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Formation of environmental competence of students of higher education

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Abstract
In the contemporary context, pressing environmental challenges, including climate change, biodiversity loss, and ecosystem degradation, necessitate the refinement of professional training programs for prospective biology teachers. The present article expounds upon a model of ecological competence formation that integrates theoretical, practical, and reflective components. The objective of the study was to assess the efficacy of this proposed model in the educational process. The study was conducted employing an experimental design, with a sample of 88 students divided into experimental and control groups. The experimental groups exhibited a marked increase in environmental knowledge, values, and skills when compared to the control groups. These findings substantiate the efficacy of the proposed model as an instrumental medium for fostering ecological competence. The model's notable adaptability underscores its capacity for integration into diverse educational contexts. Conclusively, the study underscores the imperative of leveraging the model in the pedagogy of prospective educators to address pressing environmental challenges.

Keywords: *Environmental competence, sustainable development, professional training, interactive teaching methods, reflective practices.*

Introduction

The ongoing environmental crises, characterized by global climate change, biodiversity loss, and ecosystem degradation, underscore the urgency of adopting effective measures to protect the environment and ensure sustainable development (Akhmetova et al., 2015; UNDP, 2022). These challenges necessitate a transformation in education, particularly in the training of future biology teachers who play a crucial role in shaping students' environmental awareness and responsibility (Barth et al., 2007; Lozano et al., 2013; Bawden, 2004). The integration of sustainability principles in teacher education is vital for equipping educators with the competencies needed to address environmental issues and instill an ecologically responsible mindset in future generations (Rowe, 2007; Robert et al., 2005). Education for sustainable development (ESD) extends beyond the mere dissemination of knowledge on environmental problems. It involves fostering critical thinking, interdisciplinary approaches, and practical skills essential for solving

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real-world challenges (Seilkhan et al., 2021; Itinson and Chirkova, 2020; Sabelnikova and Khmeleva, 2015). As higher education institutions increasingly assume lea-dership in promoting sustainability, the development of innovative pedagogical strategies becomes a priority (Lodge, 2019; Popova, 2024; Maryna et al., 2022). Consequently, the training of future biology teachers must incorporate methodologies that enable students to comprehend the complexity of environmental systems, recognize human environment interactions, and apply sustainable solutions in their teaching practices (Balkybek et al., 2025; Yastrub, 2022; Vdovenko, 2022). This study aims to develop and validate a model for cultivating environmental competence in biology teacher education. The proposed model consists of three fundamental components: theoretical, practical, and reflexive blocks. The theoretical component provides an in depth understanding of ecology, sustainability principles, and pressing environmental challenges (Mesquita, 2023; Zhanguzhi-nova, 2017; Dudnyk, 2023). The practical component encompasses laboratory research, fieldwork, and participation in environmental projects, fostering applied skills essential for environmental education (Kind and Chan, 2019; Kind, 2009; Eames and Birdsall, 2019). The reflexive component enables students to critically analyze their experiences, reinforcing their commitment to ecological values and sustainable practices (Williams et al., 2012; Drits-Esser et al., 2016; Mesci et al., 2019). A systematic approach underpins this model, ensuring that theoretical knowledge is effectively translated into practical application and subsequently internalized through reflection (Wahbeh and Abd-El-Khalick, 2013; Nilsson, 2014; Alonzo et al., 2019). The model's emphasis on ecological competence as a core professional attribute highlights its cognitive, axiological, and practical dimensions. The cognitive aspect imparts fundamental environmental knowledge, the axiology-cal aspect nurtures environ-mental values, and the practical aspect cultivates competences necessary for implementting sustainable practices in educational settings (Gunckel et al., 2018; Lederman et al., 1994; Plomp et al., 2007). By integrating this model into teacher education programs, pedagogical universities can enhance the quality of training for future biology teachers (Kallery, 2017; Višnjić-Jevtić and Bel, 2024; Tobin and Garnett, 1988). This, in turn, will contribute to addressing global environmental challenges and achieving sustainable development goals (Luft et al., 2011; Stagl, 2017; Pedersen and Bang, 2015). A review of Chao, 2024). The incorporation of contemporary pedagogical models, such as ecological competence frameworks, further supports the formation of environmentally responsible educators (Xiao and Mc Cright, 2007; Stern et al., 2017; Houtsonen, 2004). Additionally, studies highlight the importance of cultural and social factors in shaping teachers ecological competence (Stibbards and Puk, 2011; Liu et al., 2019). Systematic integration of environmental knowledge into teacher training curricula fosters a holistic approach that combines theoretical foundations with hands-on experience (Chang and Kidman, 2023; Harris and Gold, 2017; Liu and Lin, 2014). Long-term professional development programs have been shown to enhance teachers ability to incorporate environmental aspects into their instructional practices (Oyegoke, 2020; Moseley et al., 2010; Dlimbetova et al., 2015). Recent research also underscores the significance of digital technologies and artificial intelligence in advancing environmental education (McKay et al., 2022; Kyler, 1984; Winkelhake, 1968). Furthermore, studies indicate that integrating environmental concepts into broader pedagogical frame-works fosters interdisciplinary learning and enhances environmental competence among educators (Kent, 2004; Zameliuk, 2020; Karter, 2019). Therefore, it is hypothesized that the development of a model for the formation of environmental competence of future biology teachers should take into account the multidimensionality of this competence, including its cognitive, axiological, and practical components (Liulenko and Podzerei, 2022; Ridei and Tolochko, 2018; Jorgensen, 2008). The implementation of such a model in the educational process fosters students systemic thinking, critical approach to solving environmental problems, and the capacity to incorporate environmental considerations into teaching activities (Klochko and Fedorets, 2023; Khuraskina, 2017; Dlimbetova et al., 2015). This assertion is particularly salient in the context of the imperative to achieve sustainable development goals, which have been set before society to educate a generation that is environmentally conscious and socially responsible (McKay et al., 2022; Chao, 2024). The ecological competence framework encompasses three core components: knowledge (cognitive), values (axiological), and skills (practical). The proposed model is comprised of six interconnected stages that facilitate the integration of ecological knowledge into the educational process (Xiao and McCright, 2007; Moseley et al., 2010; Plomp et al., 2007). This model represents a logical

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equence of educational stages aimed at in-depth study of environmental issues, development of professional skills, and formation of environmentally responsible behavior (Chao, 2024; McKay et al., 2022). Thus, the literature review confirms that the effective formation of environmental competence in future biology teachers requires the integration of various methodological approaches, pedagogical concepts, and interdisciplinary models (Khuraskina, 2017; Zameliuk, 2020; Winkelhake, 1968). The competence-based approach, supported by innovative teaching methods, plays a key role in the formation of an ecological worldview and professional readiness of teachers to address environmental challenges (Jorgen-sen, 2008; Stibbards and Puk, 2011; Harris and Gold, 2017). Despite extensive research in environmental education, further studies are needed to explore the long-term impact of the cultivated environmental competence on teachers' professional practices (Liu and Lin, 2014; Moseley et al., 2010; Oyegoke, 2020). By implementing this model within teacher education programs, universities can contribute to fostering a new generation of educators who are not only well-versed in ecological concepts but are also equipped with the pedagogical competencies necessary to inspire environmental responsibility among students (Houtsonen, 2004; Özkan et al., 2024). Ultimately, the integration of this framework into education systems will support broader efforts to achieve sustainability and environmental conservation goals worldwide (Kyler, 1984; Harris and Gold, 2017). Contemporary environmental crises, including global climate change, biodiversity loss, and ecosystem degradation, present numerous complex and interrelated challenges to humanity. These problems necessitate immediate measures to preserve the environment, restore natural resources, and achieve sustainable development goals. In this regard, the education system assumes a pivotal role in shaping the environmental awareness and values of the younger generation, thereby contributing to the formation of an environmentally responsible worldview. Of particular significance is the training of future biology teachers, as they wield a substantial influence on the environmental awareness and values of schoolchildren. Biology teachers have the capacity to impart knowledge about nature and environmental problems, as well as to cultivate a conscious attitude towards the environment in pupils. This renders their professional training highly relevant. In the contemporary context, educational policy ought to prioritize the integration of sustainable development principles across all levels and facets of education. This entails more than the mere transmission of knowledge concerning global environmental issues; it also involves the cultivation of the competencies and values that are essential for their resolution. Consequently, there is an imperative to devise and implement novel pedagogical approaches and methodo-gies that will encompass the intricacy and multidimensionality of environmental challenges. These methodologies should be based on a systems approach that allows students to see the interrelationships between different components of ecosystems and their interaction with human activities. The objective of this study is to develop and validate a model for the formation of environmental competence in students preparing to become biology teachers. The model is composed of three primary components: theoretical, practical, and reflexive blocks, each of which plays a significant role in the educational process. The theoretical block is designed to cultivate students' profound and comprehensive understanding of ecology, the principles of sustainable development, and the pressing environmental challenges. This foundation enables students to progress to more advanced and hands-on aspects of the curriculum. The practical block is designed to facilitate laboratory and field research, as well as participation in environmental projects, thereby contributing to the development of students' research and applied skills. The reflexive block focuses on analyzing and evaluating one's own experience, which helps students to comprehend the significance of environmental issues and develop a sustainable system of values. In this model, particular emphasis is placed on the sequence and interrelation between the blocks. The knowledge acquired in the theoretical block is applied in the practical block, and the results of practical activities are analyzed and evaluated in the reflective block. This pedagogical approach maintains the integrity and systemic nature of learning, thereby fostering not only the assimilation of knowledge but also the development of students' critical thinking skills and the capacity for autonomous analysis and problem-solving in environmental contexts (Figure 1). The efficacy of the proposed model is contingent upon its emphasis on the cultivation of ecological competence as a pivotal professional attribute of prospective biology teachers. The model's ecological competence component encompasses cognitive, axiological, and practical aspects, each meticulously designed to nurture students' qualities deemed essen-

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tial for successful pedagogical endeavors. Specifically, the cognitive component provides fundamental knowledge, the axiological component fosters the development of values, and the practical component cultivates the competencies essential for ecological action. Consequently, the developed model of ecological competence formation is an innovative instrument that can be integrated into the educational process of pedagogical universities. It facilitates the delivery of superior training to prospective biology teachers, a development that will eventually lead to the resolution of pressing environmental issues and the realization of sustainable development objectives for society. The article's primary focus is on underscoring the significance of the proposed model and its potential to transform the educational process in the context of contemporary environmental challenges.

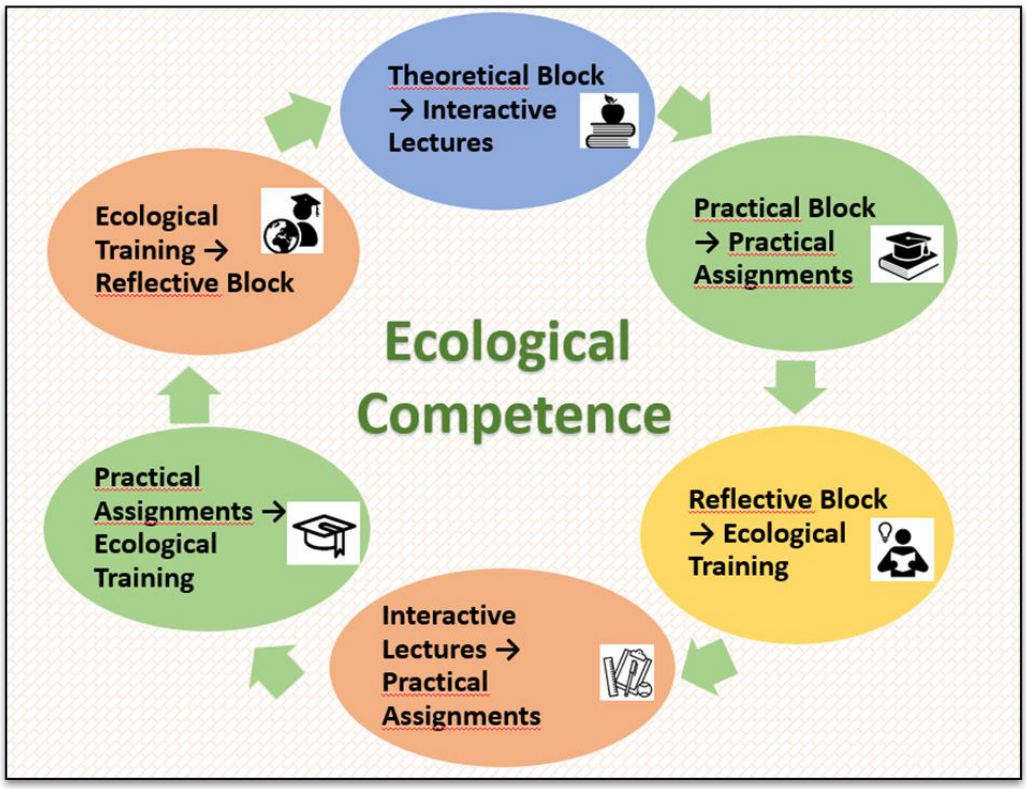

Figure 1
A model for developing students' ecological competence in training biology teachers.

Materials and Methods

Methodology for assessing environmental competence formation

To achieve the research objectives, a comprehensive methodology was employed, incorporating both quantitative and qualitative methods of analysis. It was based on modern approaches to the formation of environmental competence, as well as the principles of professional teacher training and environmental education (Ponomarova, 2018;).

Stages of Research

The study was conducted in several stages. In the analytical stage, existing models for environmental competence formation were examined, their effectiveness assessed, and their alignment with current requirements evaluated. The analysis was carried out considering the principles of professional training and pedagogical preparation. During the design stage, a model was developed, incorporating theoretical, practical, and reflective components. The foundation of this model was based on recommendations for environmental education aimed at fostering sustainable competencies. In the experimental stage, the model was implemented in the educational process, and data was collected and analyzed to assess its effectiveness (Palshkova, 2003).

Data Collection Methods

Data collection involved testing and surveys. Testing was conducted to determine students' initial level of environmental competence and to identify changes in cognitive, value-based, and practical components. Surveys were used to evaluate students 'perception of environmental values and their engagement in practi-

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cal activities (Sotska, et al., 2019).

Participants of the study

The study involved 88 students specializing in biological sciences and educational biology. The participants were divided into experimental and control groups, allowing for an objective assessment of the effectiveness of the proposed model.

Data analysis

Data processing was carried out using mathematical statistical methods. The level of environmental competence was assessed twice: before the implementation of the model and after its validation. This approach ensured systematic monitoring of the effectiveness of pedagogical innovations.

Criteria for evaluating model effectiveness

Three main criteria were used to assess the effectiveness of the model: the level of environmental knowledge, the formation of environmental values, and the development of practical skills and abilities in environmental activities. The applied methodology enabled the development and validation of a model that takes into account modern approaches to the formation of environmental literacy. It combined both traditional and innovative methods, providing a comprehensive analysis and an objective evaluation of the proposed approach (Liulenko, 2022).

The following data sources are considered primary

The following data represents the mean score of students before and after model testing (Table 1). As illustrated in Table 1, the results of the testing conducted before and after the experiment indicate a significant improvement in the experimental groups in comparison to the control groups.

Table 1
Results of testing

Group	Average score before experiment	Average score after experiment	Increase (Δ)	Change (%)
Experimental (Biology-Natural Science)	65.4	82.4	+17.0	+26.00%
Experimental (Pedagogical Biology)	64.1	81.5	+17.4	+27.20%
Control (Biology-Natural Science)	66.2	79.4	+13.2	+20.00%
Control (Pedagogical Biology)	65.9	78.7	+12.8	+19.44%

This table 1 presents the average test scores of students before and after the experiment, showing the effectiveness of the newly implemented educational model. The experimental groups demonstrated higher score improvements compared to the control groups. The percentage change column indicates that the experimental group (Pedagogical Biology) showed the highest improvement at 27.2%, while the control group (Pedagogical Biology) had the lowest improvement at 19.44%. This confirms that the new educational approach positively impacted environmental competence development. Table 2 contains test questions divided into Cognitive, Axiological, and Practical sections, the purpose of which is to assess students' environmental competence (Table 2). This table includes 30 questons divided into three categories: cognitive, axiological, and practical. Cognitive questions assess students' theoretical knowledge of ecology, environmental science, and sustainability. Axiological questions evaluate students' values, attitudes, and ethical perspectives regarding environmental responsibility. Practical questions measure students' ability to apply ecological principles to real-world scenarios, such as pollution reduction, biodiversity conservation, and sustainable practices. The test questions ensure a comprehensive evaluation of students' environmental competence and their ability to apply knowledge in practice. Table 3 provides 10 survey questions, the analysis of which will yield a comprehensive understanding of students' attitu-

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Section	№	Question
Cognitive	1	What impact does the greenhouse effect have on climate?
Cognitive	2	What are bioindicators?
Cognitive	3	What is the process of photosynthesis?
Cognitive	4	What factors influence biodiversity?
Cognitive	5	What is an ecological niche?
Cognitive	6	Which gas is released by plants during photosynthesis?
Cognitive	7	What is the role of decomposers in an ecosystem?
Cognitive	8	What does the term 'ecological succession' mean?
Cognitive	9	What are the main types of environmental pollution?
Cognitive	10	What are the main causes of climate change?
Axiological	1	What environmental protection measures do you practice in daily life?
Axiological	2	Which aspect of ecology do you consider the most important?
Axiological	3	What factors influence an individual's environmental awareness?
Axiological	4	What is your attitude toward the use of renewable energy sources?
Axiological	5	How important is the introduction of environmental education in schools?
Axiological	6	How do you assess personal responsibility for the state of the environment?
Axiological	7	What steps do you take to reduce your ecological footprint?
Axiological	8	How do you perceive government measures for environmental protection?
Axiological	9	What contributions can society make to environmental protection?
Axiological	10	What does the term 'sustainable development' mean to you?
Practical	1	How can water pollution be reduced?
Practical	2	What is the most effective method of land reclamation?
Practical	3	What measures can reduce the carbon footprint in production?
Practical	4	What technologies help reduce CO2 emissions?
Practical	5	How does waste recycling impact the environment?
Practical	6	What biotechnological methods are used for water purification?
Practical	7	What innovations in agriculture can reduce its environmental footprint?
Practical	8	How does transport infrastructure affect ecology?
Practical	9	How does science help predict and prevent environmental disasters?
Practical	10	What measures are taken to protect endangered species?

Table 2
Test questions

des and perceptions regarding environmental education (Table 3). This table 3 contains 10 survey questions designed to gather students' perceptions, attitudes, and engagement in environmental education. The questions focus on Students' participation in environmental activities; heir sources of ecological knowledge; their views on the role of teachers and government policies in environmental education; barriers preventing eco-friendly behavior; suggestions for improving environmental education programs. This survey provides qualitative insights into students' motivations and challenges in developing ecological awareness and competence. The statistical analysis results presented in Table 4, derived from a t-test with a significance level of $p < 0.01$, have confirmed significant differences between the

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experimental and control groups, thereby affirming the study's high reliability (Table 4).

№	Question
1	How often do you participate in environmental initiatives?
2	Which educational formats do you find most convenient?
3	What role should a biology teacher play in shaping ecological awareness?
4	Which sources do you use to learn about environmental issues?
5	What aspect of environmental education do you consider the most important?
6	How do you personally contribute to environmental conservation?
7	What motivates you to engage in environmental activities?
8	What barriers prevent you from adopting eco-friendly practices?
9	How would you assess the government's role in environmental protection?
10	What strategies do you think should be implemented to enhance environmental education?

Table 3
Survey questions

Compared groups	t-value	p-value
Experimental (Biology-Natural Science) vs Control (Biology-Natural Science)	3.12	$p < 0.01$
Experimental (Pedagogical Biology) vs Control (Pedagogical Biology)	3.45	$p < 0.01$

Table 4
Statistical analysis of data

The table 4 presents the results of a t-test analysis comparing the experimental and control groups. The t-values (3.12 and 3.45) and p-values ($p < 0.01$) indicate statistically significant improvements in the experi-mental groups compared to the control groups. The findings suggest that the new educational model had a meaningful impact on students' ecological competence, confirming the effectiveness of the approach in enhan-cing environmental education. The analysis of the pri-mary data indicates that the experimental groups exhibited significantly greater enhancements in envinmental competence compared to the control groups, thereby substantiating the efficacy of the recently implemented educational model. The test questions furnished a comprehensive evaluation of stu-dents' knowledge, values, and practical application of ecological concepts, ensuring a multifaceted assessment of their competencies. The survey data provided valuable insights into students' engagement, attitudes, and perceptions of environ-mental education, under-scoring the necessity for further enhancement of ecological awareness in the learning process. The statistical analysis, with signifi-cant t-values and $p < 0.01$, validates the reliability of the results, confirming the strong impact of the proposed model on students' ecological competence. These findings, based on primary empirical data, support the integration of this educational approach into broader pedagogical practices, emphasizing its potential for improving sustainability-focused education and fostering a responsible attitude toward environmental protection.

Results and Discussion

Effectiveness of the ecological competence formation model: experimental study results

The study encompassed a total of 88 students, who were categorized into two primary groups of 44 students each, based on their respective specialties: biology-natural science (6B01512) and pedagogical biology (6B01505). To facilitate a more nuanced examination, each of these groups was further subdivided into experimental and control subgroups, with each subgroup comprising 22 individuals. The experimental group underwent training utilizing a

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newly developed model of ecological competence formation, encompassing theoretical, practical, and reflexive components. In contrast, the control group maintained their training regimen under the conventional educational program. This methodological approach enabled the assessment of the impact of the novel model on the development of cognitive, axiological, and practical components of environmental competence among students pursuing diverse. training pathways The experimental group, which received training in accordance with the proposed model, exhibited a substantial enhancement in all components of environmental competence in comparison with the control group (Table 5). The analysis of the data presented in Figure 2 indicates that the experimental groups exhibited a substantial enhancement in test results in comparison to the control groups.

Group	Average score before testing	Average score after testing	Change
Experimental (Biology-Natural Sciences)	13.41	19.91	+6.50
Control (Biology-Natural Sciences)	13.32	18.32	+5.00
Experimental (Pedagogical Biology)	13.50	20.30	+6.80
Control (Pedagogical Biology)	13.55	18.41	+4.86

Table 5
Presents a comparative analysis of the experimental and control groups' test results, with the data expressed in points.

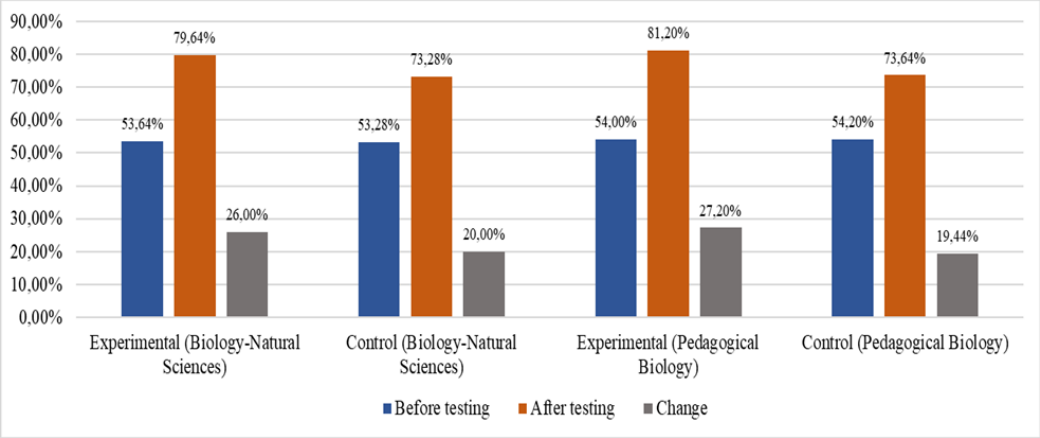

Figure 2
Presents a comparative analysis of test results in percentages between the experimental and control groups.

In the biology-natural science group, the experimental subgroup demonstrated a marked enhancement of 6.50 points, while the control group exhibited a comparatively modest improvement of 5.00 points. A comparable pattern is evident in the Pedagogical Biology group, where the experimental group exhibited an increase of 6.80 points, which is considerably higher than the 4.86-point improvement observed in the control group.The comprehensive evaluation of the data substantiates that the implementation of the innovative pedagogical model fosters profound comprehension of the subject matter and the cultivation of ecological competence among the experimental groups. The higher results of the experimental subgroups underscore the efficacy of integrating theoretical, practical, and reflective components into the educational process. This finding underscores the relevance of extending the implementation of this model in the training of prospective biology teachers. Therefore, the obtained data demonstrate that the implementation of the novel model, which is predicated on the integration of theoretical, practical, and reflective components, fosters a more profound assimilation of ecological knowledge, the formation of value attitudes, and the development of practical skills among students. This underscores the necessity for additional application and refinement of this model within the educational process for the training of future biology teachers. The integration of theoretical, practical, and reflective components proved effective in fostering ecological competence, as evidenced by the experimental groups' demonstrable improvement in test results when compared to the control groups. For instance,

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the experimental group exhibited a 26% increase in specialty area "Biology-natural science" and a 27.2% increase in the specialty area "Pedagogical biology." These figures are considerably higher than the gains of the control groups, which were 20% and 19.44%, respectively. The following diagram illustrates this improvement in percentage terms (Fig. 2). The figure illustrates the alterations in test results before and after the implementation of the model for fostering environmental competence in students. The experimental groups in both specialties exhibited a significant improvement, with an increase of 26.00% in the "Biology-Science" group and 27.20% in the "Pedagogical Biology" group. The control groups also exhibited positive dynamics, though their improvement was less significant, with increases of 20.00% and 19.44%, respectively. These findings substantiate the efficacy of the implementation of the novel teaching model in fostering ecological competence. The integration of theoretical, practical, and reflective components has proven highly effective in fostering ecological competence, as evidenced by the significant improvements demonstrated by the experimental groups compared to the control groups. These results underscore the adaptability of the proposed model to different educational contexts, making it an indispensable tool for the professional development of biology teachers. This adaptability is particularly relevant given the diverse cultural, environmental, and socio-economic conditions under which educational systems operate globally. The variegated nature of environmental challenges, including but not limited to climate change, deforestation, and water scarcity, underscores the necessity for the localization of the model to address specific ecological and societal issues. In arid regions facing water scarcity, for instance, the practical component of the model could emphasize water conservation projects and field studies, while in regions experiencing biodiversity loss, students could engage in activities focused on habitat restoration and species monitoring. These adaptations, tailored to specific regions, ensure the relevance of the training and equip future educators with the skills to effectively address the ecological challenges unique to their communities. Furthermore, the model's inherent flexibility allows for seamless integration into digital and blended learning environments, which are gaining prominence worldwide. The incorporation of online tools, virtual simulations, and collaborative platforms can enhance the accessibility and effectiveness of the model, particularly in remote or resource-limited settings. This approach enables students from diverse backgrounds to engage with interactive content, participate in virtual fieldwork, and collaborate on environmental projects, thereby enriching their learning experience and ensuring the model's broad applicability. The results of this study are in alignment with the findings of Kind and Chan (2019), who highlighted the significance of integrating pedagogical and subject knowledge to enhance educational outcomes. Similarly, Mesci et al. (2019) underscored the pivotal role of reflective practices and NOS (Nature of Science) approaches in fostering environmental awareness and competence. The implementation of interactive teaching methodolo-logies, such as flipped classrooms, project-based learning, and ecological training, aligns with the strategies outlined by Sabelnikova and Khmeleva (2015) and Itinson and Chirkova (2020). These approaches not only promote student engagement but also improve the quality of learning by fostering critical thinking and problem-solving skills. Future research should explore the long-term impact of this model on professional practice and environmental behaviour. It is imperative to evaluate the efficacy with which the competencies acquired through this model are employed in real-world teaching scenarios and their contribution to the cultivation of environmental awareness among schoolchildren. Further-more, the model's adaptability to other disciplines, including geography, environmental science and social studies, signifies a substantial opportunity for expanding its impact. Integrating the model into these fields could facilitate interdisciplinary approaches to solving environmental problems, thereby amplifying its contribution to sustainable development goals. In conclusion, the proposed model offers a robust framework for cultivating ecological competence in prospective biology teachers, while addressing pressing global environmental challenges. Its adaptability to various cultural and educational contexts renders it a valuable asset for fostering systemic ecological thinking, sustainable values, and practical skills. By localising the model to specific ecological challenges and leveraging digital tools, its imple-mentation can significantly enhance the quality of en- vironmental education across diverse regions. This approach not only prepares educators to inspire ecological awareness in their students but also contributes to the broader mission of achieving sustainability through education.

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Conclusions

The findings of this study emphasise the importance of a thorough and systematic approach to fostering environmental competence in prospective biology educators. The proposed model, comprising theoretical, practical, and reflective components, has proven highly effective in equipping students with not only the requisite knowledge but also the ability to form sustainable values and practical skills. The model has been shown to facilitate the realisation of broader objectives in sustainable education, including fostering systemic ecological thinking, raising awareness of global environmental challenges, and integrating ecological principles into professional practices. The experimental groups demonstrated substantial enhancements in their environmental competence compared to the control groups, affirming the practical value and effectiveness of the model. A salient strength of the model is its adaptability, which facilitates seamless integration into diverse educational programs and contexts. This adaptability renders it a versatile instrument not only for pedagogical universities but also for other training domains, making it universally applicable across diverse cultural and social settings. In culturally heterogeneous societies, the model can be customized to address local ecological challenges and reflect community values, thereby fostering a stronger connection between students and their immediate environment. In regions with a rich tradition of ecological knowledge, the practical and reflective components of the model can incorporate these cultural insights, promoting both environmental and cultural sustainability. Moreover, the model is well-suited to address region-specific ecological issues. In regions confronted with challenges such as deforestation or water scarcity, the practical block can concentrate on initiatives including reforestation projects or water conservation strategies. Moreover, reflective practices have the potential to assist students in analysing their roles as environmental advocates within their unique cultural and ecological contexts. By adapting the model to tackle these localised challenges, educators can empower students to become effective agents of change within their respective communities. The model's potential extends beyond the training of biology teachers. Its fundamental principles can be integrated into diverse educational programmes, fostering the development of environmentally conscious citizens and professionals in fields such as geography, environmental science, and social studies. This interdisciplinary applicability enhances the model's impact and supports the broader goals of sustainable development. Furthermore, the model demonstrates a high level of compatibility with digital and blended learning environments. The incorporation of digital tools, virtual simulations, and collaborative platforms has the potential to enhance accessibility and effectiveness, particularly in remote or resource-constrained settings. The findings of this study align with previous research that underscores the value of integrating pedagogical and subject knowledge to enhance educational outcomes. Innovative teaching methodologies, such as flipped classrooms, project-based learning, and ecological training, have been shown to improve student engagement and learning quality. These approaches are particularly relevant in addressing global environmental challenges and fostering critical thinking and problem-solving skills. Future research should concentrate on the long-term impact of the model on professional practice and environmental behaviour, particularly in evaluating how effectively acquired competencies are applied in real-world teaching scenarios. Furthermore, there is considerable potential to adapt the model for use in other disciplines and digital educational environments, thereby providing valuable insights into its scalability and broad applicability. Such research will deepen our understanding of the role of environmental education in achieving the Sustainable Development Goals and offer further opportunities for refining educational methodologies. In conclusion, the proposed model offers a robust and adaptable framework for cultivating environmental competence in future educators. Its application not only addresses the urgent need for comprehensive environmental education but also lays the foundation for a more sustainable and culturally relevant approach to teaching and learning. By fostering systemic ecological thinking, promoting the integration of local and global ecological perspectives, and encouraging interdisciplinary collaboration, the model equips educators to inspire the next generation of environmentally responsible citizens. This transformative tool has the potential to drive meaningful progress in global education and sustainability efforts.

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