DEVELOPING ENVIRONMENTAL RESEARCH COMPETENCE IN FUTURE BIOLOGY TEACHERS

DESARROLLO DE LA COMPETENCIA DE INVESTIGACIÓN AMBIENTAL EN FUTUROS PROFESORES DE BIOLOGÍA

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ABSTRACT

This article presents the results of an empirical study conducted using structural modeling to assess the environmental research competencies of future biology teachers. The study examined key factors such as environmental knowledge, environmental values, research skills, and readiness for environmental action, and explored their interrelationships. Data were collected through a questionnaire administered to 188 students of Korkyt Ata Kyzylorda University, and analyzed using the SmartPLS software. The structural model revealed that readiness for environmental action was negatively associated with environmental knowledge and values, while showing a positive association with research skills. These findings highlight the need to update the current pedagogical education curriculum, particularly emphasizing the integration of environmental education and research-based approaches. The results provide a scientific basis for shaping strategies to foster environmental values and develop practical action-oriented skills in the educational process.

Keywords:

Future Teachers, Research Competence, Structural Model, Education, Pedagogical Research.

RESUMEN

Este artículo presenta los resultados de un estudio empírico realizado mediante modelado estructural para evaluar las competencias de investigación ambiental de futuros profesores de biología. El estudio examinó factores clave como el conocimiento ambiental, los valores ambientales, las habilidades de investigación y la disposición para la acción ambiental, y exploró sus interrelaciones. Los datos se recopilaron mediante un cuestionario administrado a 188 estudiantes de la Universidad Korkyt Ata Kyzylorda y se analizaron utilizando el software SmartPLS. El modelo estructural reveló que la disposición para la acción ambiental se asoció negativamente con el conocimiento y los valores ambientales, mientras que mostró una asociación positiva con las habilidades de investigación. Estos hallazgos resaltan la necesidad de actualizar el currículo de educación pedagógica actual, enfatizando particularmente la integración de la educación ambiental y los enfoques basados en la investigación. Los resultados proporcionan una base científica para dar forma a estrategias para fomentar los valores ambientales y desarrollar habilidades prácticas orientadas a la acción en el proceso educativo.

Palabras clave:

Futuros docentes, Competencia investigativa, Modelo estructural, Educación, Investigación pedagógica.

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INTRODUCTION

One of the most pressing global challenges of the 21st century is the disruption of ecological balance, which has led to large-scale issues such as climate change, loss of biodiversity, and environmental pollution. These complex problems have a direct impact on all spheres of society, including the education system. The formation of environmental consciousness and the establishment of values aimed at sustainable development must begin at the school level. In this context, the development of environmental research competencies as an integral part of the professional training of future teachers – particularly those specializing in biology – is regarded as a highly relevant issue.

Environmental research competence is a vital and comprehensive concept that integrates knowledge, skills, values, and action-oriented practices. It encompasses a future biology teacher's ability to scientifically study and analyze natural phenomena and processes, assess environmental conditions, and instill ecological culture in learners. The development of such competence not only enhances the professional qualifications of a teacher but also deepens their personal responsibility, ecological ethics, and research-oriented mindset.

Scientific studies in this area emphasize several key priorities, including enriching the content of environmental education with theoretical and practical components, introducing instructional models based on research activities, and fostering values oriented toward environmental responsibility and action (Tilbury, 1995). However, although many studies have focused on the development of environmental education content and pedagogical paradigms, there remains a notable lack of empirical research specifically addressing the structural model of environmental research competence.

Recent research highlights the importance of preparing students and future educators to actively engage with sustainability challenges through innovative and forward-looking educational approaches. For instance, Chan & Erduran (2025) emphasize the role of future-oriented science learning in strengthening students' futures literacy, emotional engagement, and sense of agency when addressing global environmental issues in the Anthropocene. Their study demonstrates that integrating discussions about future scenarios and sustainability challenges in science education helps students develop a deeper understanding of environmental problems and motivates them to participate in responsible decision-making processes related to sustainable development.

Similarly, Biletska et al. (2021) stress the need to prepare future biology teachers to effectively integrate sustainable development principles into ecological education.

Their research highlights the importance of developing environmental awareness, ecological competence, and methodological skills among future educators, enabling them to design learning experiences that connect scientific knowledge with environmental responsibility. The authors argue that teacher education programs should incorporate interdisciplinary approaches and practical activities that foster students' understanding of ecological systems and sustainable practices.

In addition, the integration of digital technologies and innovative learning environments has been identified as a valuable strategy for strengthening environmental competencies. Maratkyzy et al. (2025) demonstrate that the use of virtual laboratories, such as the Labster platform, significantly contributes to the formation of environmental competence among students training to become biology teachers. Virtual laboratory environments allow students to conduct experiments, analyze ecological processes, and explore environmental scenarios in interactive and immersive ways, thereby enhancing both conceptual understanding and practical research skills.

Other studies highlight the importance of equipping future science teachers with the pedagogical competencies required to incorporate sustainability topics into their teaching practice. Koçulu (2025) argues that teacher education programs should support pre-service teachers in developing instructional planning skills specifically aimed at teaching the Sustainable Development Goals (SDGs) in K–12 classrooms. According to the author, integrating sustainability into lesson planning promotes interdisciplinary learning, critical thinking, and the ability to address complex global challenges through education.

Furthermore, the development of environmental competence can also be supported through interdisciplinary educational frameworks such as STEAM (Science, Technology, Engineering, Arts, and Mathematics). Tilavova (2024) emphasizes that applying the STEAM approach in teacher education promotes the development of environmental awareness, creativity, and problem-solving skills. This approach encourages future educators to integrate scientific knowledge with technological and innovative tools, enabling them to design engaging learning experiences that strengthen students' environmental responsibility and practical engagement with sustainability issues.

These studies demonstrate that contemporary research increasingly recognizes the need to combine innovative pedagogical strategies, digital technologies, and interdisciplinary approaches in order to strengthen environmental competence. Nevertheless, despite these advances, the development and empirical validation of comprehensive

structural models for environmental research competence remain an area that requires further investigation.

In pedagogical higher education institutions in Kazakhstan, this competence is generally developed in a fragmented manner, and its assessment is often limited to academic performance indicators alone. Therefore, there is an emerging need for a comprehensive, scientifically grounded methodology to evaluate the development level of environmental research competence among future biology teachers. Furthermore, the application of structural equation modeling (PLS-SEM) to identify relationships between latent variables represents a significant element of scientific innovation in this context.

The aim of the conducted research is to evaluate the environmental research competencies of future biology teachers through structural analysis. To achieve this, a questionnaire-based study was conducted, identifying four core factors - environmental knowledge, research skills, environmental values, and readiness for environmental action - and modeling their structural relationships. The findings provide a clear framework for improving teacher education programs, integrating research-based components into the educational process, and fostering the comprehensive development of students' ecological culture.

The formation of environmental research competence is currently regarded as one of the key priorities in modern education systems. This process aims not only to equip future biology teachers with environmental knowledge but also to develop their scientific inquiry skills, ecological awareness and values, as well as readiness for environmental action. Studies emphasize that this competence should be developed systematically in pedagogical practice as a holistic structure (Tilbury, 1995).

The use of innovative methods plays a significant role in the development of environmental competence. For example, Orynbekov et al. (2024) propose the use of cluster analysis to identify shortcomings in traditional ecological-pedagogical systems. Abdildauly et al. (2024) emphasize the role of field experience in enhancing research skills. Engaging students in the exploration of ecosystem relationships in natural environments enables them to apply theoretical knowledge in real-life contexts.

Moreover, the project-based learning method promotes students' independent engagement in addressing environmental issues. Amantayeva et al. (2022) emphasize that environmental projects serve as essential tools for fostering students' critical thinking, research orientation, and environmental values.

Regarding the assessment of competencies, Sarvinoz (2024) explores how integrating qualitative and quantitative methods enhances the effectiveness of evaluation. This approach enables a more precise and comprehensive assessment of learning outcomes. Additionally, Zharmenova et al. (2024) identify factors that increase students' environmental motivation and active participation through pedagogical experiments.

The university learning environment plays a crucial role in developing future teachers' environmental research competencies. Bukusheva et al. (2023) demonstrate that curriculum content, institutional support, and competitive elements embedded within educational programs positively influence the professional research orientation of preservice teachers.

Furthermore, in order to organize high-quality environmental education, a competence-based approach must be applied systematically. Doychinova (2024) emphasizes that this approach plays a decisive role in shaping action-oriented environmental knowledge, particularly in the context of digitalization and globalization processes.

Recent studies demonstrate that environmental education in schools positively influences students' connection to nature and the development of ecological values. Schmäing & Grotjohann (2022) found that after conducting lessons based on the Wadden Sea ecosystem in Germany, students showed both short- and long-term improvements in their nature connection and environmental attitudes. This research highlights the effectiveness of ecosystem-based content in successfully fostering ecological values.

Geographical location is often cited as a factor influencing environmental behavior and knowledge. In a study conducted by Kanada et al. (2022) among school students in Saint Lucia, significant differences were found between urban and rural areas in terms of environmental knowledge, attitudes, and levels of engagement. These findings underscore the importance of considering local context in the development and implementation of environmental education.

Within the framework of the European Union's GreenSCENT project, a system of environmental competencies was developed to align educational programs with the goals of sustainable development. Tomassi et al. (2024) proposed a competency model synchronized with the European Qualifications Framework for environmental education, which significantly influenced the structuring of both educational content and systems.

Research conducted in the Republic of Kazakhstan has also yielded significant findings. Sapanova et al. (2023) identified that while Kazakhstani school students possess limited environmental knowledge and awareness, their attitudes toward ecology are generally positive. The study highlighted that extracurricular activities play an effective role in increasing students' environmental awareness.

The importance of systems thinking is increasingly emphasized for the systematic development of environmental knowledge and competencies. Demirci et al. (2024) proposed a model that integrates elements of systemic, cultural, and critical literacy to help learners achieve the goals of sustainable development. This model facilitates a more effective understanding of the complexities inherent in environmental and sustainability education.

The works of contemporary researchers demonstrate that the development of environmental research competence is not limited to educational content alone but is closely linked to teaching methods, the learning environment, systems thinking, and context-based approaches rooted in local realities. In this regard, the application of structural approaches and multifactorial models enhances the quality of pedagogical practice and provides a foundation for advancing the professional competence of future teachers to a higher level.

As the literature review demonstrates, the development of environmental research competence is a multifaceted, systemic, and context-adapted process. To foster this competence effectively, it is essential to combine theoretical knowledge with methodological approaches that integrate project-based and field learning, pedagogical experimentation, systems thinking, and intercultural literacy. In addition, external factors such as the educational environment and local context (e.g., urban/rural differences) play a crucial role. The analysis of both global and national experiences reveals a growing demand for scientifically grounded, structurally designed pedagogical models that promote environmental responsibility among future biology teachers. Therefore, the present study seeks to address these gaps by providing a comprehensive assessment of pre-service teachers' environmental research competence.

MATERIALS AND METHODS

This study focuses on assessing the environmental research competence of pre-service biology teachers. The primary objective is to identify students' levels of environmental knowledge, research skills, environmental values, and readiness for environmental action, and to analyze the interrelationships among these variables through structural equation modeling (SEM).

The study was conducted among students majoring in Biology at Korkyt Ata Kyzylorda University. A specially designed questionnaire was voluntarily completed by 188 students (3rd and 4th year). The sampling was organized in a random and open manner. The age and gender distribution of the participants provided diverse characteristics that aligned with the research objectives.

As a research instrument, an author-developed questionnaire consisting of 12 items was used. The questionnaire covered four core components of environmental research competence: Environmental Knowledge (EK), Research Skills (RS), Environmental Values (EV), and Readiness for Environmental Action (REA). Each component was represented by three indicators. Students rated their responses using a 5-point Likert scale (1 – Strongly Disagree, 5 – Strongly Agree).

The collected data were analyzed using SmartPLS 4.0 software. This tool, based on Partial Least Squares Structural Equation Modeling (PLS-SEM), enables the assessment of causal relationships between latent variables, path coefficients, internal consistency, and validity indices. The methodological framework allowed for a comprehensive and empirical evaluation of students' environmental research competence and facilitated the identification of interactions among structural components. This approach served as a foundation for developing scientifically grounded recommendations aimed at enhancing ecologically-oriented competencies within the teacher preparation system.

RESULTS AND DISCUSSION

This study was aimed at empirically examining the interrelationship between prospective teachers' environmental knowledge, environmental values, research skills, and their readiness for environmental action.

The findings revealed a noticeable discrepancy between students' readiness for action and their environmental knowledge and values within the current educational system. This indicates a lack of sufficient alignment between pedagogical content and instructional approaches.

Furthermore, the study clearly highlighted the need to reconsider the mechanisms by which environmental education and research skills influence the value orientations of future teachers. Therefore, this research provides a scientifically grounded basis for identifying critical gaps in the current educational framework and for exploring directions to improve teacher preparation in the area of environmental competency (Figure 1)
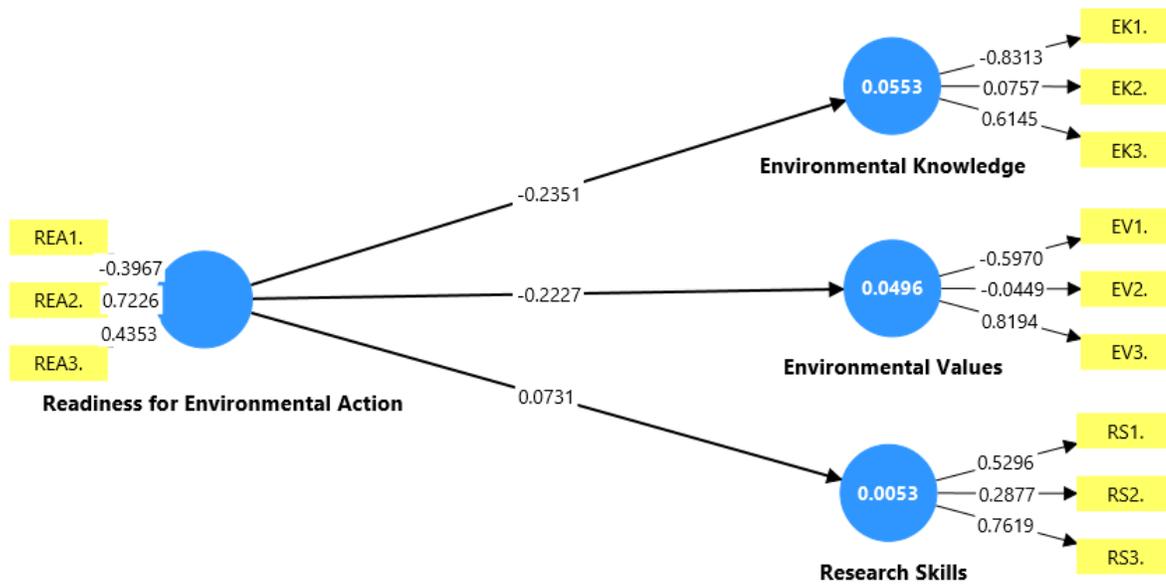
Figure 1: The pathways of influence from readiness for environmental action to knowledge, values, and research skills (SmartPLS output).

The results of the structural modeling conducted using the SmartPLS software revealed the relationships between pre-service teachers' readiness for environmental action and three key latent constructs: environmental knowledge, environmental values, and research skills.

In the developed model, the construct "Readiness for Environmental Action" was treated as an independent variable, and its paths of influence were identified as follows:

- Effect on Environmental Knowledge: $\beta = -0.2351$

- Effect on Environmental Values: $\beta = -0.2227$

- Effect on Research Skills: $\beta = 0.0731$

These coefficients indicate the direction and strength of relationships between the readiness for environmental action and the other constructs in the structural model.

The obtained results indicate that students with a high level of readiness for environmental action do not necessarily possess a correspondingly high level of environmental knowledge and values. Moreover, their connection with research skills appears to be weak.

Moreover, the analysis of indicator loadings (outer loadings) revealed that some variables exhibited negative loadings (e.g., EK1 = –0.8313, EV1 = –0.5970), indicating that students provided somewhat inconsistent responses to certain knowledge or value indicators. However, indicators with loadings above 0.7 (e.g., EK3, EV3, RS3) demonstrated strong reliability and relevance from the perspective of the measurement model.

Table 1: Path coefficients – influence of "Readiness for environmental action" on other constructs.

Structural Path	Path coefficients
Readiness for Environmental Action -> Environmental Knowledge	-0,2351
Readiness for Environmental Action -> Environmental Values	-0,2227
Readiness for Environmental Action -> Research Skills	0,0731

The path coefficients enabled the interpretation of the structural relationships within the proposed model. As presented in Table 1, the construct 'Readiness for Environmental Action' demonstrated varying levels of influence on the other latent variables. Specifically, its effect on Environmental Knowledge was negative ($\beta = -0.2351$), as was its effect on Environmental Values ($\beta = -0.2227$), while its influence on Research Skills was relatively weak and positive ($\beta = 0.0731$).

The findings indicate that students' readiness to engage in environmental action is, on the one hand, negatively associated with their level of environmental knowledge and value orientations, while on the other hand, it can be positively influenced through the development of research skills. Moreover, the results suggest that enhancing readiness for environmental engagement should not be limited to cognitive or affective factors alone, but should also involve the cultivation of practice-based competencies.

Thus, the path coefficients obtained from the structural model serve to clarify the research hypotheses and represent significant practical indicators for assessing the preparedness level of future teachers in the field of environmental education.

The main objective of the present study was to empirically assess the interrelationship between future teachers' readiness for environmental action and their levels of environmental knowledge, value orientations, and research skills. The results of the structural modeling revealed that future educators exhibit complex and non-uniform relationships between their readiness to engage in environmental education and the internal constructs of knowledge, values, and skills.

The negative directional relationships identified in the study (readiness for environmental action → environmental knowledge: β = –0.2351; environmental values: β = –0.2227) indicate that future biology teachers' levels of environmental knowledge and value orientations do not directly align with their actual readiness to engage in environmental action. These findings highlight a disconnect between cognitive and affective understandings and their translation into practical behavior. In other words, while students may be theoretically informed about environmental issues, their behavioral or practical engagement remains insufficient.

Such inconsistencies can be attributed to the lack of coherence between content and methodology within the current education system—specifically, the insufficient integration of theoretical knowledge with practical experience. This underscores the importance of incorporating practical, project-based, and service-oriented approaches into educational programs that are directly aimed at fostering environmental action.

From another perspective, the obtained results related to research skills (β = 0.0731), although weak, indicated a positive association. This suggests that prospective teachers may demonstrate interest in environmental issues from a research-oriented standpoint and engage actively through scientific inquiry. However, the low strength of this relationship highlights the continuing lack of a systematic program and pedagogical support for the development of research skills in the environmental context.

The presence of negative values in some of the outer loadings (e.g., EK1 = –0.8313, EV1 = –0.5970) indicates a degree of internal misunderstanding among students regarding certain indicators. On one hand, this suggests that students may hold inconsistent perspectives on environmental issues, possibly due to the limited content relevance and clarity of certain measurement indicators used in the study.

Although the R^2 values in the model were relatively low (EK = 0.0553, EV = 0.0496, RS = 0.0053), the study retains its significance as an initial empirical analysis. These results provide important guidance for future research, particularly in identifying which areas of environmental education require further development and refinement.

In this regard, the study highlights the need to deepen future teachers' theoretical knowledge through practical application in order to enhance their environmental awareness and readiness for action. It recommends the broader implementation of task-oriented and transformative teaching methods aimed at fostering value-based orientations. Furthermore, the findings underscore the necessity of integrating research skills with environmental content to support students' development as investigative professionals.

CONCLUSIONS

This study aimed to assess the level of environmental research competence among prospective biology teachers and to identify the factors that genuinely influence their readiness for environmental action. The results of the structural modeling using SmartPLS revealed that the relationship between students' readiness for environmental action and their environmental knowledge, values, and research skills is complex and inconsistent.

The research findings suggest that prospective teachers may demonstrate insufficient readiness in terms of environmental knowledge and values, while their research skills show only a weak correlation with practical readiness for environmental action. This highlights the urgent need to bridge the gap between theory and practice, as well as between values and action, within teacher education programs.

In addition, the negative values observed in several indicator loadings suggest that students at Korkyt Ata Kyzylorda University did not fully align with certain environmental attitudes, or that there may be a disconnect between the program content and the students' lived experiences. This underscores the need to revise the educational process by integrating environmental education

with research-based approaches, and to implement practical programs and targeted projects that foster students' readiness for action.

In conclusion, this study provides a foundation for proposing innovative approaches aimed at enhancing future educators' environmental awareness and readiness for action. The findings contribute not only to the improvement of educational content but also to the alignment of prospective teachers' professional training with principles of environmental sustainability and global responsibility.

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