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DEVELOPMENT OF A CLIMATE CHANGE E-MODULE THROUGH ANALYSIS OF RAINFALL TRENDS AND PATTERNS TO ENHANCE THE 4C SKILLS OF PROSPECTIVE PHYSICS TEACHERS

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Abstract
Climate change education demands innovative strategies that equip future educators with both scientific understanding and 21st-century teaching skills. This study aims to develop and evaluate an inquiry-based e-module on climate change, centered around local rainfall trend data, to enhance the conceptual knowledge and 4C competencies—critical thinking, creativity, collaboration, and communication—of pre-service physics teachers in Indonesia. The research employed the ADDIE instructional design model and involved validation by experts and pilot implementation with 57 student teachers. The e-module was developed using multimedia tools and structured around guided inquiry stages. Validation results indicated high content and media quality, while effectiveness testing showed a significant increase in cognitive learning, with a mean N-Gain score of 0.71. Performance assessments also revealed very high achievements across all 4C dimensions. Participants demonstrated improved analytical reasoning, contextual problem-solving, and scientific communication skills.These findings suggest that integrating local climate data into inquiry-based digital learning modules fosters both cognitive and competency-based outcomes. The module aligns with curricular standards and responds to the growing need for climate-responsive teacher education. It provides a scalable model for future implementation in diverse educational settings and contributes to the advancement of environmental literacy and data-driven pedagogy in science education..

***Keywords**: Inquiry-Based Learning, Climate Change Education, Pre-Service Physics Teachers, 4C Competencies*

Abstrak
Pendidikan perubahan iklim menuntut strategi inovatif yang mampu membekali calon pendidik dengan pemahaman ilmiah serta keterampilan mengajar abad ke-21. Penelitian ini bertujuan untuk mengembangkan dan mengevaluasi sebuah e-modul berbasis inkuiri tentang perubahan iklim yang berpusat pada data tren curah hujan lokal, guna meningkatkan pemahaman konseptual dan kompetensi 4C—berpikir kritis, kreativitas, kolaborasi, dan komunikasi—pada calon guru fisika di Indonesia. Penelitian ini menggunakan model desain pembelajaran ADDIE dan melibatkan validasi oleh para ahli serta implementasi uji coba kepada 57 mahasiswa calon guru. E-modul dikembangkan menggunakan perangkat multimedia dan disusun berdasarkan tahapan inkuiri terbimbing. Hasil validasi menunjukkan kualitas konten dan media yang tinggi, sementara uji efektivitas menunjukkan peningkatan signifikan dalam pembelajaran kognitif, dengan skor rata-rata N-Gain sebesar 0,71. Penilaian kinerja juga menunjukkan pencapaian yang sangat tinggi dalam seluruh dimensi 4C. Partisipan menunjukkan peningkatan dalam penalaran analitis, pemecahan masalah kontekstual, dan keterampilan komunikasi ilmiah. Temuan ini menunjukkan bahwa integrasi data iklim lokal ke dalam modul pembelajaran digital berbasis inkuiri mendorong pencapaian hasil pembelajaran secara kognitif maupun kompetensial. Modul ini selaras dengan standar kurikulum dan menjawab kebutuhan mendesak akan pendidikan guru yang responsif terhadap isu iklim. Modul ini menawarkan model yang dapat direplikasi dan

diskalakan untuk implementasi di berbagai konteks pendidikan, serta berkontribusi pada penguatan literasi lingkungan dan pedagogi berbasis data dalam pendidikan sains..

***Kata Kunci**: Pembelajaran Berbasis Inkuiri, Pendidikan Perubahan Iklim, Calon Guru Fisika, Kompetensi 4C, Pengembangan E-Modul*

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INTRODUCTION

Climate change presents one of the most pressing challenges of the 21st century, with far-reaching consequences across environmental, economic, and social systems. In Indonesia, these changes manifest as increasingly erratic rainfall patterns, intensifying extreme weather events, and rising temperatures, all of which pose threats to agriculture, water resources, and ecosystem stability. Consequently, there is an urgent need for educational strategies that not only build awareness but also foster the capacity to understand and respond to these global phenomena. One promising approach lies in integrating climate change education into teacher preparation programs, particularly for pre-service physics teachers who are expected to translate scientific understanding into meaningful classroom practices.

Despite the growing global emphasis on climate education, many instructional models remain overly theoretical and detached from students' lived experiences. As a result, learners struggle to grasp the complex, systemic nature of climate issues or to apply scientific knowledge in real-world contexts. Recent pedagogical research highlights the value of inquiry-based learning (IBL) and data-driven instruction, which empower students to engage with authentic environmental data, ask meaningful questions, and develop evidence-based conclusions. These approaches align with the goals of the Merdeka Curriculum in Indonesia, which advocates for contextualized, competency-based learning that cultivates critical thinking, creativity, collaboration, and communication (4C).

This study addresses the gap between theoretical knowledge and empirical understanding by developing a digital learning module (e-module) on climate change that uses real-world rainfall trend data. Rainfall, as a primary climate variable, serves as a tangible and locally relevant entry point for understanding broader climate dynamics. By engaging with historical and current precipitation data from their own regions, students are encouraged to analyze patterns, identify anomalies, and explore possible drivers and impacts of climate variability. Such activities not only enhance content mastery but also build data literacy, systems thinking, and environmental agency—skills that are essential for 21st-century science education.

To bridge the gap between scientific content and pedagogical relevance, the e-module is designed based on guided inquiry principles. This structured approach facilitates step-by-step engagement in scientific practices, from problem formulation to data interpretation and argument construction. Prior studies have shown that Argument-Driven Inquiry (ADI) and STEM-integrated digital modules significantly improve conceptual understanding and critical thinking skills among pre-service teachers (Erenler et al., 2025; Misbah et al., 2024). By embedding similar strategies, this module aims to deepen students' comprehension of climate change while fostering independent reasoning and collaborative problem-solving.

The module further integrates systems thinking, a pedagogical approach that enables learners to understand complex interrelationships within climate systems. This perspective is especially important in climate education, where cause-effect linkages are often non-linear and multifaceted. According to (Ignacio et al., 2024), e-learning tools that incorporate systems thinking significantly enhance depth and accuracy of reasoning in climate science. In this study, students explore how changes in rainfall patterns relate

to broader atmospheric processes and how these shifts affect ecological and social systems.

A unique feature of the module is its focus on contextualized data and geospatial visualization. Research indicates that students develop a stronger understanding of environmental issues when they investigate local phenomena through the lens of global systems (Stephenson Reaves, 2023; Zalles & Pallant, 2014). By allowing students to work with rainfall data from their own communities, the module strengthens their ability to make connections between abstract scientific concepts and observable environmental changes. This fosters both climate literacy and a sense of place-based responsibility, empowering learners to act as informed agents of change.

Beyond cognitive gains, the module is explicitly designed to cultivate 21st-century competencies, collectively known as 4C: critical thinking, creativity, collaboration, and communication. These skills are increasingly recognized as essential for future educators. For example, problem-based learning (PBL) environments that integrate virtual experiments and real-world data have been shown to significantly improve critical thinking (Handayani, 2024; Pertiwi et al., 2024). Similarly, project-based modules that encourage students to develop innovative solutions to environmental problems foster creativity and reflective thinking (Maor et al., 2023).

The collaborative dimension of the module involves group-based inquiry tasks, peer feedback sessions, and joint analysis of climate data. These elements have been found to enhance interpersonal communication and teamwork among pre-service teachers, particularly when facilitated through digital platforms (Susanti et al., 2024). Moreover, students are required to present their findings through written reports and oral presentations, practices that have been shown to strengthen scientific communication and rhetorical clarity (Macchi et al., 2025).

Despite the proven potential of such approaches, many existing teacher education programs lack access to localized, data-rich, and pedagogically grounded climate learning tools. This research addresses that gap by developing, validating, and testing an e-module tailored to the Indonesian educational context. The innovation lies not only in the integration of climate data but also in the module's alignment with national curriculum standards and its emphasis on interdisciplinary learning.

Thus, the aim of this study is to design and evaluate the effectiveness of a climate change e-module that incorporates local rainfall trend analysis and guided inquiry to enhance both conceptual understanding and 4C skills among prospective physics teachers. The novelty of the study rests on its dual emphasis: bridging theoretical and empirical climate knowledge, and simultaneously building the pedagogical competencies needed for 21st-century science instruction. The module's scope includes content development, validation by experts, and effectiveness testing through implementation with pre-service teachers.

In doing so, this study contributes to the emerging field of climate change education by offering a replicable and scalable model of e-learning that is data-informed, inquiry-driven, and competency-oriented. It provides a concrete strategy for integrating climate literacy into teacher education and equipping future educators with the knowledge, skills, and dispositions necessary to address environmental challenges in meaningful and transformative ways.

METHODS

This study employed the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design model to guide the systematic creation and testing of an inquiry-based e-module focused on climate change education. The ADDIE framework was selected for its comprehensive structure and adaptability, especially

within the context of teacher education for prospective physics teachers (Mat et al., 2025a; Rizal et al., 2022). This methodology section is divided into five interrelated phases that reflect the sequential design and evaluation processes aligned with the structure used in the research.

In the Analysis phase, researchers conducted a diagnostic review of the current instructional materials available for pre-service physics teachers. This included identifying key competencies such as critical thinking, creativity, collaboration, and communication (4C), which are essential for 21st-century learning. Through surveys, interviews, and curriculum analysis, the researchers identified content gaps in climate change education and the lack of empirical, data-driven learning tools. Curriculum mapping aligned the intended e-module with national education standards and the Merdeka Curriculum, focusing on scientific literacy and local environmental issues such as rainfall variability (Budiarto et al., 2024; E. P. Sari, 2024). The analysis emphasized integrating local wisdom and contextual data into the learning experience (Cheng & Chu, 2016; Mat et al., 2025b).

The Design phase translated the needs analysis into pedagogical strategies. A storyboard and modular flowchart were created to structure the e-module around key learning objectives, including exploration of local climate trends. The content was built to support inquiry-based activities such as data interpretation, pattern recognition, and evidence-based argumentation. Multimedia components—including diagrams, rainfall data graphs, interactive animations, and embedded quizzes—were selected to enhance cognitive engagement and knowledge construction (Putra et al., 2019; Rini et al., 2023). Culturally relevant case studies and region-specific data sets were embedded to enhance authenticity and learner motivation (D. W. Sari et al., 2025).

During the Development phase, the e-module was created using digital authoring tools Kvisoft Flipbook Maker and Flip PDF Professional, which supported integration of multimedia features and cross-platform accessibility (Islami et al., 2021; Nurjayadi & Sadono, 2021). The module consisted of four thematic components: an introductory conceptual framework on climate change, a segment dedicated to rainfall data analysis, an application section for evaluating environmental impacts, and a reflective evaluation module.

Content validation was conducted by multiple experts in the fields of education, digital learning, and science communication. They evaluated content quality, language clarity, instructional coherence, and digital usability using instruments such as Aiken's V index for inter-rater agreement (Columbano, 2019; Putra et al., 2024). The validation process yielded high levels of agreement across all components, prompting only minor revisions to enhance interactivity and reduce cognitive load.

The Implementation phase involved pilot testing with 57 pre-service physics teachers enrolled in a teacher training program. Learners accessed the e-module via a Learning Management System (LMS) compatible with desktop and mobile devices (Rizal et al., 2022). Over a three-week cycle, students engaged in individual and group activities, including analyzing real-time rainfall datasets, generating hypotheses, constructing arguments, and sharing insights through collaborative online forums.

Instructor monitoring logs indicated high engagement levels across asynchronous activities, while formative feedback tools embedded in the LMS supported adaptive instructional interventions. Students were encouraged to reflect on their learning via weekly journals and group discussions. The implementation was followed by a usability survey and semi-structured interviews to collect qualitative insights into student experience, which informed the subsequent evaluation and revision processes (Andrini et al., 2019).

RESULTS AND DISCUSSION

1. Research Findings

1.1. Characteristics of the Rainfall Data and Inquiry-Based Climate Change E-Module

In the Define stage of development, the study determined the product to be developed as an inquiry-based electronic module (e-module) focusing on climate change. The decision to develop this e-module arose from the scarcity of interactive and empirically grounded teaching materials that stimulate student engagement in climate-related topics. The e-module was designed to be accessible online and to align with the Core Competencies (Kompetensi Inti or KI) and Basic Competencies (Kompetensi Dasar or KD) of the Indonesian 2013 Curriculum. It emphasizes guided inquiry learning to actively involve students in the learning process, particularly within the topic of global warming and its implications.

The curriculum analysis ensured that the content matched national standards and educational outcomes. Table 4.1 outlines the core competencies targeted in the module, which include religious values, character development, scientific knowledge, and problem-solving. Specifically, students are expected to analyze global warming and its impact (KD 3.12) and propose solutions (KD 4.12). The learning objectives derived from this include understanding the concepts of global warming and climate change, developing observational and analytical skills, and identifying the causes and consequences of climate change.

A motivational needs analysis revealed that students showed low interest in physics lessons on global warming, primarily due to unengaging materials. The module addressed this by incorporating real-world data and contextually rich content. Content was curated and structured systematically to align with the curriculum and be relevant to students' everyday experiences.

1.2 E-Module Design Process

During the Design stage, the e-module framework was built upon guided inquiry principles. The format was designed to support the five inquiry steps: identifying problems, designing and conducting experiments, collecting data, interpreting findings, and drawing conclusions. This format encouraged students to become active knowledge constructors.

Multimedia integration played a central role in the design. Visual aids, instructional videos, and interactive tasks were used to explain the phenomenon of climate change and guide students through the inquiry process. Resources, including images and conceptual references, were drawn from reputable textbooks, the Indonesian Ministry of Education’s physics modules, and creative digital media. These were used to prepare engaging and accurate learning content.

The module included a cover page, introduction, usage instructions, learning objectives, content explanations, interactive student tasks, and evaluations. Figure 1 illustrates the layout and navigation interface of the e-module, highlighting its smartphone compatibility and interactive flow.

To ensure quality assurance, assessment instruments were developed for expert validation. These instruments were based on previous studies (Masie et al., 2025; Sirojjuddin et al., 2025) and adapted to assess aspects such as content relevance, pedagogical coherence, linguistic clarity, and technical usability. Instruments were

designed for different validators: content experts, media experts, language experts, teacher practitioners, and student users.

1.3 E-Module Validity Results

Validation results are presented in Table 4.2. Overall, the module received an average validity score of 87.25%, which categorizes it as "Very Valid."

Table 4.2. E-Module Validity Scores by Validator

Validator	Average Score
Content Expert	84%
Media Expert	92%
Language Expert	80%
Teacher Practitioner	93%
Overall Average	87.25%
Category	Very Valid

Content expert evaluations focused on alignment with learning objectives, scientific accuracy, and guided inquiry compatibility. The module received particularly high ratings for clarity of inquiry-based content, relevance of evaluation items, and the integration of inquiry syntax.

Media validation emphasized layout clarity, typeface readability, image quality, and navigation simplicity. Scores reached up to 100% for categories such as visual clarity and instructional design, demonstrating high student usability.

Language experts assessed grammar, sentence structure, terminology appropriateness, and adherence to formal language norms. Despite scoring slightly lower than other validators (80%), the module was considered clear and accessible (Retta et al., 2023).

Teacher practitioners gave high scores for practicality and classroom integration. They reported that the e-module was helpful in guiding students to understand complex climate concepts and stimulated learner activity.

1.4 Effectiveness of the E-Module on Concept Mastery

The module’s effectiveness in enhancing students' conceptual understanding of climate change was evaluated using a pretest-posttest design. The participants were 57 pre-service physics teachers. Pre- and post-tests were administered to measure cognitive gains, and N-Gain scores were calculated.

Table 4.3 presents average scores before and after module implementation. The average pretest score was 48.56, and the average posttest score was 78.26. The mean N-Gain score was 0.71, indicating a high category of learning improvement.

Table 4.3. Pretest-Posttest Results and N-Gain

Assessment	Average Score
Pretest	48.56
Posttest	78.26
N-Gain	0.71 (High)

These results confirm the module’s effectiveness in supporting cognitive development. Previous studies on similar e-modules have shown comparable effectiveness levels, with N-Gain scores ranging from 0.5 to 0.8 (Leng et al., 2024).

1.5 The E-Module's Contribution to 4C Competency Development

To evaluate the module's impact on 4C competencies, the study used a combination of rubrics, observational data, and student reflections. Table 4.4 shows performance results in each of the 4C dimensions. Critical thinking reached an average of 94%, collaboration 93%, communication 94%, and creativity 94%, placing all competencies within the "Very High" category.

Table 4.4. 4C Competency Achievement Scores

Competency	Average Score
Critical Thinking	94%
Collaboration	93%
Communication	94%
Creativity	94%

These findings align with prior research showing that well-designed e-modules can significantly enhance 4C skills (Arifin et al., 2024; Ma`arif et al., 2022). Guided inquiry frameworks, combined with real data and reflective tasks, contribute to improvements in critical thinking and communication. Integration of cultural and environmental issues through interactive media also fosters collaboration and creativity.

Overall, the results suggest that the developed e-module is valid, effective, and pedagogically sound. It enhances conceptual understanding and supports the development of essential 21st-century competencies. Continued refinement based on user feedback can further improve its scalability and impact in teacher education contexts.

2. Discussion

2.1. Characteristics of the Rainfall Data and the Inquiry-Based Climate Change E-Module

The findings of this study confirm that the development of an inquiry-based e-module grounded in local rainfall data successfully addresses both content mastery and the cultivation of 21st-century skills, particularly the 4Cs: communication, collaboration, critical thinking, and creativity. The alignment between the e-module's characteristics and the principles of inquiry-based learning (IBL) is evident in the module's structure and pedagogical goals. According to (Constantinou et al., 2024), effective IBL promotes student agency by guiding learners through meaningful problem-solving and data interpretation tasks, which was reflected in the inquiry stages embedded in the module: problem identification, data analysis, evidence-based conclusions, and reflection. The module's inclusion of localized climate data further enhances its relevance. As highlighted by (Meekaew & Saenkum, 2025), incorporating regional climate data not only personalizes the learning experience but also fosters environmental awareness and scientific reasoning.

Curricularly, the module aligns with the Indonesian 2013 curriculum and the Merdeka Curriculum's emphasis on contextual and inquiry-driven learning. This supports previous findings that curriculum-aligned IBL interventions are more effective in promoting higher-order thinking and subject-specific competencies (Wilson et al., 2025). Furthermore, the integration of local rainfall patterns empowers students to understand climate change as both a global and a local phenomenon. Such contextualization is critical to ensure the applicability of scientific learning to students' lived realities and future teaching practices.

2.2 Validity and Design Effectiveness of the E-Module

The results from the expert validation phase indicate that the developed e-module meets a high standard of instructional design and content integrity, with an overall validity score of 87.25%. This supports the assertion of (Alyusfitri et al., 2024), who found that e-modules designed with multimedia integration and interactive elements significantly improve both usability and instructional effectiveness. The module's high scores in content, media, and teacher practicality suggest that it not only delivers accurate and pedagogically sound content but also supports classroom implementation.

The multimedia-rich design directly contributes to learner engagement and retention. As supported by Constantinou et al. (2018), interactive elements such as simulations, animations, and digital tools can scaffold scientific understanding, particularly in abstract subjects like climate change. The integration of smartphone-compatible formats and real-world datasets mirrors findings from Alyusfitri et al. (2024), who demonstrated a positive correlation between multimedia integration and student achievement.

The module's effectiveness was further validated through a pretest-posttest evaluation. With an N-Gain score of 0.71, categorized as high, the e-module demonstrates its capacity to significantly improve student understanding. This is in line with (Caretta & Pepa, 2024; Lenzenweger, 2020), who reported similar gains in conceptual mastery through the use of inquiry-based digital modules.

2.3 Impact on Conceptual Understanding and Cognitive Gains

The improvement in pre-service physics teachers' conceptual understanding of climate change confirms the module's cognitive efficacy. The substantial gain from the pretest average of 48.56 to the posttest average of 78.26 demonstrates how structured inquiry, combined with localized datasets, fosters meaningful learning. These outcomes are consistent with those observed in previous IBL interventions, where guided exploration of empirical data led to deep learning and long-term knowledge retention (Constantinou et al., 2024).

This result is particularly significant in teacher education contexts. The literature emphasizes the necessity for teacher training programs to go beyond content transmission and focus on developing analytical and pedagogical reasoning skills (Wilson et al., 2025; Yezierski & Herrington, 2011). The ability to translate scientific phenomena like climate change into instructional practices requires not only subject mastery but also experience with inquiry and contextual adaptation. The module's use of localized rainfall data serves as a bridge between abstract scientific principles and practical teaching applications.

2.4 Development of 4C Competencies

The module's most notable contribution lies in its impact on 4C skill development. The assessment results showing very high performance across all 4C domains reinforce the efficacy of IBL frameworks in fostering essential competencies. This supports findings from Nahar and Machado (2025), who demonstrated that sustained IBL projects in science education significantly improve students' communication, collaboration, creativity, and critical thinking.

Critical thinking was fostered through tasks requiring hypothesis generation, evidence evaluation, and the formulation of conclusions based on rainfall data. According to (Constantinou et al., 2024), such tasks are foundational to developing scientific literacy and critical thinking. The structured guidance provided in the module supported learners in navigating data complexity and refining their reasoning.

Creativity was encouraged through the use of open-ended tasks and design challenges, where learners developed models and environmental scenarios based on changing rainfall patterns. These tasks align with the principles of constructivist learning and reflect earlier findings by (Alyusfitri et al., 2024), who emphasized the importance of creative problem-solving in multimedia-based instruction.

Collaboration was embedded through peer-based discussions, data interpretation groups, and team evaluations. These elements reflect the findings of (Kousloglou et al., 2023), who noted that mobile-technology-supported IBL fosters collaboration through digital interactions and cooperative learning structures. Communication was also strengthened as students were required to present findings, defend conclusions, and respond to peer critiques. As shown by (Nahar & Machado, 2025), such dialogic practices are instrumental in refining both oral and written scientific communication.

These outcomes highlight the module's potential as a tool for holistic teacher preparation. As emphasized by (Yezierski & Herrington, 2011), teacher professional development should focus on cultivating the instructional strategies necessary to teach through inquiry, rather than only about inquiry. The module supports this by providing direct experience with inquiry tasks that mirror authentic classroom situations.

2.5 Implications for Teacher Education and Curriculum Integration

The success of the e-module indicates promising directions for curriculum innovation in teacher education programs. Its structure aligns with emerging pedagogical models that emphasize experiential, student-centered, and competency-based learning. Moreover, its compatibility with digital platforms and mobile access allows for flexible and inclusive use, particularly in regions with limited resources or infrastructure.

This study supports the integration of IBL and digital tools into pre-service teacher education as a means of responding to national and global calls for education that prepares learners for climate action and sustainable development. As stated by Meekaew and Saenkum (2025), climate education must move from abstract content delivery to situated, participatory practices. Embedding real-time and localized climate data into the learning process not only enhances engagement but also equips future educators with the tools to promote environmental literacy and agency.

2.6 Limitations and Future Research Directions

While the module demonstrated effectiveness, some limitations must be acknowledged. The study involved a relatively small and localized sample, which may limit the generalizability of findings. Further studies should replicate the intervention across diverse educational contexts to explore scalability and contextual adaptations. Additionally, while 4C competencies were assessed through rubrics and self-reports, future research could incorporate longitudinal studies to evaluate the retention of these competencies and their transfer to real classroom settings.

Furthermore, professional development for in-service teachers using this module may offer additional insights into its practical application in ongoing school curricula. As suggested by (Wilson et al., 2025), long-term and cross-curricular PD programs enhance both teacher efficacy and student learning outcomes when designed with sustained inquiry and reflection components.

The discussion affirms that the inquiry-based e-module developed in this study is both pedagogically sound and practically applicable. Its foundation in localized climate data and multimedia-driven instruction offers a replicable model for future curriculum design in science teacher education, particularly in addressing climate change and sustainability challenges through education.

CONCLUSION

This study concludes that the development and implementation of an inquiry-based e-module, incorporating local rainfall data, is highly effective in improving both conceptual understanding of climate change and the 4C competencies—critical thinking, creativity, collaboration, and communication—among pre-service physics teachers. The module demonstrated strong validity in terms of content relevance, pedagogical structure, language clarity, and media design, as confirmed by expert evaluations. Significant cognitive gains were observed, with high N-Gain scores reflecting the module's impact on content mastery. Furthermore, the integration of real-world climate data into a guided inquiry framework encouraged meaningful engagement and contextual learning, enabling participants to develop analytical, reflective, and communicative skills relevant for future teaching practice. These findings support the theoretical expectations of inquiry-based learning and reinforce the need for localized, data-driven instruction in science teacher education. By aligning with national curriculum standards and leveraging digital learning environments, the module offers a replicable and scalable model for climate change education. Future research could expand this model across diverse educational contexts and assess its long-term impact on classroom practice. Overall, this study contributes to the growing body of knowledge on climate literacy, digital pedagogy, and the integration of environmental data into teacher training..

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