education. As practitioners positioned at the intersection of scientific knowledge and pedagogical practice, they are uniquely equipped to demonstrate the intricate relationships between human societies and natural ecosystems, to illustrate principles of rational resource management, and to inspire students toward environmentally responsible behaviors (Sumatokhin, 2019; Verbitsky, 2014). However, the realization of this potential depends fundamentally on the quality of their

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pre-service preparation—specifically, the extent to which their university training develops what scholars have termed "ecological-pedagogical competence" (Shapran, 2018; Zharmenova et al., 2023).

Ecological-pedagogical competence encompasses a multidimensional set of capacities: deep disciplinary knowledge in ecology and biology; pedagogical skills to design and implement effective environmental learning experiences; the ability to foster holistic nature perception among students; and the personal commitment to model sustainable practices (Lamekhova, 2022; Shapran, 2018). This competence extends beyond mere content knowledge to include the capacity to stimulate students' critical thinking, to facilitate collaborative problem-solving around real environmental challenges, and to integrate local ecological contexts into meaningful learning experiences (Stevenson, 2017; Tilbury, 2011).

Despite the recognized importance of ecological-pedagogical competence, substantial evidence suggests that its integration into biology teacher preparation programs remains inadequate across diverse national contexts (Khrolenko et al., 2022; Mogensen et al., 2023). Curricula often treat environmental education as peripheral rather than central, rely on passive instructional methods rather than active engagement, and fail to connect theoretical knowledge with practical application in authentic ecological contexts (Kourova et al., 2018; Okolelov et al., 2020). These systemic shortcomings compromise the capacity of graduating teachers to fulfill their potential as environmental educators.

This review synthesizes contemporary research on the formation of ecological-pedagogical competence in university-based biology teacher education, drawing primarily on empirical studies conducted in Kazakhstani higher education institutions while situating these findings within international scholarship. The review addresses four interrelated questions: What constitutes ecological-pedagogical competence in the context of biology teacher preparation? How is environmental education currently integrated into biology teacher training curricula? What are students' perceptions, self-assessments, and pedagogical preferences regarding their ecological preparation? And what evidence-based strategies can enhance the development of ecological-pedagogical competence in teacher education programs?

2. Conceptual Foundations of Ecological-Pedagogical Competence

2.1 Defining Ecological-Pedagogical Competence

The concept of ecological-pedagogical competence has evolved through interdisciplinary scholarship spanning environmental education, teacher education, and sustainability science. At its core, this competence represents the integrated capacity to facilitate learning that promotes ecological literacy, environmental responsibility, and sustainable behaviors among students (Shapran, 2018; Zharmenova et al., 2023). However, precise definitions vary across cultural and institutional contexts, reflecting different educational traditions and environmental priorities.

In the Kazakhstani educational context, ecological-pedagogical competence is understood as encompassing several interrelated components: (1) foundational knowledge in ecology, biology, and environmental science; (2) pedagogical skills to design and implement effective environmental instruction; (3) the capacity to foster students' holistic perception of nature and understanding of conservation imperatives; (4) the ability to promote rational natural resource use; and (5) personal ecological consciousness and commitment to sustainable practices (Kurmanbayev et al., 2026; Sumatokhin, 2019). This multidimensional conceptualization aligns with international frameworks that emphasize the integration of cognitive, affective, and behavioral dimensions of environmental education (UNESCO, 2021).

Shapran (2018) has contributed significantly to operationalizing this concept through empirical research identifying the essential features and structural components of ecological competence among biology students in pedagogical universities. This work demonstrates that ecological competence is not unitary but comprises distinct yet interrelated facets: scientific knowledge, pedagogical-methodological skills, value-orientational components, and activity-practical components. The pedagogical dimension specifically requires the capacity to translate scientific understanding into effective educational practice—a translation that demands both subject-matter expertise and pedagogical content knowledge specific to environmental topics.

2.2 Theoretical Frameworks Informing Ecological Teacher Preparation

Several theoretical frameworks inform contemporary approaches to developing ecological-pedagogical competence. The ecological-evolutionary approach, articulated by Lamekhova (2022), emphasizes the integration of ecological principles with evolutionary biology to provide students with comprehensive understanding of organism-environment interactions. This approach is particularly relevant for biology teacher preparation, as it enables future teachers to explain adaptive strategies, biodiversity patterns, and ecosystem dynamics through unified theoretical lenses.

Tilbury's (2011) transformative learning framework has profoundly influenced international environmental education discourse. Tilbury argues that the primary goal of teacher professional preparation should be a paradigm shift "from simple material delivery to transformative learning," in which the educator functions as a catalyst for social and ecological change rather than merely a

transmitter of environmental information. This framework positions teachers as change agents who stimulate students' self-analysis, decision-making skills, and collaborative capacity to address complex socio-ecological challenges. The transformative orientation challenges traditional didactic approaches and demands that teacher education programs cultivate critical reflection, systems thinking, and action competence among pre-service teachers.

Stevenson (2017) advances a culturally situated perspective that questions the universality of standardized "environmental education" approaches that fail to account for local ecological and social specificities. Advocating for community-integrated learning, Stevenson proposes that teachers serve as bridges between educational institutions and the actual environmental conditions of their regions. This place-based approach cultivates initiative—the capacity to influence local environments and actively participate in positive ecological transformations. For biology teacher education, this perspective implies that ecological-pedagogical competence must include the ability to identify, analyze, and respond to locally specific environmental issues using locally relevant biological knowledge.

The concept of lifelong continuous environmental education, developed by Verbitsky (2014) and others, provides a temporal dimension to ecological-pedagogical competence. This framework recognizes that environmental challenges evolve continuously, requiring teachers to engage in ongoing professional development and to cultivate similar dispositions toward lifelong environmental learning among their students. Universities, within this framework, create conditions for forming stable ecological positions, awareness of personal responsibility for environmental problems, and consideration of environmental impacts across professional, social, and everyday life domains (Shapran, 2018).

2.3 International Perspectives on Environmental Teacher Competence

International scholarship offers complementary perspectives that enrich understanding of ecological-pedagogical competence. Mogensen et al. (2023) emphasize research methodologies for environmental education that prioritize action-oriented and participatory approaches. Their work highlights the importance of engaging pre-service teachers in authentic environmental research and community-based projects as essential components of competence development.

Amantayeva et al. (2022) demonstrate the effectiveness of project-based learning in forming environmental competence among future biology teachers. Their research shows that carefully designed project tasks can simultaneously develop disciplinary knowledge, pedagogical skills, and personal environmental commitment. This finding aligns with broader evidence that active, experiential learning modalities are more effective than passive instruction for developing the complex, integrated capacities that ecological-pedagogical competence requires.

Dlimbetova et al. (2023) examine socio-economic mechanisms in environmental education, revealing how economic incentives and institutional structures influence the effectiveness of ecological teacher preparation. Their work underscores that competence development cannot be understood solely in pedagogical terms but must account for the broader policy and economic contexts that shape educational priorities and resource allocation.

3. Current State of Environmental Education in Biology Teacher Preparation

3.1 Curriculum Structure and Content Analysis

Empirical investigation of biology teacher preparation curricula reveals significant variation in how ecological-pedagogical competence is addressed, yet consistent patterns of under-integration persist across institutions. Analysis of leading Kazakhstani universities implementing biology teacher preparation programs indicates that while ecological disciplines are present in academic plans, their volume, sequencing, and integration with pedagogical training often remain insufficient (Kurmanbayev et al., 2026).

Curriculum analysis typically examines several criteria: the presence and volume of ecological disciplines in academic plans; the integration of environmental themes into general biology courses; the utilization of interdisciplinary approaches and project activities for forming ecological-pedagogical competence; and the availability of specialized courses and seminars focused on ecology teaching methods and ecological culture development (Kurmanbayev et al., 2026). Across these dimensions, programs frequently exhibit fragmentation rather than integration, with ecological content distributed across multiple courses without coherent progression or explicit connections to pedagogical practice.

The sequencing of ecological content presents particular challenges. Early-course students often encounter environmental topics in isolation from broader biological contexts, while later courses may assume foundational ecological understanding that students have not adequately developed. This structural discontinuity undermines the cumulative formation of ecological-pedagogical competence and fails to capitalize on the progressive deepening that effective curriculum design should facilitate.

3.2 The Integration Gap: Student Perceptions

Student surveys and interviews consistently reveal perceived inadequacies in environmental education integration. Research involving first- through fourth-year

biology teacher candidates at Korkyt Ata Kyzylorda University demonstrates that substantial proportions of students at all levels regard ecological education as insufficiently represented in their academic programs (Kurmanbayev et al., 2026).

Among first- and second-year students, only 40% expressed positive assessments of environmental education integration, while 55% indicated insufficient attention to ecological content. Among third- and fourth-year students, positive assessments increased to 60%, suggesting some improvement through academic progression, yet 30% continued to report inadequate integration. These findings indicate that even among advanced students, significant dissatisfaction with ecological preparation persists.

Students specifically highlight the deficiency of practical and applied aspects of ecology within their programs. While theoretical foundations may be adequately addressed, the translation of ecological knowledge into pedagogical practice—designing environmental learning activities, conducting field investigations, facilitating student projects—receives insufficient attention. This applied gap is particularly consequential for teacher preparation, as future teachers require not only ecological knowledge but also the pedagogical skills to effectively communicate that knowledge and inspire environmental action among their own students.

The perceived insufficiency of ecological content is especially pronounced at early stages of training. First- and second-year students, who are establishing their academic identities and foundational understandings, express particular need for strengthened environmental education. This timing is critical because early exposure shapes students' orientations toward ecological topics and their perceptions of environmental education's importance within their professional identities. Inadequate early integration may generate lasting dispositions that marginalize environmental concerns within teachers' professional practice.

4. Student Self-Assessment and Competence Development

4.1 Progression of Ecological Knowledge

Longitudinal assessment of students' self-evaluated ecological and biological knowledge reveals positive developmental trajectories alongside persistent concerns about baseline preparation. Research comparing first- and second-year students with third- and fourth-year students demonstrates substantial improvement in self-assessed knowledge levels across academic progression (Kurmanbayev et al., 2026).

Among lower-division students, 55% rated their knowledge as "average" or below, with only 40% rating their knowledge as "high" or "very high." In contrast, among upper-division students, 65% rated their knowledge as "high" or "very high," with only 35% providing lower ratings. This progression indicates effective knowledge accumulation through the academic program and suggests that specialized coursework successfully builds ecological understanding.

However, the relatively low self-assessments among early-stage students raise important questions about foundational preparation. The fact that a majority of first- and second-year students perceive their ecological knowledge as insufficient suggests that either pre-university environmental education is inadequate or that university programs fail to adequately consolidate and extend prior learning. This baseline weakness may have cascading effects, as students who enter specialized ecological coursework without solid foundations may struggle to achieve the integrated, applied understanding that ecological-pedagogical competence requires.

The pattern of knowledge development also reveals the importance of cumulative, sequential curriculum design. The substantial improvement among upper-division students suggests that later courses effectively build upon earlier foundations, yet the weak starting point indicates that the foundational courses may not optimally prepare students for subsequent advancement. Curriculum revision might therefore focus on strengthening early ecological content while maintaining the progressive deepening that produces advanced competence.

4.2 Participation in Ecological Activities

Beyond formal coursework, participation in ecological activities—research projects, environmental initiatives, community engagement—contributes significantly to competence development. Survey data reveal marked differences in participation rates between lower- and upper-division students, with important implications for program design (Kurmanbayev et al., 2026).

Among first- and second-year students, only 20% reported active participation in ecological activities, while 60% reported no participation and 20% planned future involvement. Among third- and fourth-year students, participation increased to 45%, with 40% reporting no participation and 15% planning future involvement. This progression indicates that students increasingly engage with ecological practice as they advance through their programs, yet substantial non-participation persists even among advanced students.

The low participation rates among early-stage students are particularly concerning because experiential engagement with ecological issues is essential for developing the practical skills and personal commitment that distinguish ecological-pedagogical competence from mere ecological knowledge. Students who do not participate in environmental activities during their training are less likely to incorporate such activities into their future teaching practice. The fact that 60% of lower-division

students report no ecological participation suggests that programs may not effectively facilitate or require such engagement during the critical early years of teacher formation.

The barriers to participation likely include structural factors—limited availability of ecological projects, inadequate institutional support, competing academic demands—as well as motivational factors—students' unawareness of opportunities, perceived irrelevance to career goals, or insufficient ecological self-efficacy. Addressing these barriers requires intentional institutional commitment to creating accessible, meaningful ecological engagement opportunities at all stages of teacher preparation.

5. Pedagogical Preferences and Effective Methods

5.1 Student Preferences for Active Learning

Student assessments of teaching methods reveal strong preferences for active, interactive, and experiential learning modalities over passive, lecture-based instruction. This pattern is consistent across academic levels, though with some variation in emphasis that reflects developmental progression (Kurmanbayev et al., 2026).

Practical exercises emerge as the most preferred method across all levels, with 35% of lower-division and 40% of upper-division students identifying them as most effective. Seminars are also highly valued, particularly among advanced students (30% preference), suggesting that discussion-based, collaborative learning becomes increasingly appreciated as students develop greater disciplinary sophistication. Project-based learning and field research receive strong endorsement, with students recognizing their capacity to develop critical thinking skills and practical application abilities.

In contrast, traditional lectures receive the lowest preference ratings (20% among lower-division, 15% among upper-division students), and online courses register minimal interest (0% preference). These findings challenge the continued dominance of lecture-based instruction in many university programs and support calls for pedagogical transformation toward more engaged, student-centered approaches.

The preference for practical and interactive methods reflects students' understanding of their future professional roles. As prospective teachers, they recognize that they will need to design and facilitate active learning experiences for their own students and therefore value opportunities to experience such methods as learners. This professional orientation makes them particularly receptive to pedagogical approaches that model the interactive, inquiry-based instruction they aspire to implement.

The developmental shift in preferences—from stronger emphasis on practical exercises among younger students to greater appreciation of seminars among advanced students—suggests that pedagogical strategies should be differentiated across the academic trajectory. Early courses might emphasize hands-on, concrete experiences that build foundational skills and motivation, while later courses can increasingly incorporate sophisticated discussion, analysis, and reflective practice.

5.2 Field Research and Project-Based Learning

Field research and project-based learning receive particular emphasis in student recommendations for program improvement. These methods are valued not only for their effectiveness in developing ecological knowledge but also for their capacity to cultivate critical thinking, independent investigation skills, and the ability to apply theoretical knowledge in authentic contexts (Okolelov et al., 2020).

Students identify field exercises as essential for connecting classroom learning with real ecological phenomena. The direct observation of organisms, ecosystems, and environmental processes in natural settings provides experiential grounding for abstract concepts and fosters the observational skills that biology teachers must possess. However, students report insufficient fieldwork opportunities in current programs, with calls for substantial expansion of field-based components.

Project-based learning is valued for its capacity to develop integrated competence—combining knowledge application, collaborative skills, problem-solving, and creative thinking within sustained, authentic tasks. Students recognize that environmental projects model the kind of complex, real-world challenges they will face as teachers and prepare them to design similar experiences for their future students. The preference for project work aligns with international evidence demonstrating its effectiveness in environmental teacher education (Amantayeva et al., 2022).

6. Digital Technology Integration in Ecological Teacher Education

6.1 Student Demand for Technological Innovation

Contemporary students demonstrate strong interest in the integration of information and communication technologies (ICT) into ecological education. Both lower- and upper-division students express proposals for expanding the use of digital technologies, though with somewhat different emphases reflecting their developmental positions (Kurmanbayev et al., 2026).

Lower-division students tend to emphasize the technological component itself—virtual laboratories, online courses, digital platforms—while upper-division students focus more on methodological and pedagogical applications of technology. This developmental pattern

suggests that early exposure to educational technologies builds foundational digital literacy that later enables sophisticated pedagogical integration.

Students specifically propose the inclusion of modern educational platforms, online courses, and virtual laboratories to supplement traditional teaching methods. They anticipate that such integration would increase participation in online projects by approximately 40%, enhance motivation for ecological study, and develop digital competencies alongside ecological knowledge. The expectation that ICT integration would stimulate independent study and research reflects students' recognition that effective teachers must be self-directed learners capable of continuously updating their knowledge through diverse resources.

6.2 Virtual and Augmented Learning Environments

Virtual laboratories receive particular attention as tools for overcoming constraints on traditional field and laboratory work. These digital environments can simulate ecological processes, ecosystem dynamics, and environmental experiments that might be difficult, dangerous, or impossible to observe directly. For teacher preparation, virtual laboratories offer opportunities to explore diverse ecological scenarios, repeat experiments with varying parameters, and visualize complex spatial and temporal processes.

However, virtual environments must complement rather than replace direct experiential engagement with natural systems. The risk of technological substitution—where digital simulations displace authentic field experience—could undermine the very ecological sensitivity and nature connection that ecological-pedagogical competence aims to cultivate. Effective integration therefore requires thoughtful balance, using technology to extend and enhance rather than replace direct environmental experience.

Online collaborative platforms and digital project environments are also valued for their capacity to facilitate knowledge exchange and cooperation among students. These tools can support the collaborative, community-engaged learning that environmental education requires, connecting pre-service teachers with peers, mentors, and environmental professionals across geographical distances.

7. Recommendations for Program Reform

Synthesizing empirical findings with international best practices, this review proposes seven strategic recommendations for enhancing ecological-pedagogical competence in biology teacher preparation programs.

7.1 Implement a Mandatory Propedeutic Ecology Course

Programs should establish an obligatory foundational course in ecology that addresses both fundamental principles and applied aspects of the discipline. This course should serve as methodological groundwork for subsequent specialized study, ensuring that all students enter advanced coursework with solid, shared foundational understanding.

The propedeutic course should integrate theoretical and practical components, utilizing interactive educational technologies including problem-based and case-based learning. Early, intensive engagement with ecological content can address the baseline knowledge deficiencies identified among lower-division students and establish environmental education as a central rather than peripheral component of teacher professional identity.

7.2 Ensure Progressive Integration of Ecological Disciplines

Curricula should implement narrative progression in which ecological disciplines increase in weight and sophistication as students advance academically. Specialized courses should reflect contemporary conditions and prospective developments in ecological science, interconnected to form holistic understanding rather than isolated knowledge fragments.

This progressive integration requires careful curriculum mapping to ensure coherent sequencing, explicit connections between courses, and cumulative development of both ecological knowledge and pedagogical application skills. Each successive course should build upon and extend prior learning while introducing new dimensions of ecological-pedagogical competence.

7.3 Expand Practical and Field-Based Components

Programs should substantially increase the proportion of practical, seminar-based, field practicum, and laboratory work with ecological orientation. Interactive collective projects modeling solutions to real, ecologically significant problems should be incorporated throughout the curriculum.

The expansion of practical components requires institutional investment in field sites, laboratory facilities, and community partnerships that can provide authentic contexts for student engagement. It also demands that faculty develop the facilitation skills required for effective project-based and experiential instruction.

7.4 Stimulate Early Engagement in Ecological Activities

Institutions should formalize mechanisms for encouraging and rewarding student participation in volunteer eco-initiatives, applied research projects, public campaigns, and other environmental activities from the earliest stages of academic study. Rather than reserving ecological engagement for advanced students, programs should create accessible, scaffolded opportunities that progressively develop students' practical skills and environmental commitment.

Early engagement can address the low participation rates currently observed among lower-division students and establish patterns of environmental activism that will persist into professional practice. Institutionalization of such engagement—through formal recognition, academic credit, or portfolio requirements—can ensure that ecological participation becomes an expected rather than optional component of teacher preparation.

7.5 Comprehensive Implementation of Digital Technologies

Programs should systematically integrate digital and information-communication technologies into ecological education structures. This includes expanding virtual and electronic learning formats, modeling ecological processes through simulation, and developing integrated digital environments for interdisciplinary ecological study.

The implementation should be guided by pedagogical purposes rather than technological availability, ensuring that digital tools genuinely enhance learning rather than merely modernizing delivery. Faculty development is essential, as effective technology integration requires instructors who can navigate, evaluate, and pedagogically deploy diverse digital resources.

7.6 Develop Specialized Elective Courses

Institutions should create elective specialized courses reflecting cutting-edge achievements and trends in ecological science. These might include "green" technologies, renewable energy sources, eco-engineering methods, and other emerging fields that will shape the environmental challenges future teachers must address.

Collaboration with industry-leading companies under university auspices can provide authentic contexts for exploring these advanced topics. Such partnerships can also create pathways for student professional development, internships, and eventual employment in environmental education and related fields.

7.7 Expand Research Opportunities in Ecology and Sustainability

Programs should stimulate student involvement in collective and individual research projects in ecology and sustainable development, conducted within educational institutions. A grant system should be organized to provide material support for student research, recognizing that financial constraints may otherwise limit participation.

Research engagement develops the investigative skills, critical thinking, and scientific literacy that effective environmental educators require. It also fosters personal identification with ecological science and commitment to evidence-based environmental practice. By supporting student research from early stages, programs can cultivate the inquiry-oriented disposition that distinguishes exemplary biology teachers.

8. Discussion and Synthesis

8.1 The Competence-Implementation Gap

The evidence synthesized in this review reveals a persistent gap between the recognized importance of ecological-pedagogical competence and its actual implementation in biology teacher preparation programs. While students, faculty, and policymakers generally acknowledge the strategic significance of environmental education, curricula, pedagogical practices, and institutional structures often fail to optimally support competence development.

This gap manifests in multiple dimensions: insufficient volume and integration of ecological content; reliance on passive instructional methods despite student preferences for active learning; inadequate practical and field-based components; limited opportunities for authentic ecological engagement; and insufficient attention to the pedagogical skills specifically required for environmental education. Addressing these deficiencies requires comprehensive, coordinated reform rather than isolated interventions.

8.2 The Developmental Dimension

Student data reveal important developmental patterns that should inform program design. The progression from lower to upper division shows improvement in knowledge, participation, and satisfaction, indicating that programs do facilitate competence development over time. However, the weak starting point and persistent dissatisfaction even among advanced students suggest that current approaches are suboptimal.

Optimal program design would provide strong foundational preparation that accelerates early development, maintains progressive deepening throughout the program, and ensures that all graduates—regardless of their specific trajectory—achieve threshold competence in ecological-pedagogy. This requires attention to sequencing, scaffolding, and cumulative assessment that current programs may lack.

8.3 The Cultural and Institutional Context

The Kazakhstani context, while specific in its particulars, reflects broader patterns observable in diverse national settings. The challenges of integrating environmental education into teacher preparation, the student preferences for active learning, and the potential of digital technologies are not unique to Kazakhstan but resonate with international scholarship (Mogensen et al., 2023; Stevenson et al., 2017). This contextual specificity combined with universal patterns suggests that recommendations derived from this context may have broader applicability, while requiring adaptation to local conditions.

The Soviet educational legacy in Kazakhstani higher education, with its emphasis on theoretical knowledge and disciplinary specialization, may contribute to the observed gaps between ecological knowledge and pedagogical application. Transforming this legacy requires not merely curriculum revision but fundamental reorientation toward competence-based, student-centered, and practice-integrated teacher preparation.

9. Limitations and Future Research Directions

The research synthesized in this review, while informative, has several limitations that should guide future investigation. First, much of the empirical data derives from single-institution studies, potentially limiting generalizability. Multi-institutional comparative research would clarify which findings reflect universal patterns and which are context-specific.

Second, reliance on student self-assessment, while valuable for understanding perceptions, may not accurately reflect actual competence levels. Objective performance assessments, classroom observations, and longitudinal tracking of graduates into professional practice would provide more robust evidence of program effectiveness.

Third, the perspectives of faculty, administrators, and employing schools are underrepresented in current research. Understanding how these stakeholders perceive ecological-pedagogical competence and its development would enrich the evidence base for program reform.

Fourth, the long-term impact of ecological-pedagogical preparation on graduates' teaching practice remains largely unstudied. Longitudinal research following graduates into their professional careers would reveal whether and how pre-service preparation translates into effective environmental education in schools.

Fifth, the potential of innovative pedagogical approaches—such as service-learning, community-based research, international collaboration, and immersive field experiences—deserves more systematic investigation. While student preferences for active learning are clear, the specific conditions that maximize the effectiveness of different approaches require further research.

Finally, the rapidly evolving environmental challenges of the twenty-first century—climate change, biodiversity loss, emerging pollutants—demand that ecological-pedagogical competence itself continue evolving. Research must therefore attend not only to current best practices but also to the adaptive capacity of teacher education programs to prepare educators for environmental challenges that are not yet fully apparent.

10. Conclusion

The formation of ecological-pedagogical competence in biology teacher education represents a critical imperative for educational systems responding to global environmental crises. This review has synthesized evidence demonstrating that while students develop increasing ecological knowledge and engagement through academic progression, significant gaps persist in the integration of environmental education into teacher preparation curricula, the application of active and experiential pedagogies, and the provision of authentic ecological engagement opportunities.

Students consistently express preferences for practical, interactive, and technologically enriched learning modalities that align with international best practices in environmental education. Their self-assessments and recommendations provide valuable guidance for program reform, pointing toward more integrated, progressive, and practice-oriented approaches to ecological-pedagogical preparation.

The seven strategic recommendations presented—ranging from foundational course implementation through digital technology integration to research opportunity expansion—offer a comprehensive framework for transforming biology teacher education. Realizing this transformation requires institutional commitment, faculty development, resource allocation, and sustained attention to the evolving environmental challenges that future teachers must address.

Ultimately, the measure of ecological-pedagogical competence lies not in what pre-service teachers know about ecology but in what their future students learn about environmental responsibility. By strengthening the preparation of biology teachers, educational systems can multiply their impact, cultivating generations of environmentally literate citizens capable of the informed, responsible, and collective action that planetary sustainability demands. The urgency of environmental crises permits no delay in this essential educational work.

References

Amantayeva, A., Karbayeva, S., Childibayev, Z., Turlybekova, G., Issayev, G., & Stankevich, P. (2022). Forming environmental competence in future biology teachers through project tasks. *Cypriot Journal of Educational Sciences*, *17*(2), 492–505. https://doi.org/10.18844/cjes.v17i2.7184

Dlimbetova, G., Kurmanbayev, R., Akimish, D., Toktaganova, G., & Zharmenova, B. (2023). The effectiveness of socio-economic mechanisms in environmental education of young people in Kazakhstan. *Economic Annals-XXI*, *203*(5–6), 33–42. https://doi.org/10.21003/ea.V203-04

Khrolenko, M., Mehem, O., Kushakova, I., & Kurilchenko, I. (2022). Formation of ecological competence of future biology teachers in the process of professional training. *Revista Tempos e Espaços em*

Educação, *15*(34), e17330. https://doi.org/10.20952/revtee.v15i34.17330

Kourova, S. I., Sharypova, N. V., & Pavlova, N. V. (2018). Sistema nauchno-issledovatel'skoy deyatel'nosti studentov po biologii, geografii i khimii s uchetom innovatsionnykh tendentsiy v vuze [The system of scientific and research activities of students in biology, geography, and chemistry, taking into account innovative trends in higher education]. *Sovremennye Problemy Nauki i Obrazovaniya*, *(6)*. https://science-education.ru/ru/article/view?id=28308

Kurmanbayev, R. H., Amanbayeva, M. B., Zharmenova, B. K., Baikenzheeva, A. T., & Berdenkulova, A. Zh. (2026). Soderzhanie problemy formirovaniya ekologo-pedagogicheskoy kompetentsii v protsesse podgotovki uchiteley biologii v vuze [The content of the problem of the formation of ecological and pedagogical competence in the process of training biology teachers at the university]. *Gumilyov Journal of Pedagogy*, *2026*(1), 167–186. https://doi.org/10.53498/gjp.2026.1.167

Lamekhova, E. A. (2022). Metodika realizatsii ekologo-evolyutsionnogo podkhoda pri izuchenii biologii rannego ontogeneza ptits [Methodology for implementing the ecological and evolutionary approach in studying the biology of early ontogenesis in birds]. *Samarskiy Nauchnyy Vestnik*, *11*(1), 301–306. https://doi.org/10.55355/snv2022111307

Miklyaeva, M. A., Miklyaev, S. A., & Solopova, A. S. (2021). Razvitie kommunikativnoy kompetentnosti kak faktor uspeshnogo formirovaniya obuchayushchikhsya [Development of communicative competence as a factor of successful student formation]. *Nauka i Obrazovanie*, *4*(1), 45–52.

Minchenkov, E. E. (2016). *Prakticheskaya didaktika v prepodavanii estestvennonauchnykh distsiplin* [Practical didactics in the teaching of natural science disciplines] (2nd ed., rev.). Lan'.

Mogensen, F., Fang, W. T., Hassan, A., & LePage, B. A. (2023). Research methods for environmental education. In *The living environmental education* (Sustainable Development Goals Series). Springer. https://doi.org/10.1007/978-3-031-24239-9_2

Okolelov, A. Yu., Miklyaeva, M. A., Filatova, M. M., & Semerukhin, M. S. (2020). Formirovanie ekologicheskogo soznaniya obuchayushchikhsya pri izuchenii kursa biologii v obshcheobrazovatel'nykh uchebnykh zavedeniyakh [Formation of students' environmental awareness in the study of biology in general education institutions]. *Nauka i Obrazovanie*, *3*(3), 199–208.

Ponomarenko, Y. V., Yessaliev, A. A., Kenzhebekova, R. I., Moldabek, K., Larchekova, L. A., Dairbekov, S. S., & Asambaeva, L. (2016). Students' environmental competence formation as a pedagogical problem. *International Journal of Environmental and Science Education*, *11*(18), 10993–11002.

Shapran, Yu. P. (2018). Essential features, structural components and measurement of ecological competence of biology students of pedagogical university. *Pedagogical Education: Theory and Practice*, *18*(1), 320–325. https://doi.org/10.24143/2075-5200-2018-18-1-320-325

Stevenson, R. B. (2017). Educating for environment and sustainability: Australian perspectives. In *Schooling for sustainable development* (pp. 45–62). Springer.

Stevenson, R. B., Lasen, M., Ferreira, J. A., & Davis, J. (2017). Approaches to embedding sustainability in teacher education: A synthesis of the literature. *Teaching and Teacher Education*, *63*, 405–417. https://doi.org/10.1016/j.tate.2017.01.013

Sumatokhin, S. V. (2019). Estestvenno-nauchnaya gramotnost' kak tsel' razvitiya shkol'nogo biologicheskogo obrazovaniya [Scientific literacy as a goal of the development of school biological education]. *Biologiya v Shkole*, *(1)*, 15–23.

Tilbury, D. (2011). Education for sustainable development: An expert review of processes and learning. In *UNESCO education for sustainable development* (pp. 1–52). UNESCO.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations. https://sdgs.un.org/2030agenda

United Nations Educational, Scientific and Cultural Organization. (2021). *Education for sustainable development: A roadmap*. UNESCO Publishing.

Verbitsky, A. A. (2014). Printsipy i tseli nepreryvnogo ekologicheskogo obrazovaniya [Principles and goals of continuous environmental education]. *Obrazovanie Cherez Vsyu Zhizn': Nepreryvnoe Obrazovanie v Interesakh Ustoychivogo Razvitiya*, *12*(1), 207–210.

Zharmenova, B. K., Kurmanbayev, R. H., Amantayeva, M. B., Berdenkulova, A. Zh., & Baikenzheeva, A. T. (2023). Formirovanie ekologicheskoy kompetentnosti budushchikh uchiteley biologii v protsesse professional'noy podgotovki [Formation of ecological competence of future biology teachers in the process of professional training]. *Pedagogical Education in Russia*, *(2)*, 44–53. https://doi.org/10.26170/pir23-02-05