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INTEGRATION OF ENVIRONMENTAL CONTENT INTO NATURAL SCIENCE DISCIPLINES AS A FACTOR IN FORMING STUDENTS' ENVIRONMENTAL COMPETENCE

Abstract. The article presents the results of a pedagogical study aimed at developing environmental competence among students in teacher education programs through the integration of environmental content into natural science disciplines. The relevance of the study is determined by the need to prepare future teachers capable of addressing contemporary environmental challenges within the context of sustainable development and the digital transformation of education. The purpose of the study is to design and experimentally validate a model for developing environmental competence based on the STEAM approach and interdisciplinary integration. The study was conducted at Zhetysu University named after I. Zhansugurov and involved 127 students. The research employed a pedagogical experiment, testing, questionnaires, and statistical data analysis. The experimental design included diagnostic, formative, and control stages. The results demonstrated a significant improvement in the environmental competence of students in the experimental group: the proportion of students with a high level increased from 18% to 42%, while the proportion with a low level decreased from 36% to 14%. A statistically significant correlation was identified between the cognitive and activity-based components ($r = 0.96$; $p < 0.001$). The findings confirm the effectiveness of integrating environmental content and STEAM technologies into the educational process and highlight their potential for modernizing teacher education programs.

Keywords: environmental competence, STEAM, higher education, interdisciplinary approach, environmental education

Introduction

Contemporary environmental challenges, including climate change, ecosystem degradation, and increasing anthropogenic pressure, necessitate a reconsideration of the content of higher education and the strengthening of the environmental orientation in the training of future teachers (Khutorskoi, 2013; Sterling, 2001; UNESCO, 2017; Wiek et al., 2011). Within the framework of sustainable development, environmental competence is understood as an integrative personal characteristic that combines knowledge, values, and practical skills required for environmentally responsible behavior (Li et al., 2024; Damoah et al., 2024; Imran et al., 2024).

An analysis of current research indicates that traditional educational programs remain insufficiently oriented toward practice-based and interdisciplinary learning. The scholarly literature emphasizes the need to integrate environmental content across various academic disciplines and to employ active teaching methods, including project-based learning, inquiry-based tasks, and case study analysis (Baidenko, 2018; Gilmanshina et al., 2018; Olimov et al., 2024; Supratman et al., 2025).

Particular attention is given to the STEAM approach, which enables the integration of scientific knowledge, engineering thinking, digital tools, and creative forms of knowledge representation. This approach fosters the development of systems thinking in environmental contexts and strengthens the connection between theoretical preparation and practical problem-solving (Bybee, 2013; Cebrián et al., 2015; Yakman, 2008).

At the same time, most existing studies focus primarily on school-level education, while the issue of comprehensive integration of environmental content into natural science disciplines within

higher pedagogical education remains insufficiently explored. Therefore, the aim of this study is to develop and experimentally validate a model for forming students' environmental competence based on the integration of environmental content and STEAM technologies.

Literature Review

Contemporary research in environmental education confirms that the integration of environmental content into natural science disciplines is one of the key factors in developing students' environmental competence (Olimov et al., 2024; Supratman et al., 2025; Handayani et al., 2024). This approach contributes to the development of environmental literacy, systems thinking, value orientations, and practice-oriented behavior, thereby fostering a holistic readiness for environmentally responsible action.

The scholarly literature identifies two principal models of integrating environmental content: interdisciplinary and subject-oriented. The interdisciplinary model involves embedding environmental topics across multiple disciplines – such as biology, chemistry, physics, and geography – thereby promoting a holistic scientific worldview and systems-based environmental thinking (Jonāne, 2008; Karimova, 2023). In contrast, the subject-oriented model, most commonly implemented within biology, facilitates deeper acquisition of ecological knowledge through the study of local ecosystems and engagement in practice-based tasks (Supratman et al., 2025).

A substantial body of research emphasizes the role of pedagogical technologies in ensuring the effectiveness of such integration. The most effective approaches include active learning methods, such as project-based learning, inquiry-based learning, and fieldwork. These methods enhance students' research skills, critical thinking, and reflective abilities, while also supporting the application of knowledge in real-world contexts (Gilmanshina et al., 2018; Olimov et al., 2024; Herlanti et al., 2024). In contrast, traditional reproductive teaching methods are considered less effective in fostering environmental competence.

The content dimension of environmental education encompasses a broad range of topics, including ecosystems, biodiversity, sustainable development, natural resource management, and environmental safety. Moreover, increasing attention is given to the formation of environmental values, responsibility, and ecological awareness, reflecting a shift from a knowledge-based to a value-oriented educational paradigm (Leicht, 2023; Supratman et al., 2025; Lovren et al., 2023).

Empirical studies provide strong evidence for the effectiveness of integrating environmental content. For example, a quasi-experimental study involving 925 students demonstrated that integrated instruction leads to a higher level of environmental worldview formation compared to traditional approaches (Olimov et al., 2024). Additionally, such approaches promote environmentally responsible behavior, including participation in conservation activities and the development of sustainable environmental attitudes (Supratman et al., 2025).

Particular importance is attributed to the development of environmental thinking as an integrative learning outcome. Environmental thinking is conceptualized as a synthesis of systems-based scientific reasoning and practical activity aimed at solving environmental problems (Gilmanshina et al., 2018). This approach supports the ability to analyze complex natural–anthropogenic systems and make informed decisions.

Despite the proven effectiveness of integrating environmental content, the literature also identifies several barriers to its implementation. These include insufficient teacher preparedness, limited instructional resources, time constraints within curricula, and inadequate institutional support (Supratman et al., 2025). Addressing these challenges requires the development of comprehensive strategies focused on teacher training and curriculum enhancement.

A review of the literature indicates that most studies are concentrated at the level of secondary education, whereas the integration of environmental content within higher pedagogical education remains insufficiently explored. Furthermore, there is a lack of comprehensive models that account for the interdisciplinary nature of teacher training and the use of modern educational technologies, including the STEAM approach.

Thus, the identified research gap lies in the need to develop and empirically validate a model for integrating environmental content into natural science disciplines within higher pedagogical education. The present study aims to address this gap by proposing and testing an effective model for the development of students' environmental competence.

Methods and Materials

The study was conducted at Zhetysu University named after I. Zhansugurov and was aimed at examining the effectiveness of integrating environmental content into natural science disciplines as a factor in the formation of students' environmental competence. The participants included students enrolled in teacher education programs in natural science disciplines (6B01509-Geography, 6B01508-Biology, 6B01506-Chemistry, and 6B01503-Physics). The total sample consisted of 127 students, who were divided into an experimental group (EG) and a control group (CG).

The methodological framework of the study was based on competency-based, systemic, and interdisciplinary approaches in education. The competency-based approach was considered as the foundation for the development of students' environmental competence, encompassing a set of environmental knowledge, value orientations, and practical skills aimed at fostering a responsible attitude toward the environment. The systemic approach made it possible to examine the process of environmental competence formation as an integrated pedagogical system, including educational content, teaching methods, and learning outcomes. The interdisciplinary approach ensured the integration of environmental knowledge into the content of various natural science disciplines.

The study was carried out in several stages. At the diagnostic (ascertaining) stage, the initial level of environmental competence of students in both the experimental and control groups was assessed. For this purpose, testing, questionnaires, and analysis of students' academic performance were employed. Environmental competence was evaluated based on three key components: the cognitive component (level of environmental knowledge), the value-motivational component (attitudes toward environmental issues and readiness for environmentally responsible behavior), and the activity-based component (the ability to apply environmental knowledge in solving practical tasks).

At the formative stage, the integration of environmental content into natural science disciplines was implemented. Environmental modules were introduced into eight courses within the teacher education programs in physics, chemistry, biology, and geography: *Electricity and Magnetism*, *Fundamentals of Micro- and Nanotechnologies*, *Colloid Chemistry*, *Low-Waste and Zero-Waste Chemical Technologies*, *Soil Biology*, *Biological Resources of Kazakhstan*, *Meteorology with Basics of Climatology*, and *Soil Geography*. Within these courses, problem-based lectures, practical assignments, case study analysis, as well as project-based and research-oriented student activities were applied.

At the control stage, a repeated assessment of students' environmental competence in both the experimental and control groups was conducted in order to identify changes resulting from the implementation of the integrated educational modules. The obtained data were compared with the results of the initial diagnostic stage.

Statistical data processing included comparative analysis, correlation analysis, and Student's t-test. Differences were considered statistically significant at $p < 0.05$. The comparison of indicators between the experimental and control groups made it possible to determine the effectiveness of integrating environmental content into natural science disciplines in the process of training future teachers.

Results and Discussion

The results of the conducted pedagogical experiment indicate a pronounced positive dynamic in the development of environmental competence among students in the experimental group, thereby confirming the effectiveness of integrating environmental content into natural science disciplines.

As shown in Table 1, following the implementation of the formative stage, a substantial increase in the proportion of students demonstrating a high level of environmental competence was observed, rising from 18% to 42%, while the proportion of students with a low level decreased from 36% to 14%. The increase in the high-level category amounted to 24%, whereas the decrease in the low-level category reached 22%, indicating a significant improvement in the overall quality of student training.

Table 1

Levels of environmental competence (%)

Level	EG pre-test	EG post-test	CG pre-test	CG post-test
High	18	42	17	22
Medium	46	44	45	48
Low	36	14	38	30

In the control group, the observed changes were less pronounced, with the increase in the proportion of students demonstrating a high level amounting to only 5%, which confirms that the identified effects are attributable to the implemented model rather than external factors.

The obtained results are consistent with international studies demonstrating that the integration of environmental content and active pedagogical approaches contributes to the development of students' environmental literacy and ecological thinking (Olimov et al., 2024; Hu et al., 2025).

Statistical analysis confirmed the reliability of the identified changes. A strong correlation was found between the cognitive and activity-based components (r = 0.96), indicating a close relationship between theoretical knowledge and practical skills. The application of Student's t-test revealed statistically significant differences between the experimental and control groups (t = 2.14; $p < 0.05$), confirming the robustness of the results.

These findings are consistent with the concept of developing key competencies for sustainable development, which suggests the synchronous development of cognitive and activity-based characteristics (Wiek et al., 2011).

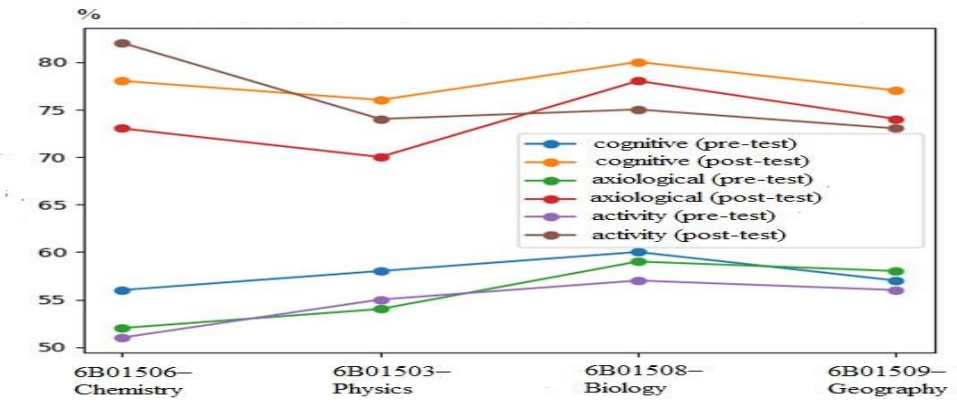
An analysis of results across educational programs revealed differences in the dynamics of environmental competence development. The average value of the cognitive component increased from 58% to 78%, the axiological component from 56% to 74%, and the activity-based component from 55% to 76%. The most pronounced growth in the activity-based component was observed among students in the Chemistry program (up to 82%), which can be explained by the practice-oriented nature of the courses *Colloid Chemistry* and *Low-Waste and Zero-Waste Chemical Technologies*.

At the same time, students in the Biology program demonstrated the most balanced development across all components of environmental competence, which is associated with the combination of field-based studies and the analysis of natural ecosystems.

The obtained results support the findings of Supratman et al. (2025), confirming the high effectiveness of practice-oriented teaching methods in environmental education (Figure 1).

Figure 1

Dynamics of Students' Environmental Competence Components (pre- and post-intervention, %)

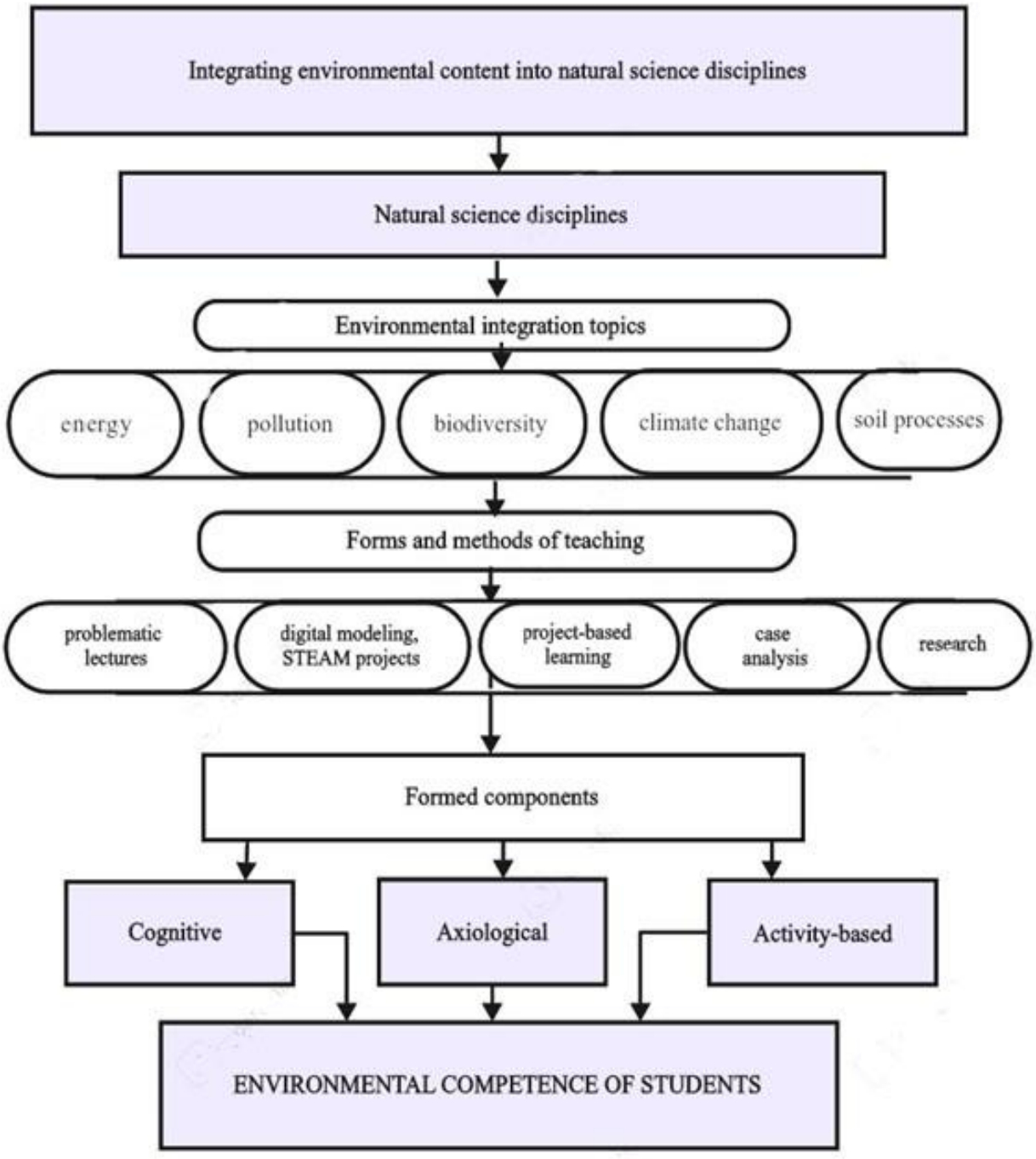


Correlation analysis revealed a very strong relationship between the cognitive and activity-based components of environmental competence ($r = 0.96$; $p < 0.001$), indicating that the development of theoretical knowledge directly contributes to the enhancement of practical skills. The application of Student's *t*-test confirmed statistically significant differences between the experimental and control groups ($t = 2.14$; $p < 0.05$).

The implementation of the proposed model ensured the systematic integration of environmental topics into natural science disciplines, thereby establishing an interdisciplinary foundation for students' environmental training (Figure 2). This approach aligns with contemporary trends in education for sustainable development, which emphasize the integration of environmental knowledge across subject areas (Cebrián et al., 2015).

Figure 2

Model of integration of environmental topics into educational programs



As illustrated in Figure 2, the model is based on a sequential logic: from the incorporation of environmental topics into course content, to the selection of appropriate teaching methods, and further to the formation of cognitive, axiological, and activity-based components of environmental competence. This structure demonstrates the interdisciplinary nature of the model and provides a clear representation of its implementation mechanism within the educational process.

A comparison of the obtained results with contemporary studies indicates that the integration of environmental content and STEAM technologies not only enhances the level of environmental knowledge but also strengthens the value-based and practical dimensions of teacher education. Unlike a number of studies that primarily report improvements in the cognitive component, the present study demonstrates a comprehensive development of all components of environmental competence, thereby confirming the effectiveness of the interdisciplinary approach (Cebrián et al., 2015; Gilmanshina et al., 2018; Redman et al., 2021; Wiek et al., 2011).

The limitations of the study include the fact that the sample was drawn from a single university and that the experimental period was relatively limited in duration. At the same time, the practical significance of the study lies in the potential for scaling the proposed model. The findings can be applied in the modernization of teacher education programs in natural science disciplines.

Conclusion

The conducted study confirmed that the integration of environmental content into natural science disciplines is an effective approach to fostering students' environmental competence. The proposed model ensures the comprehensive development of cognitive, axiological, and activity-based components through the interdisciplinary integration of content, the application of active teaching methods, and the use of STEAM technologies.

The practical significance of the study lies in the potential application of the developed model for the modernization of teacher education programs in physics, chemistry, biology, and geography. Future research should focus on expanding the sample size, involving multiple universities, and assessing the long-term effects of environmental competence development.

Disclosure Statement

AI tools were not used to create the scientific content of the manuscript. Mendeley was used for reference management and bibliography formatting, while Boardmix was used only for preparing schematic figures. All graphs, analyses, interpretation of results, and conclusions were prepared and verified by the authors.

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ҚОРШАҒАН ОРТА МАЗМҰНЫН ЖАРАТЫЛЫСТАНУ ҒЫЛЫМДАРЫ ЦИКЛІ ПӘНДЕРІНЕ КІРІКТІРУ СТУДЕНТТЕРДІҢ ЭКОЛОГИЯЛЫҚ ҚҰЗЫРЕТТІЛІГІН ҚАЛЫПТАСТЫРУ ФАКТОРЫ РЕТІНДЕ

Аңдатпа. Мақалада жаратылыстану ғылымдары циклі пәндеріне экологиялық мазмұнды кіріктіру арқылы педагогикалық мамандықтар студенттерінің экологиялық құзыреттілігін қалыптастыруға бағытталған педагогикалық зерттеудің нәтижелері ұсынылған. Зерттеудің өзектілігі тұрақты даму және білім беруді цифрландыру жағдайында заманауи экологиялық мәселелерді шешуге қабілетті болашақ мұғалімдерді даярлау қажеттілігімен айқындалады. Зерттеудің мақсаты – STEAM-тәсіл және пәнаралық интеграция негізінде экологиялық құзыреттілікті қалыптастыру моделін әзірлеу және оны эксперименттік тұрғыда негіздеу. Зерттеу І. Жансүгіров атындағы Жетісу университетінің базасында 127 студенттің қатысуымен жүргізілді. Зерттеу барысында педагогикалық эксперимент, тестілеу, сауалнама жүргізу және статистикалық деректерді өңдеу әдістері қолданылды. Эксперимент құрылымы констатаушы, қалыптастырушы және бақылау кезеңдерін қамтыды. Зерттеу нәтижелері эксперименттік топ студенттерінің экологиялық құзыреттілік деңгейінің едәуір артқанын көрсетті: жоғары деңгейдегі студенттердің үлесі 18%-дан 42%-ға дейін өсті, ал төмен деңгей 36%-дан 14%-ға дейін төмендеді. Когнитивтік және іс-әрекеттік компоненттер арасында статистикалық тұрғыдан мәнді байланыс анықталды ($r = 0,96$; $p < 0,001$). Алынған нәтижелер білім беру үдерісіне экологиялық мазмұн мен STEAM-технологияларды кіріктірудің тиімділігін дәлелдейді және болашақ мұғалімдерді даярлау бағдарламаларын жаңғыртуда қолдануға мүмкіндік береді.

Түйін сөздер: экологиялық құзыреттілік, STEAM, жоғары білім, пәнаралық тәсіл, экологиялық білім беру

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ИНТЕГРАЦИЯ ЭКОЛОГИЧЕСКОГО СОДЕРЖАНИЯ В ДИСЦИПЛИНЫ ЕСТЕСТВЕННОНАУЧНОГО ЦИКЛА КАК ФАКТОР ФОРМИРОВАНИЯ ЭКОЛОГИЧЕСКОЙ КОМПЕТЕНТНОСТИ СТУДЕНТОВ

Аннотация. В статье представлены результаты педагогического исследования, направленного на формирование экологической компетентности студентов педагогических специальностей посредством интеграции экологического содержания в дисциплины естественнонаучного цикла. Актуальность исследования обусловлена необходимостью подготовки будущих учителей, способных решать современные экологические проблемы в условиях устойчивого развития и цифровизации образования. Цель работы заключается в разработке и экспериментальной апробации модели формирования экологической компетентности на основе STEAM-подхода и междисциплинарной интеграции. Исследование проведено на базе Жетысуского университета имени И. Жансугурова с участием 127 студентов. В работе использованы методы педагогического эксперимента, тестирования, анкетирования, а также статистической обработки данных. Эксперимент включал констатирующий, формирующий и контрольный этапы. Результаты показали значительное повышение уровня экологической компетентности студентов экспериментальной группы: доля высокого уровня увеличилась с 18 % до 42 %, а низкого снизилась с 36 % до 14 %. Выявлена статистически значимая взаимосвязь между когнитивным и деятельностным компонентами ($r = 0,96$; $p < 0,001$). Полученные результаты

подтверждают эффективность интеграции экологического содержания и STEAM-технологий в образовательный процесс и могут быть использованы при модернизации программ подготовки будущих учителей.

Ключевые слова: экологическая компетентность, STEAM, высшее образование, междисциплинарный подход, экологическое образование

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