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Enhancing students' environmental literacy through STEM and project-based learning

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ABSTRACT

Amid escalating global environmental challenges and the increasing emphasis on sustainable development, enhancing students' environmental literacy has become a critical priority in higher education. However, conventional instructional approaches remain predominantly theory-oriented and insufficient in fostering interdisciplinary thinking and real-world problem-solving competencies. Addressing this gap, this study proposes the integration of the science, technology, engineering, and mathematics–project-based learning (STEM–PjBL) model, which combines STEM education with PjBL to promote active engagement in authentic environmental problem-solving contexts. This study offers a novel contribution by implementing the STEM–PjBL approach within a Chemical Ecology course, thereby linking interdisciplinary STEM integration with the development of environmental literacy and systems thinking. A quantitative research design was employed involving 70 master's students from Abai Kazakh National Pedagogical University with prior exposure to environmental disciplines. A 15-item diagnostic instrument was developed to assess environmental literacy, with content validity confirmed using Aiken's V (0.70–0.91). Data were analyzed using descriptive statistics, correlation analysis, and Student's t-test. The findings indicate a high level of environmental literacy (mean=85.1) and provide empirical evidence supporting the effectiveness of the STEM–PjBL approach. The results demonstrate improvements in systems thinking and environmentally responsible behavior, highlighting its potential to enhance environmental education practices in higher education.

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1. INTRODUCTION

In the context of escalating global environmental problems, such as climate change, ecosystem degradation, biodiversity loss, and environmental pollution, the development of environmental literacy has become one of the key priorities of modern education [1]. Addressing these challenges requires not only scientific, technological, and political measures but also the preparation of specialists capable of understanding complex environmental processes, analyzing environmental risks, and making informed decisions in the field of sustainable development [2]. In this regard, the higher education system plays a crucial role in fostering environmental responsibility, ecological thinking, and the competencies necessary to address contemporary environmental challenges [3], [4].

Environmental literacy is considered by researchers as a fundamental component of education for sustainable development [5]. It encompasses not only knowledge of the functioning of natural and ecological systems but also the ability to analyze environmental problems, evaluate possible solutions, and engage in environmentally responsible actions in both social and professional contexts [6], [7]. Contemporary studies emphasize that environmental literacy integrates cognitive, value-based, and behavioral components, enabling individuals to understand the interconnections between natural and social systems and to act in the interest of environmental sustainability [8]–[10].

Despite the increasing attention to environmental education, traditional pedagogical approaches in higher education are often primarily focused on the transmission of theoretical knowledge and do not always ensure the development of practical skills for solving environmental problems [11], [12]. As a result, students may possess a certain level of environmental knowledge but experience difficulties in applying this knowledge to analyze real-world environmental situations. This highlights the need for the implementation of innovative pedagogical approaches that promote research activity, critical thinking, and interdisciplinary competencies among students [13]. One of the effective approaches aimed at developing students' research activity is project-based learning (PjBL). This approach involves organizing the learning process around the completion of research and practice-oriented projects. During project work, students analyze real-world problems, develop potential solutions, and present the outcomes of their work. Such a format of learning contributes to the development of critical thinking, communication skills, and learner autonomy [14], [15].

In recent years, considerable attention has been given to the development of science, technology, engineering, and mathematics (STEM) education [16], [17]. The STEM approach focuses on integrating knowledge from various scientific disciplines and applying it in practice to solve complex problems. Within STEM education, students learn to use scientific knowledge, technological tools, and engineering methods to analyze real-world issues and develop innovative solutions. This approach contributes to the formation of 21st-century skills, including analytical thinking, innovation capacity, and interdisciplinary collaboration [18]. Particular interest lies in the integration of the STEM approach and PjBL, as both approaches are grounded in inquiry-based learning, interdisciplinary interaction, and the practical application of knowledge [19], [20]. Their combination creates favorable conditions for developing students' abilities to analyze and solve complex environmental problems. The use of integrated educational models enables students not only to acquire theoretical knowledge but also to apply it in practice by analyzing real environmental situations and proposing possible solutions.

In contemporary conditions, addressing environmental challenges requires the implementation of innovative educational approaches aimed at developing students' systemic environmental thinking and their ability to apply scientific knowledge to the analysis of real-world environmental situations. One of the most effective directions for modernizing the educational process is the integration of STEM education and PjBL [19], [20]. This approach facilitates the interdisciplinary integration of knowledge in STEM, while also stimulating students' active research engagement. During project-based activities, students analyze environmental problems, conduct research, develop potential solutions, and present the outcomes of their work. Such a learning format contributes to the development of environmental knowledge, analytical skills, environmental awareness, and a responsible attitude toward the environment among students [21], [22].

A conceptual model for the development of students' environmental literacy based on the integration of STEM education and PjBL is presented in Figure 1. The conceptual model presented in Figure 1 reflects the interrelationship between contemporary environmental challenges, the system of environmental education, and the integration of innovative pedagogical approaches. The model demonstrates that the application of STEM education in combination with PjBL facilitates the organization of students' research and practice-oriented learning activities, including problem identification, conducting research, project development, and the presentation of solutions. The implementation of these educational practices is aimed at developing the key components of students' environmental literacy, including environmental knowledge, analytical skills, environmental awareness, and environmentally responsible behavior.

Despite the growing interest among researchers in the development of environmental literacy and the application of innovative pedagogical approaches, a number of issues remain insufficiently explored. Contemporary studies confirm the effectiveness of STEM education and PjBL in developing critical thinking, research skills, and students' ability to apply scientific knowledge in practice [19], [20], [23]. However, most existing studies examine these approaches in isolation or focus primarily on school education. At the same time, empirical studies aimed at analyzing the integration of STEM education and PjBL in the development of environmental literacy among higher education students remain limited. This highlights the need for further research focused on evaluating the effectiveness of integrating STEM and PjBL within the educational process [24]. At the same time, empirical research examining the integration of STEM education and PjBL in fostering environmental literacy among university students remains scarce [21], [25]. In particular, the potential of integrated STEM–PjBL educational models in the training of students in natural science programs and their impact on the development of environmental thinking and environmentally responsible behavior has not been sufficiently investigated. Thus, the relevance of the present study is determined by the need for theoretical conceptualization and empirical evaluation of the effectiveness of integrating the STEM approach and PjBL in the development of students' environmental literacy.

The aim of the study is to analyze the level of students' environmental literacy and to evaluate the effectiveness of integrating STEM education and PjBL in the development of students' environmental competencies. In accordance with this aim, the study addresses the following research questions:

- What is the level of environmental literacy among master's students with prior training in environmental disciplines, including the course "Chemical Ecology" completed at the undergraduate level?
- Which components of environmental literacy (cognitive, affective, and behavioral) are the most and least developed among students?
- To what extent does the integration of STEM education and PjBL contribute to the development of students' environmental literacy?

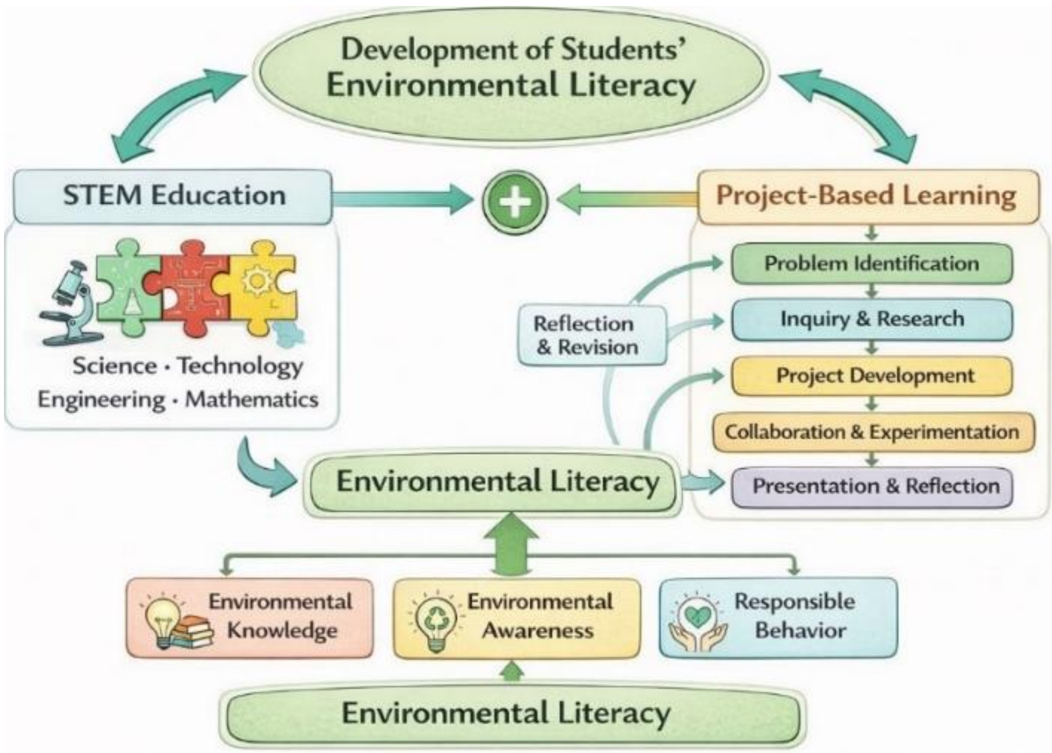

Figure 1. Conceptual model for the development of students' environmental literacy based on the integration of STEM education and PjBL

2. METHOD

2.1. Research design and sampling procedure

The research followed a clearly defined chronological sequence. At the first stage, the STEM–PjBL approach was integrated into the instructional process of the course. The intervention included sequential stages such as problem identification, research activities, solution development, project design, and presentation of results over one academic semester. At the second stage, data collection was conducted at the final stage of the course after students had completed all learning activities. The study followed a post-test design, meaning that no pre-test was administered; the assessment focused on evaluating the level of environmental literacy achieved after the implementation of the STEM–PjBL approach. The selection of this research design was determined by the need to assess the final learning outcomes resulting from the full implementation of the instructional model [9], [10].

The study was conducted within the framework of an educational intervention based on the integration of the STEM approach and PjBL in teaching environmental and chemistry-related disciplines.

This integrated pedagogical model was aimed at enhancing students' learning engagement, developing interdisciplinary thinking, and fostering the ability to apply scientific knowledge to the analysis and solution of real-world environmental problems [21], [25]. Within the study, an integrated pedagogical model combining STEM education and PjBL was implemented. This model is based on the interdisciplinary integration of the key STEM disciplines within the process of completing practice-oriented student projects. As illustrated in Figure 1, the educational process is organized through sequential stages, including problem identification, research implementation, solution development, project design, and presentation of results [14]–[16]. Such an approach promotes active student engagement in research activities, enables the application of theoretical knowledge to real environmental problems, and fosters the development of critical thinking, scientific analysis, and interdisciplinary collaboration skills [20].

Figure 2 presents the conceptual framework of the integration of STEM education and PjBL (STEM–PjBL) applied in this study. The model illustrates the sequence of instructional stages, including problem identification, research activities, solution development, project design, and presentation of results. This framework guided the implementation of the educational intervention and supported the development of students' environmental literacy and systems thinking.

The study included 70 master's students enrolled in the "Chemical Ecology" educational program at Abai Kazakh National Pedagogical University (Almaty, Kazakhstan). Participants were selected using a convenience sampling method, as the study targeted students undertaking courses related to ecology and Chemical Ecology. The study was conducted during the 2024–2025 academic year. The sample size is consistent with those reported in similar empirical studies in the field of environmental education and the application of STEM approaches and PjBL in higher education [19], [20].

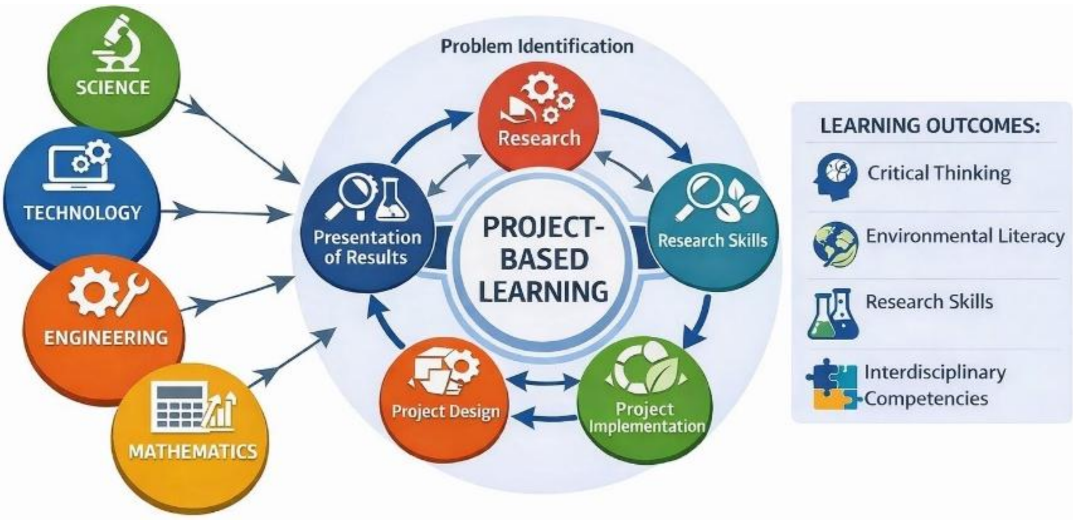

Figure 2. Conceptual model of the integration of STEM education and PjBL (STEM–PjBL)

2.2. Participants

The study involved 70 second-year master's students enrolled in the 6M01510 chemistry program. The inclusion criteria were defined to ensure the relevance and consistency of the sample. Participants were required to be second-year master's students in the specified program, have successfully completed the "Chemical Ecology" course prior to data collection, and actively attend classes during the study period. These criteria ensured that all participants possessed sufficient academic background and had been fully exposed to the instructional model, as well as consistently engaged in the learning process, which was necessary for the reliable assessment of environmental literacy outcomes.

Participants were selected using a convenience sampling method due to practical constraints associated with the study context. Specifically, access to a broader population of respondents was limited, and the sample was restricted to students enrolled in the target program and course during the study period. In addition, the use of convenience sampling allowed for time-efficient data collection and ensured the availability and accessibility of participants. This approach is widely used in educational research conducted within specific instructional settings, where the aim is to evaluate the effectiveness of a particular pedagogical intervention. However, this sampling method may limit the generalizability of the findings, which is acknowledged as a study limitation.

2.3. Instrument development and data collection

To assess the level of students' environmental literacy, a diagnostic questionnaire consisting of 15 items was developed. The instrument was designed to measure the key components of environmental literacy commonly identified in contemporary models of environmental education: i) understanding of physical and ecological systems; ii) knowledge of the social, cultural, and political aspects of environmental processes; iii) awareness of current environmental issues; iv) ability to analyze and evaluate alternative solutions to environmental problems; and v) civic engagement and readiness for environmentally responsible actions [6], [7].

To assess the content validity of the diagnostic instrument, Aiken's V coefficient was employed, which is widely used in educational research to evaluate the degree of agreement among expert judgments [26]. The obtained values ranged from 0.73 to 0.91, indicating an acceptable level of validity of the developed instrument. Prior to the main study, the questionnaire underwent a pilot testing procedure, which allowed for the refinement of item wording and improvement of the reliability of the measurements.

Empirical data were collected through a student survey using the developed diagnostic instrument. The questionnaire was administered during regular class sessions. Prior to the data collection, students were informed about the purpose of the study, and voluntary participation was ensured. All participants completed the questionnaire individually. The collected data were then systematized and prepared for subsequent statistical analysis.

2.4. Data analysis

Quantitative statistical methods were employed to analyze the collected data. At the first stage, descriptive statistics were calculated, including mean values and the percentage distribution of responses for each component of environmental literacy. At the second stage, inferential statistical methods were applied, including correlation analysis and Student's t-test. These methods made it possible to identify statistically significant differences in students' environmental literacy indicators and to determine relationships between the cognitive and behavioral components of environmental literacy. The results of the statistical analysis enabled the determination of the overall level of students' environmental literacy and the identification of key trends in its development within the context of integrating the STEM approach and PjBL.

3. RESULTS AND DISCUSSION

3.1. Instrument validation

At the first stage of the study, a diagnostic instrument was developed to assess the level of students' environmental literacy. The instrument was designed in accordance with contemporary approaches to educational measurement and competency assessment. To ensure the scientific rigor and reliability of the instrument, a validation procedure was conducted following widely accepted methodologies for the development of diagnostic tools in educational research. The assessment questionnaire consisted of 15 items aimed at measuring the key components of students' environmental literacy. The content validity of the instrument was evaluated using Aiken's V coefficient, which is widely applied to assess the level of agreement among experts in pedagogical and psychological studies. According to the criteria proposed by Aiken, an instrument is considered valid if the coefficient value is at least 0.78.

The results of the content validity assessment of the diagnostic instrument, calculated using Aiken's V coefficient, are presented in Table 1. The table shows the validity coefficient values for each indicator of environmental literacy. The results of the analysis showed that the values of Aiken's V coefficient for most indicators ranged from 0.83 to 0.91, indicating a high level of content validity of the developed diagnostic instrument. For only a few indicators, the coefficient values ranged from 0.73 to 0.74, which also fall within acceptable limits for educational measurement. The developed diagnostic instrument was piloted on a sample of 70 master's students from Abai Kazakh National Pedagogical University, who had prior training in environmental disciplines, including the course "Chemical Ecology" completed at the undergraduate level. The purpose of the pilot study was to test the applicability of the instrument in real educational settings where an integrated approach based on STEM education and PjBL is implemented. The testing results revealed a high level of students' environmental literacy, with the majority demonstrating high and very high levels of performance in tasks related to the understanding of environmental systems and processes.

3.2. Environmental literacy results

Figure 3 illustrates the percentage distribution of correct responses for each item in the environmental literacy assessment. The figure highlights variations in students' performance across different indicators, allowing for the identification of strengths and weaker areas in their understanding of environmental concepts. The analysis of the data presented in Figure 3 shows that the highest scores were recorded for questions 1, 2, 3, 5, 6, 12, 14, and 15, where the proportion of correct responses exceeded 90%.

Table 1. Validity analysis using Aiken's V coefficient

Environmental literacy aspect	Item no.	Indicator	Aiken's V	Mean value by aspect
Physical and ecological systems	1	I understand the relationship between living organisms and their environment.	0.89	0.91
	2	I know that ecosystem imbalance affects human quality of life.	0.90	
	3	I understand how human activities influence climate and natural processes.	0.91	
Social, cultural, and political systems	4	I am familiar with the main environmental protection laws and regulations.	0.73	0.87
	5	I understand that compliance with environmental legislation is important for sustainable development.	0.89	
	6	I know that cultural and traditional norms contribute to nature conservation.	0.89	
Environmental issues	7	I understand the causes of natural and biophysical environmental problems.	0.86	0.76
	8	I know that social conflicts can lead to environmental degradation.	0.85	
	9	I am aware of the most common factors contributing to environmental crises.	0.86	
Multiple solutions to environmental problems	10	I am familiar with existing solutions aimed at reducing negative environmental impacts.	0.83	0.64
	11	I can propose alternative solutions to environmental problems.	0.74	
Civic engagement and action strategies	12	I believe that civic engagement plays an important role in addressing environmental problems.	0.90	0.89
	13	I am willing to participate in environmental protection activities.	0.89	
	14	I know specific actions I can personally take to protect the environment.	0.88	
	15	I understand that joint efforts by society and government are necessary to effectively address environmental problems.	0.90	

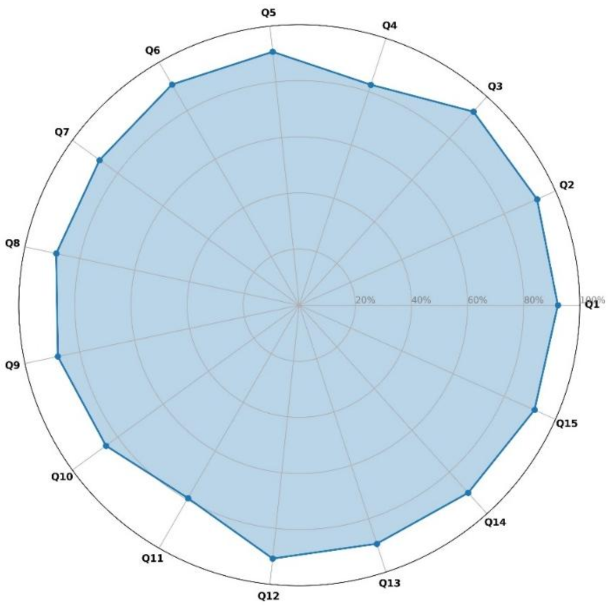

Figure 3. Percentage of correct responses by students on environmental literacy assessment items

The lowest score was recorded for question 11, where 79.4% of students (56 out of 70) provided correct answers. This indicator reflects the level of students' ability to analyze different solutions to environmental problems and to propose alternative approaches to addressing them. For a more detailed analysis of the level of environmental literacy, an assessment criteria system presented in Table 2.

In particular, 20 students (28.4%) demonstrated a very high level of environmental literacy, 43 students (60.9%) showed a high level, and only 7 students (10.2%) exhibited a moderate level. The overall mean score of students' environmental literacy was 85.1 points, which corresponds to a high level according to the established assessment scale. Figure 4 presents the distribution of mean environmental literacy scores across the main components. The figure provides a comparative view of students' performance in different dimensions, including understanding of ecological systems, environmental issues, and problem–solving abilities.

The data presented in Figure 4 indicate that the highest level of environmental literacy is observed in the component "understanding of physical and ecological systems," whereas relatively lower scores were recorded for the component "multiple solutions to environmental problems." This suggests that students demonstrate strong conceptual understanding of environmental processes but encounter difficulties when required to generate alternative solutions to complex environmental issues. Such results may be explained by the fact that traditional educational approaches tend to emphasize knowledge acquisition rather than the development of higher-order thinking skills, including problem-solving and decision-making. Therefore, the findings highlight the need to further strengthen instructional strategies aimed at developing students' analytical and predictive competencies within the STEM–PjBL framework.

Table 2. Criteria for levels of students' environmental literacy

Percentage interval (%)	Level category	Number of students
86<N≤100	Very high level	20
72<N≤86	High level	43
58<N≤72	Moderate level	7

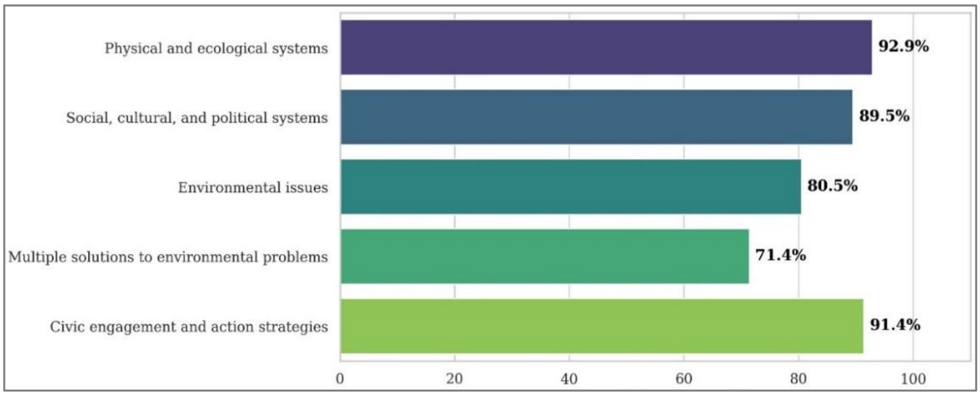

Figure 4. Level of students' environmental literacy across key components

3.3. Discussion

The obtained results are consistent with the findings of contemporary research in environmental education, which demonstrate that the integration of STEM education and PjBL contributes to the development of systems thinking and environmental literacy. The high level of students' environmental literacy can be explained by the implementation of an integrated educational model based on the combination of STEM education and PjBL. These approaches are focused on the interdisciplinary integration of knowledge, the development of systems thinking, and the application of scientific knowledge to solving real environmental problems [25]. Studies show that the use of the STEM approach in combination with project–based activities contributes to a deeper understanding of environmental processes, the development of analytical skills, and the formation of environmentally responsible behavior among students. Similar results have been reported in a number of studies on the application of STEM–PjBL in environmental education, where an increase in students' environmental literacy levels has been observed.

At the same time, comparatively lower results on items related to the analysis of alternative solutions to environmental problems indicate the need for further development of students' analytical and predictive skills. These competencies are essential for making environmentally informed decisions and developing sustainable development strategies. The obtained results also confirm the effectiveness of integrating the STEM approach and PjBL in the training of future specialists in the natural sciences. This educational model contributes to the development of critical thinking, research skills, and the ability to apply scientific knowledge in practice-oriented contexts.

Moreover, a high level of students' environmental literacy is closely associated with the development of environmentally responsible behavior and civic engagement. This is consistent with findings in the field of environmental education, which suggest that innovative educational approaches contribute to the formation of environmental culture and responsibility for the state of the environment. Thus, the integration of STEM education and PjBL can be considered an effective pedagogical strategy for fostering students' environmental literacy and preparing specialists capable of addressing contemporary environmental challenges. The implementation of this model promotes the development of interdisciplinary thinking, research skills, and environmentally responsible behavior among learners.

4. CONCLUSION

This study evaluated the effectiveness of integrating STEM education and PjBL in enhancing students' environmental literacy. The findings revealed a high level of environmental literacy among participants (mean score=85.1), confirming the development of cognitive, affective, and behavioral components. The results provide clear answers to the research questions. First, the overall level of environmental literacy among master's students was found to be high. Second, the strongest components were related to understanding environmental systems and civic responsibility, while comparatively lower performance was observed in proposing alternative solutions to environmental problems. Third, the integration of STEM and PjBL was shown to effectively promote systems thinking, interdisciplinary learning, and the practical application of knowledge. The study highlights the significance of the STEM–PjBL model as an effective pedagogical approach for developing environmental literacy in higher education, contributing to the formation of critical thinking and environmentally responsible behavior. However, several limitations should be acknowledged. The sample was limited to one university, which restricts generalizability, and the use of a post-test design and self-reported data may affect the depth and objectivity of the findings. Future research should expand the sample across different institutions and apply mixed-method approaches to provide deeper insights into the impact of STEM–PjBL, as well as explore its long-term effects on students' environmental behavior.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author, [BI], upon reasonable request.

REFERENCES

[1] UNESCO, *Education for sustainable development goals: learning objectives*. Paris: UNESCO, 2017, doi: 10.54675/CGBA9153.

[2] N. Blanco-Portela, J. Benayas, L. R. Pertierra, and R. Lozano, "Towards the integration of sustainability in higher education institutions: a review of drivers of and barriers to organisational change and their comparison against those found of companies," *Journal of Cleaner Production*, vol. 166, pp. 563–578, Nov. 2017, doi: 10.1016/j.jclepro.2017.07.252.

[3] W. L. Filho *et al.*, "Sustainability leadership in higher education institutions: an overview of challenges," *Sustainability*, vol. 12, no. 9, p. 3761, May 2020, doi: 10.3390/su12093761.

[4] P. Yelubayeva, E. Tashkyn, and G. Berkinbayeva, "Addressing challenges in Kazakh education for sustainable development," *Sustainability*, vol. 15, no. 19, p. 14311, Sep. 2023, doi: 10.3390/su151914311.

[5] H. Huang and C. Te Hsin, "Environmental literacy education and sustainable development in schools based on teaching effectiveness," *International Journal of Sustainable Development and Planning*, vol. 18, no. 5, pp. 1639–1648, May 2023, doi: 10.18280/ijsdp.180535.
[6] W. McBeth and T. L. Volk, "The national environmental literacy project: a baseline study of middle grade students in the United States," *The Journal of Environmental Education*, vol. 41, no. 1, pp. 55–67, 2009, doi: 10.1080/00958960903210031.
[7] N. M. Ardoin, A. W. Bowers, and E. Gaillard, "Environmental education outcomes for conservation: a systematic review," *Biological Conservation*, vol. 241, p. 108224, Jan. 2020, doi: 10.1016/j.biocon.2019.108224.
[8] T. Marcinkowski and A. Reid, "Reviews of research on the attitude–behavior relationship and their implications for future environmental education research," *Environmental Education Research*, vol. 25, no. 4, pp. 459–471, Apr. 2019, doi: 10.1080/13504622.2019.1634237.
[9] A. Redman, A. Wiek, and M. Barth, "Current practice of assessing students' sustainability competencies: a review of tools," *Sustainability Science*, vol. 16, no. 1, pp. 117–135, Jan. 2021, doi: 10.1007/s11625-020-00855-1.
[10] M. Al Gifary, D. K. Walanda, R. Dzulhijjah, M. Napitupulu, E. Sulmeini, and Ratman, "Students' perception of environmental literacy through education sustainable development-oriented chemistry learning," in *2nd International Interdisciplinary Conference on Environmental Sciences and Sustainable Developments Education and Green Economy (IICESSD EGE 2022)*, 2023, pp. 27–32, doi: 10.2991/978-2-38476-172-2_6.
[11] M. C. Monroe, R. R. Plate, A. Oxarart, A. Bowers, and W. A. Chaves, "Identifying effective climate change education strategies: a systematic review of the research," *Environmental Education Research*, vol. 25, no. 6, pp. 791–812, Jun. 2019, doi: 10.1080/13504622.2017.1360842.
[12] M. Hajj-Hassan, R. Chaker, and A.-M. Cederqvist, "Environmental education: a systematic review on the use of digital tools for fostering sustainability awareness," *Sustainability*, vol. 16, no. 9, p. 3733, Apr. 2024, doi: 10.3390/su16093733.
[13] Y. Li *et al.*, "A systematic review of high impact empirical studies in STEM education," *International Journal of STEM Education*, vol. 9, no. 1, p. 72, 2022, doi: 10.1186/s40594-022-00389-1.
[14] R. Sánchez-García and S. Reyes-de-Cózar, "Enhancing project-based learning: a framework for optimizing structural design and implementation—A systematic review with a sustainable focus," *Sustainability*, vol. 17, no. 11, 2025, doi: 10.3390/su17114978.
[15] W. L. Filho, C. Shiel, and A. Paço, "Implementing and operationalising integrative approaches to sustainability in higher education: the role of project-oriented learning," *Journal of Cleaner Production*, vol. 133, pp. 126–135, Oct. 2016, doi: 10.1016/j.jclepro.2016.05.079.
[16] R. M. Capraro, M. M. Capraro, and J. R. Morgan, *STEM project-based learning: an integrated science, technology, engineering, and mathematics (STEM) approach*. Rotterdam: SensePublishers, 2013, doi: 10.1007/978-94-6209-143-6.
[17] B. Wahono, P.-L. Lin, and C.-Y. Chang, "Evidence of STEM enactment effectiveness in Asian student learning outcomes," *International Journal of STEM Education*, vol. 7, no. 1, p. 36, Dec. 2020, doi: 10.1186/s40594-020-00236-1.
[18] F. W. Ginting, M. Mellyzar, and I. R. Lukman, "Analysis of student environmental literacy: PjBL-based learning that is integrated STEM," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 1, pp. 242–248, Jan. 2023, doi: 10.29303/jppipa.v9i1.2599.
[19] T. U. Pertiwi, D. Oetomo, and B. Sugiharto, "The effectiveness of STEM project-based learning in improving students' environmental literacy abilities," *JPBI (Jurnal Pendidikan Biologi Indonesia)*, vol. 10, no. 2, pp. 476–485, Jul. 2024, doi: 10.22219/jpbi.v10i2.33562.
[20] Y. Rahmawati *et al.*, "Students' engagement in STEAM PjBL-design thinking for environmental literacy," *Journal of Education Culture and Society*, vol. 16, no. 1, pp. 555–580, Jun. 2025, doi: 10.15503/jecs2025.2.555.580.
[21] Ariyatun, Sudarmin, A. Rahmawati, Winarto, and T. Wibowo, "Reconstruction of the engineering design project (EDPj) learning model based on Ethno-ESD to actualize students' sustainable environmental literacy," *LUMAT: International Journal on Math, Science and Technology Education*, vol. 12, no. 4, p. 11, Apr. 2025, doi: 10.31129/LUMAT.12.4.2300.
[22] K. Kabylbek, L. M. DeChano-Cook, D. Childibaev, and N. Balta, "Determining high school students' functional environmental literacy and the effect of participatory action research on functional environmental literacy," *Environmental Education Research*, vol. 31, no. 6, pp. 1207–1223, Jun. 2025, doi: 10.1080/13504622.2024.2437572.
[23] A. B. Murat and G. M. Abyzbekova, "Environmental education: a study of Kazakhstan students' knowledge, attitudes, and practices in waste management," *Sustainability and Climate Change*, vol. 18, no. 5, 2025, doi: 10.1177/26922932251384876.
[24] Z. O. Zhilbaev, L. S. Syrymbetova, G. K. Dlimbetova, and A. Y. Aliyeva, "Case study: Kazakhstan. Educational challenges in transitioning to a green economy," in *Recognizing Green Skills Through Non-formal Learning: A Comparative Study in Asia*, M. Pavlova and M. Singh, Eds., Singapore: Springer Nature Singapore, 2022, pp. 153–165, doi: 10.1007/978-981-19-2072-1_8.
[25] H. Wahyudi, A. Gani, M. Syukri, R. R. Fazli, and Safrijal, "The effect of PjBL-STEM integrated with green chemistry principles on enhancing creative thinking skills and environmental literacy," *EduChemia: Jurnal Kimia dan Pendidikan*, vol. 10, no. 1, pp. 95–114, Jul. 2025, doi: 10.30870/educhemia.v10i1.32815.
[26] L. R. Aiken, "Three coefficients for analyzing the reliability and validity of ratings," *Educational and Psychological Measurement*, vol. 45, no. 1, pp. 131–142, Mar. 1985, doi: 10.1177/0013164485451012.

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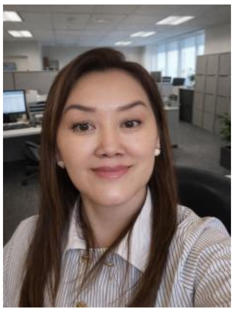

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