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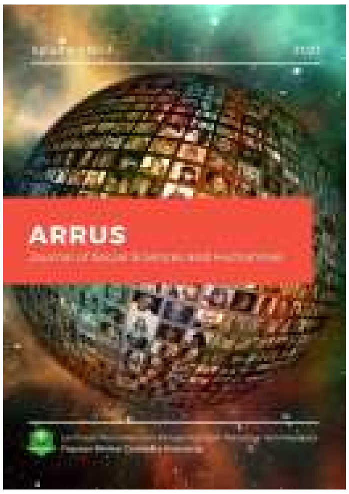

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RESEARCH ARTICLE

Integrating Climate Change Issues into Biology Instruction to Enhance Preservice Biology Teachers' Climate Literacy and Systems Thinking

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Abstract: This study examines the effectiveness of biology instruction integrating climate change issues in enhancing preservice biology teachers' climate literacy and systems thinking. A quantitative quasi-experimental pretest-posttest control group design was employed involving 60 preservice biology teachers, with 30 students in the experimental group and 30 in the control group. The experimental group received climate-integrated biology instruction, whereas the control group received conventional instruction. Data were collected using climate literacy and systems thinking tests and analyzed using descriptive statistics, MANCOVA, and ANCOVA. The results revealed a significant difference between the groups in the combined posttest scores after controlling for pretest scores (Wilks' Lambda = 0.302, $p < 0.001$). Further analysis indicated significant effects on climate literacy ($p < 0.001$) and systems thinking ($p < 0.001$). The experimental group demonstrated greater gains in climate literacy (mean gain = 19.95; N-gain = 0.459) and systems thinking (mean gain = 17.57; N-gain = 0.382) compared to the control group. These findings suggest that integrating climate change issues into biology instruction effectively enhances preservice biology teachers' climate literacy and systems thinking.

Keywords: climate change education, biology instruction, climate literacy, systems thinking, preservice biology teachers

1. Introduction

Climate change has increasingly become an important issue in education because it affects not only ecological systems but also how learners understand science, society, and their responsibility toward the future (Aeschbach et al., 2025). In higher education, climate change is no longer positioned merely as scientific content, but as a complex educational issue that demands students' critical and reflective thinking skills (Hill et al., 2025). Within this context, preservice teachers occupy a particularly important position because they are expected to become future educators who can translate global environmental problems into meaningful classroom learning experiences (Ramadani et al., 2025). Therefore, teacher education programs are challenged to provide learning experiences that help preservice teachers develop not only disciplinary understanding but also broader intellectual competencies relevant to contemporary issues (Miani et al., 2025).

Biology instruction offers a meaningful context for addressing this challenge. As a school subject and university discipline, biology deals with living systems, ecological relationships, environmental change, and interactions among organisms and their surroundings (Chen et al., 2026). These characteristics make biology highly relevant for discussing climate change in educational settings. However, if biology instruction remains limited to the transmission of

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isolated concepts, preservice teachers may acquire fragmented knowledge without being able to connect biological ideas to real world environmental issues (Aeschbach et al., 2025). For this reason, integrating climate change issues into biology instruction may provide a more contextual and educationally meaningful approach that helps preservice biology teachers understand scientific content while also reflecting on its wider significance (Martin et al., 2025).

In teacher education, two competencies are particularly relevant in this regard, namely climate literacy and systems thinking (Rial et al., 2025). Climate literacy refers to the ability to understand climate related concepts, causes, impacts, mitigation, and adaptation in ways that support informed interpretation and responsible decision making (Aguilar et al., 2025). Systems thinking refers to the ability to recognize interconnections, identify relationships among components, and understand how changes in one part of a system influence other parts (Ramadani et al., 2025). For preservice biology teachers, these two competencies are not only cognitive outcomes but also professional resources. They are expected to help future teachers interpret environmental issues in scientifically accurate yet educationally meaningful ways, and later guide school students in understanding complex global challenges (Peretz, 2025).

A growing body of research has emphasized the educational importance of climate change education and systems thinking (Husamah et al., 2025). Recent studies highlight that a key goal of climate change education is promoting climate literacy in learners, while systems thinking is increasingly recognized as essential for addressing complex problems from a holistic perspective (Karayol & Topsakal, 2025). At the same time, research in teacher education suggests that preservice teachers need more practical, experiential learning and pedagogical preparation that enables them to embrace complexity and manage scientific uncertainties (Ramadani et al., 2025). Nevertheless, recent scholarship appears to examine climate literacy and systems thinking more often in separate strands of research, and fewer studies have investigated both outcomes simultaneously within biology instruction for preservice biology teachers

This study addresses that gap by examining the effect of integrating climate change issues into biology instruction on preservice biology teachers' climate literacy and systems thinking. The study is positioned within teacher education and educational research because it focuses on how an instructional approach can support the development of competencies needed by future biology teachers. By doing so, the study contributes to the discussion of how higher education, particularly biology teacher education, can respond more meaningfully to contemporary environmental challenges.

2. Literature Review

2.1. *Climate Change Education in Teacher Education*

Climate change education has developed as an important area of educational inquiry because climate change is not only a scientific issue but also a social, ethical, and pedagogical one (Ballesta et al., 2025). In educational settings, teaching climate change involves more than presenting scientific facts; it also requires helping learners interpret evidence, understand uncertainty, relate science to daily life, and respond to environmental challenges with awareness and responsibility (Lautensach et al., 2025). For this reason, climate change education is often discussed within broader conversations about sustainability education, citizenship, and future oriented learning (Chan & Erduran, 2025).

In teacher education, the relevance of climate change education is even more pronounced (Morote et al., 2025) . Preservice teachers are expected to develop sufficient understanding of climate-related issues before entering the profession, because their future teaching practices may shape how school students perceive environmental crises and societal responses to them (Aguilar et al., 2025). As a result, teacher education programs need to equip preservice teachers with knowledge and pedagogical sensitivity that allow them to

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translate climate related issues into learning experiences that are scientifically grounded and educationally meaningful (Aguilar et al., 2025). This makes climate change education a teacher preparation issue as much as a curriculum issue.

2.2. *Climate Literacy as an Educational Outcome*

Climate literacy is widely understood as a multidimensional competence that includes knowledge of climate systems, awareness of human influence on climate change, understanding of impacts, and recognition of mitigation and adaptation strategies (Martin et al., 2025). In educational research, climate literacy is important because it reflects not only what learners know, but also how they interpret climate related information and apply it in informed ways (Ariza et al., 2024). Studies have shown that educational interventions can improve climate literacy, particularly when learning is contextual, issue-based, and connected to authentic problems.

For preservice biology teachers, climate literacy is especially important because it supports both personal understanding and future pedagogical practice (Kouam, 2025). A preservice teacher who is climate literate is more likely to present climate issues accurately, connect them with biological concepts, and facilitate classroom discussion in ways that encourage inquiry and reflection (Morote et al., 2025). Thus, in the context of teacher education, climate literacy should be viewed not only as a learning outcome but also as part of professional readiness.

2.3. *Systems Thinking in Biology Education*

Systems thinking has increasingly been recognized as a core competence in biology and science education because many scientific phenomena arise from interactions among multiple components rather than from simple linear cause-and-effect relationships (Momsen et al., 2022) In biology, learners are required to understand organisms, populations, ecosystems, and environmental processes as dynamic and interconnected systems (Li & Li, 2025). From this perspective, systems thinking enables students to move beyond fragmented knowledge toward relational, integrative, and holistic reasoning

This competence is particularly important in climate change education because biological systems provide a meaningful bridge for understanding climate complexity (Miani et al., 2025). Ecosystems, for example, make visible how changes in one component may trigger cascading effects across food webs, biodiversity, ecological balance, and human life (Momsen et al., 2022). Through biological systems, students can understand climate change not as an isolated event, but as a systemic phenomenon involving interdependence, feedback, adaptation, and imbalance across environmental dimensions.

For preservice biology teachers, systems thinking is especially relevant because it supports their ability to interpret biological content in ways that reflect the complexity of living systems and to translate that complexity into meaningful classroom learning (Luft et al., 2022). It also provides a conceptual foundation for teaching environmental and socioscientific issues, including climate change, in ways that are coherent and educationally relevant (Momsen et al., 2022). When future teachers are able to think systemically, they are better prepared to explain how environmental changes affect biodiversity, ecological stability, and human life in interconnected ways.

2.4. *Integrating Climate Change Issues into Biology Instruction*

The integration of climate change issues into biology instruction is theoretically justified because climate change is closely related to central biological themes such as biodiversity, adaptation, ecological interaction, population dynamics, and ecosystem change (Mengzhi et al., 2025). Instruction that connects these topics with authentic climate related issues can create more meaningful learning experiences, especially for preservice teachers who need to link content knowledge with future teaching pract (Thanapornsangsuth et al., 2025). In this sense, climate change does not function merely as an additional topic, but as a context that enriches how biology is learned and taught.

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From an educational perspective, issue integrated instruction can also support higher order thinking because learners are required to analyze relationships, interpret evidence, and connect disciplinary concepts to real world challenges (Wu et al., 2025). Studies have suggested that climate change related learning can foster deeper engagement when it is designed around authentic problems and encourages learners to see interdependence across systems. Therefore, integrating climate change issues into biology instruction is expected to support both climate literacy and systems thinking among preservice biology teachers (Morote et al., 2025; Ramadani et al., 2025).

Although previous studies have examined climate change education, climate literacy, and systems thinking, fewer studies have investigated these constructs together within biology instruction for preservice biology teachers (Martin et al., 2025). Existing studies tend to focus on either climate-related understanding or systems-based reasoning rather than examining both as simultaneous outcomes of a single instructional intervention (Jin et al., 2025). This indicates a need for further research on whether integrating climate change issues into biology instruction can strengthen both competencies in teacher education contexts. Hypotheses:

H1: There is a significant difference in climate literacy between preservice biology teachers who receive biology instruction integrated with climate change issues and those who receive conventional instruction.

H2: There is a significant difference in systems thinking between preservice biology teachers who receive biology instruction integrated with climate change issues and those who receive conventional instruction.

H3: There is a significant simultaneous effect of integrating climate change issues into biology instruction on preservice biology teachers' climate literacy and systems thinking.

3. Research Method and Materials

This study employed a quantitative approach using a quasi experimental pretest posttest control group design. The design was selected because the study was conducted in naturally existing classes without random assignment of individual participants. This design enabled the researchers to compare the effect of biology instruction integrating climate change issues with that of conventional biology instruction on preservice biology teachers' climate literacy and systems thinking while controlling for their initial differences through pretest scores.

This study was conducted in the Biology Education Study Program at Widya Mandira Catholic University during the odd semester of the 2025-2026 academic year. The participants consisted of 60 preservice biology teachers enrolled in the same course and selected through cluster purposive sampling, as the study involved intact classes predetermined by the institution. The participants were divided into two groups: an experimental class comprising 30 preservice biology teachers and a control class comprising 30 preservice biology teachers. Both groups were considered relatively comparable in terms of academic background, course level, and prior learning experience before the intervention was implemented.

The instructional treatment in this study consisted of biology instruction integrating climate change issues. In the experimental class, biological concepts were taught by explicitly linking them with climate related topics such as biodiversity loss, ecosystem disruption, environmental change, species adaptation, and ecological imbalance. The instructional activities emphasized contextual learning, discussion of authentic issues, case based analysis, and the identification of relationships among biological and environmental components. In contrast, the control class received conventional biology instruction in which biological concepts were presented without systematic integration of climate change issues. Although both groups studied similar biology content, only the experimental class experienced instruction designed to connect biological knowledge with real environmental challenges.

The study involved one independent variable and two dependent variables. The independent variable was biology instruction integrating climate change issues. The dependent variables

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were climate literacy and systems thinking. Climate literacy was defined as preservice biology teachers' understanding of climate change concepts, causes, impacts, mitigation, and adaptation, as well as their ability to interpret climate related issues using scientific reasoning. Systems thinking was defined as the ability to identify components within biological and environmental systems, recognize relationships among these components, and explain interdependence and change across systems.

Data were collected using three instruments: a climate literacy test, a systems thinking test, and an observation sheet. The climate literacy instrument was a researcher-developed achievement test consisting of 50 multiple choice items designed to assess participants' understanding of climate change concepts, including causes, impacts, mitigation, and adaptation, as well as their ability to relate these issues to biological knowledge. The systems thinking instrument was a researcher-developed test consisting of 15 open ended (essay) items aimed at measuring participants' ability to identify components of biological and environmental systems, analyze interrelationships among those components, and explain patterns of interdependence and system dynamics. The observation sheet was used to monitor the fidelity of instructional implementation in both groups.

Prior to data collection, both instruments were validated by experts in biology education and educational assessment. The results of content validation showed that the climate literacy instrument achieved an Aiken's V ranging from 0.85 to 0.92, while the systems thinking instrument ranged from 0.83 to 0.90, indicating high content validity. The instruments were subsequently pilot-tested to examine their internal consistency. Reliability analysis using Cronbach's Alpha yielded coefficients of 0.82 for the climate literacy test and 0.78 for the systems thinking test, indicating good reliability. Revisions were made based on expert feedback and pilot-test results before the instruments were administered in the main study. An observation sheet was used to monitor the fidelity of instructional implementation in both groups.

The study was conducted in three stages. First, both the experimental and control groups completed the pretest to determine their initial levels of climate literacy and systems thinking. Second, the instructional treatment was implemented over fourteen meetings. During this period, the experimental group participated in biology instruction integrating climate change issues, whereas the control group received conventional instruction. Third, at the end of the intervention, both groups completed the posttest using the same instruments.

The collected data were analyzed using descriptive and inferential statistics. Descriptive statistics included mean scores, standard deviations, gain scores, and normalized gain scores. Inferential analysis was conducted after testing the assumptions of normality and homogeneity. Since this study involved two dependent variables and used pretest scores as covariates, Multivariate Analysis of Covariance (MANCOVA) was employed as the main statistical technique. This was followed by Univariate Analysis of Covariance (ANCOVA) to examine the effect of the treatment on each dependent variable separately. All analyses were performed using IBM SPSS Statistics version 25, with a significance level of 0.05.

The structure of the research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental Class	Climate literacy test: Systems thinking test	Biology instruction integrating climate change issues	Climate literacy test: Systems thinking test
Control Class	Climate literacy test: Systems thinking test	Conventional biology instruction	Climate literacy test: Systems thinking test

The variables and indicators measured in this study a summarized in Table 2.

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Table 2. Variables and Indicators

Variables	Indicators
Climate literacy	Understanding climate change concepts, causes, impacts, mitigation, and adaptation
Systems thinking	Identifying system components, recognizing relationships, explaining interdependence, and analyzing system change
Instructional treatment	Integration of climate change issues into biology instruction through contextual, issue-based, and discussion oriented learning

To maintain the validity of the implementation, the researchers ensured that both classes were taught within the same academic context, used comparable biology content coverage, and were given equal instructional time. The difference between the two classes was limited to the instructional approach applied during the intervention. This procedure was intended to reduce the influence of external variables and strengthen the interpretation that any significant posttest difference was associated with the instructional treatment.

4. Results and Discussion

4.1. Results

4.1.1. Descriptive Statistics

Table 3 presents the descriptive statistics of the pretest and posttest scores for both groups

Table 3. Descriptive Statistics of Pretest and Posttest Scores

Variable	Group	N	Mean Pretest	SD	Mean Posttest	SD	Mean Gain	Mean N-gain
Climate Literacy	Experimental	30	55.24	6.86	75.19	7.72	19.95	0.459
Climate Literacy	Control	30	53.95	6.67	62.35	6.29	8.40	0.181
Systems Thinking	Experimental	30	53.61	6.21	71.18	6.82	17.57	0.382
Systems Thinking	Control	30	53.33	5.17	61.21	5.85	7.88	0.166

As shown in Table 3, the mean pretest scores of the two groups were relatively comparable across both variables. Following the instructional treatment, the experimental group demonstrated greater improvement than the control group in both climate literacy and systems thinking.

4.1.2. Assumption Testing

Prior to the main analysis, the assumptions for multivariate analysis were examined. The results of the normality test indicated that the residuals were normally distributed. The residuals for climate literacy yielded a Shapiro-Wilk value of 0.987, $p = 0.773$, whereas the residuals for systems thinking yielded a Shapiro-Wilk value of 0.968, $p = 0.116$. The homogeneity of variance assumption was also met. Levene's test showed that the posttest scores were homogeneous for climate literacy, $F = 1.139$, $p = 0.290$, and for systems thinking, $F = 0.520$, $p = 0.474$

In addition, the homogeneity of covariance matrices assumption was satisfied, as indicated by Box's M = 2.512, $p = 0.490$. The homogeneity of regression slopes assumption was also met, since the interaction between group and pretest scores was not statistically significant. These results indicate that the data were suitable for further analysis using MANCOVA.

4.1.3. MANCOVA Results

The MANCOVA results revealed a statistically significant difference between the experimental and control groups on the combined posttest scores of climate literacy and systems thinking after controlling for the preservice biology teachers' pretest scores.

Table 4. Results of MANCOVA

Effect	Wilks' Lambda	*F*	df	p
Group	0.302	63.48	(2,55)	<0.001

The result indicates that biology instruction integrating climate change issues had a significant multivariate effect on the two dependent variables simultaneously.

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4.1.4. Univariate ANCOVA Results

Because the multivariate test was statistically significant, follow-up univariate ANCOVA analyses were conducted.

Table 5. Results of Univariate ANCOVA by Group Effect

Dependent Variable	Source	*F*	df	p	Partial η^2
Climate Literacy	Group	84.30	(1,57)	< 0.001	0.597
Systems Thinking	Group	56.23	(1,57)	< 0.001	0.497

The ANCOVA results showed that the experimental group achieved significantly higher posttest scores than the control group in both climate literacy and systems thinking. The effect size values further indicate that the instructional treatment had a strong effect on both variables.

4.1.5. Adjusted Mean Scores

Table 6 presents the adjusted posttest means after controlling for pretest scores.

Table 6. Adjusted Posttest Means after Controlling for Pretest Scores

Variable	Experimental	Control	Difference
Climate Literacy	74.61	62.92	11.69
Systems Thinking	71.09	61.31	9.78

Substantively, these findings confirm that the integration of climate change issues into biology instruction not only improved the preservice biology teachers' scores, but also made a meaningful contribution after initial differences in prior ability had been controlled for. The results support all three proposed hypotheses. Specifically, H1 and H2 were supported by the significant univariate effects of the instructional treatment on climate literacy and systems thinking, respectively, whereas H3 was supported by the significant multivariate effect on the combined dependent variables.

4.2. Discussion

The findings of this study indicate that integrating climate change issues into biology instruction was more effective than conventional instruction in improving preservice biology teachers' climate literacy and systems thinking. Although the experimental and control groups began with relatively comparable pretest scores, the experimental group demonstrated higher posttest scores and greater gains on both variables after the intervention. These differences, supported by the multivariate and univariate analyses, suggest that the instructional treatment made a meaningful contribution to the observed outcomes. More importantly, the findings are particularly significant in the context of preservice teacher education because they show that climate-integrated biology instruction does not merely enhance academic achievement, but also supports forms of understanding that are closely related to future professional practice.

A key contribution of this study lies in examining climate literacy and systems thinking simultaneously within biology instruction for preservice biology teachers. Previous studies have often treated climate related understanding and systems based reasoning as separate outcomes (Jin et al., 2025). In contrast, the present findings suggest that integrating climate change issues into biology instruction can foster both competencies at the same time. This is important because climate change is not simply an additional biology topic, it is a complex socio scientific issue that connects core biological concepts such as biodiversity, adaptation, ecological interactions, population dynamics, and ecosystem change with real societal challenges. For preservice teachers, learning biology through climate related issues may therefore function as a bridge between disciplinary understanding and pedagogical relevance (Idrissi, 2025; Winter et al., 2025). They are not only learning what climate change is, but also how biological knowledge can be mobilized to explain, interpret, and teach contemporary environmental issues in school contexts.

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The significant improvement in climate literacy suggests that embedding climate change issues into biology instruction helped preservice biology teachers develop a more meaningful and applicable understanding of climate related concepts. Rather than learning biological content as isolated knowledge, participants in the experimental group were encouraged to connect scientific ideas with authentic environmental issues, including biodiversity loss, ecosystem disruption, and adaptation to environmental change. This likely promoted deeper conceptual engagement because students were required to interpret evidence, evaluate information, and apply biological concepts in meaningful contexts (Sembiring & Yusuf, 2025). For preservice teachers, this is especially important because climate literacy is not only a matter of personal understanding, but also a component of professional readiness (Kundariati et al., 2025; Ünal et al., 2025). Future biology teachers are increasingly expected to explain climate related concepts accurately, identify misinformation, and guide students in interpreting environmental claims critically (Ariza et al., 2024). In this sense, stronger climate literacy may better equip preservice teachers to respond to climate skepticism in schools by grounding classroom discussion in scientific evidence rather than opinion alone.

The improvement in systems thinking is equally important when viewed from the perspective of teacher preparation (Budak & Ceyhan, 2024). Climate change is inherently systemic, involving interdependent ecological, biological, social, and human dimensions that cannot be adequately understood through linear cause-and-effect reasoning alone. By integrating climate change issues into biology instruction, the experimental group was exposed to learning experiences that required them to identify system components, trace interactions, recognize interdependence, and interpret change across multiple levels of biological organization. Such experiences likely encouraged students to move beyond fragmented understanding toward a more relational and holistic mode of thinking. For preservice biology teachers, this competence is professionally valuable because teaching environmental topics in schools often requires the ability to explain complex causal chains, feedback processes, and unintended consequences. Teachers who can think systemically are likely to be better prepared to help school students understand why climate change affects biodiversity, food webs, ecological balance, and human life in interconnected ways (Martín & Martín, 2024; Peretz, 2025).

These findings can also be interpreted through the lens of teacher professional development. From the perspective of Shulman's concept of pedagogical reasoning and pedagogical content knowledge, effective teacher preparation goes beyond mastering subject matter (Kong, 2025). It involves the ability to transform disciplinary knowledge into forms that are understandable and meaningful for learners. Climate integrated biology instruction appears to support this process by engaging preservice teachers with scientific content in ways that are closely connected to authentic contexts, interpretation, and explanation (Laius et al., 2024). Likewise, from the perspective of transformative learning, encountering climate change as a real and complex issue may encourage preservice teachers to reassess prior assumptions, connect knowledge with responsibility, and develop more critical and reflective ways of thinking. This suggests that the gains observed in this study may represent not only cognitive improvement, but also early movement toward professional growth as future educators in the climate era

The results are also relevant to the preparation of preservice teachers for teaching socio-scientific issues. Climate change is a highly contested topic in many public contexts and often involves uncertainty, competing values, misinformation, and ideological disagreement (Essien, 2025). In school settings, teachers may therefore face questions not only about scientific facts, but also about controversy, skepticism, and the social implications of environmental decisions. Preservice teachers who develop stronger climate literacy and systems thinking may be better prepared to manage such classroom complexity (Peretz, 2025). They may be more capable of facilitating evidence-based discussion, connecting local experiences with global processes, and helping students reason through controversial environmental issues in a balanced and scientifically grounded way (Kyza & Georgiou, 2025).

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In this sense, the integration of climate change into biology instruction may contribute directly to the development of professional capacities needed for teaching socio scientific issues in future classrooms.

From a broader teacher education perspective, the results suggest that climate literacy and systems thinking should not be viewed solely as academic outcomes, but also as dimensions of professional competence. Preservice biology teachers are expected to become educators who can explain scientific concepts accurately, connect them to contemporary environmental challenges, and design learning experiences that are relevant to students' lives and futures (Sembiring & Yusuf, 2025; Steinwachs & Martens, 2025). The present findings therefore imply that climate integrated biology instruction may function not only as a content enrichment strategy, but also as a pedagogical approach for strengthening professional readiness. It helps preservice teachers learn how to interpret complex environmental problems, how to relate biology to public issues, and how to position scientific understanding within meaningful educational practice. In this way, the findings support the argument that teacher education should prepare future teachers not only to know science, but also to teach science in ways that are socially relevant, critically reflective, and responsive to the realities of climate change.

Despite these promising findings, several limitations should be acknowledged. First, the study involved participants from a single study program within one institutional context, which may limit the transferability of the findings to other teacher education settings. Second, the study employed a quasi experimental design using intact classes, so the results should be interpreted with appropriate caution even though pretest scores were used to account for baseline differences. Third, the instructional intervention was implemented over a limited number of meetings, and a longer intervention might yield different or stronger effects. Fourth, the study focused only on climate literacy and systems thinking; other dimensions of preservice teacher development, such as pedagogical beliefs, pedagogical content knowledge, instructional design competence, self-efficacy for teaching climate change, and readiness to handle socio scientific controversy, were not directly examined. Future research could therefore extend this work by involving broader samples, longer intervention periods, and additional indicators of teacher development, including whether the observed gains are sustained over time and transferred into actual teaching practice during school placements or early teaching experiences

Overall, the findings suggest that integrating climate change issues into biology instruction is a promising approach for enhancing preservice biology teachers' climate literacy and systems thinking while also contributing to their professional preparation as future educators. By connecting disciplinary learning with authentic global issues, this approach appears to make biology learning more meaningful, more intellectually integrated, and more relevant to the realities of classroom teaching. The study therefore supports the view that climate change should be positioned not only as content to be learned, but also as a pedagogical context through which preservice teachers develop the knowledge, reasoning, and professional capacities needed to teach science in an increasingly complex and climate affected world.

5. Conclusion

The findings of this study indicate that the integration of climate change issues into biology instruction was more effective than conventional instruction in improving preservice biology teachers' climate literacy and systems thinking. Preservice biology teachers in the experimental class demonstrated higher posttest scores than those in the control class on both dependent variables. These findings suggest that climate change-integrated biology instruction can serve as a meaningful and effective approach to strengthening climate-related understanding and systems thinking in biology teacher education. The study also highlights the educational value of using authentic environmental issues as an instructional context for promoting more relevant and conceptually integrated learning.

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