



Can STEM-PjBL Improve Climate Change Knowledge? The Mediating Role of Science Process Skills in Junior High School Physics

Ning Intan Lestari Apriliza¹, Kullawat Inthaud²

¹Physics Education Study Program, Universitas Sriwijaya, Sumatera Selatan, Indonesia

²Yupparaj Wittayalai School, Chiang Mai, Thailand

Article Info

Article history:

Received Aug 3, 2026

Revised Sep 7, 2026

Accepted Oct 9, 2026

Online First Oct 16, 2026

Keywords:

Climate Change Education

Climate Change Knowledge

Physics Education

Science Process Skills

STEM Project-Based Learning (STEM-PjBL)

ABSTRACT

Purpose of the study: This study examined the relationships among STEM project-based learning (STEM-PjBL) learning experience, science process skills, and climate change knowledge among junior high school students in physics education.

Methodology: A quantitative explanatory correlational design was employed involving 200 junior high school students with prior STEM-PjBL experience. Data were collected using a 16-item STEM-PjBL learning experience questionnaire, a structured observation rubric for science process skills, and a 24-item objective climate change knowledge test. Partial least squares structural equation modeling (PLS-SEM) and bootstrapping were used to evaluate the measurement and structural models and test the hypothesized relationships.

Main Findings: All three hypothesized relationships were positive and statistically significant. STEM-PjBL learning experience had the strongest association with science process skills ($\beta = 0.521$, $p < 0.001$), followed by its association with climate change knowledge ($\beta = 0.219$, $p < 0.001$). Science process skills were also positively associated with climate change knowledge ($\beta = 0.161$, $p < 0.001$). The model explained 27.1% of the variance in science process skills and 44.3% in climate change knowledge.

Novelty/Originality of this study: This study integrates STEM-PjBL learning experience, science process skills, and climate change knowledge within a single PLS-SEM framework. By examining their direct relationships simultaneously, it provides evidence of the relative strength of these associations and highlights the relevance of integrated STEM project experiences and scientific competencies for climate change education without assuming causal effects or an untested mediation mechanism.

This is an open access article under the [CC BY](https://creativecommons.org/licenses/by/4.0/) license



Corresponding Author:

Ning Intan Lestari Apriliza,

Physics Education Study Program, Universitas Sriwijaya,
Indralaya, Ogan Ilir, South Sumatra 30662, Indonesia

Email: ningintanapriliza@gmail.com

1. INTRODUCTION

Climate change has become a critical global challenge that requires students to understand scientific evidence, evaluate environmental problems, and make informed decisions about mitigation and adaptation. Science education can contribute to this effort by connecting scientific concepts with authentic environmental problems and practical solutions [1]-[3]. Physics learning is particularly relevant because energy transfer, thermal processes, and energy consumption are closely associated with climate-related issues [4]-[6]. STEM-integrated project-based learning (STEM-PjBL) offers opportunities to connect scientific inquiry with

Journal homepage: <http://cahaya-ic.com/index.php/SJPE>

technological application, engineering design, and mathematical reasoning [7]-[9]. These integrated experiences may help students develop science process skills while constructing meaningful knowledge about climate change [10], [11]. Consequently, understanding the relationships among STEM-PjBL learning experiences, science process skills, and climate change knowledge is important for strengthening climate-oriented science education.

Despite growing attention to climate change education, students may still hold incomplete or scientifically inaccurate ideas about the greenhouse effect, climate systems, and the causes of global warming. A systematic review by recent researchers identified recurring student difficulties involving global warming, the greenhouse effect, and the carbon cycle, while also highlighting limited research on students' understanding of climate systems and the nature of climate science [12]-[14]. These difficulties suggest that exposure to climate-related content does not necessarily ensure scientifically grounded understanding [15]-[17]. Meanwhile, STEM-PjBL activities require students to observe phenomena, formulate questions, investigate problems, interpret data, and evaluate proposed solutions [18], [19]. However, the extent to which students' experiences of STEM-PjBL are associated with their science process skills and climate change knowledge requires further empirical examination.

An appropriate approach is to examine STEM-PjBL as a multidimensional learning experience rather than merely as the completion of a classroom project. Wan et al. [20] conceptualized STEM-PjBL experience through scientific inquiry, technological application, engineering design, and mathematical processing. These dimensions can be connected to science process skills, including observation, hypothesis formulation, experimental investigation, data interpretation, and scientific communication. For example, students designing an energy-efficient house can investigate thermal conditions, compare construction materials, interpret temperature measurements, and explain how energy efficiency relates to greenhouse gas emissions [21], [22]. Such activities provide a relevant context for examining students' learning experiences, practical scientific skills, and understanding of climate change [23], [24]. A quantitative correlational approach using partial least squares structural equation modeling (PLS-SEM) can estimate the proposed relationships among these constructs without requiring an experimental control group [25]-[27].

Recent research has examined STEM-PjBL experiences, science process skills, and climate change learning, although these topics have often been investigated separately. Wan et al. [20] validated a four-dimensional STEM-PjBL experience scale and demonstrated its relevance to students' STEM-related interests and aspirations. In Indonesia, Peny et al. [28] reported that project-based and problem-based learning approaches could support climate change literacy among junior high school students in disaster-prone areas. Hafitri and Efwinda [29] investigated STEM-PjBL on global warming and examined students' learning outcomes alongside science process skills. Additionally, a systematic review published in 2024 synthesized 44 studies on students' ideas about the scientific foundations of climate change and identified recurring conceptual difficulties and underexplored aspects of climate science [12]. Collectively, these studies provide a foundation for integrating STEM-PjBL experiences, science process skills, and climate change knowledge within a single empirical framework.

Although previous studies provide evidence for the educational relevance of STEM-PjBL, important gaps remain in understanding the relationships among students' learning experiences, science process skills, and climate change knowledge. Research on STEM-PjBL experience has emphasized the structure of learning experiences and their associations with STEM-related interests, rather than specifically examining climate change knowledge [20]. Studies of climate change learning have investigated literacy outcomes, while studies of STEM-PjBL have also examined science process skills and learning outcomes [28]. However, the available studies identified for this introduction do not establish whether perceived STEM-PjBL learning experience is positively associated with science process skills and climate change knowledge simultaneously in junior high school physics education. They also leave a need to examine whether science process skills are directly associated with climate change knowledge within the same structural model [30], [31], [32]. This study addresses these gaps by testing three direct relationships among the three constructs using data from students who have already experienced STEM-PjBL-based learning.

The originality of this study lies in examining STEM-PjBL learning experience, science process skills, and climate change knowledge together within a single PLS-SEM framework. Unlike studies focusing primarily on learning effectiveness or pretest-posttest differences, this research investigates the associations among individual students' reported learning experiences, observed scientific skills, and objectively assessed climate knowledge. It operationalizes STEM-PjBL learning experience through scientific inquiry, technological application, engineering design, and mathematical processing, consistent with the multidimensional approach developed by Wan et al. [20]. Science process skills are assessed through structured observation, while climate change knowledge is measured using an objective test addressing scientific concepts, causes, consequences, and possible responses. The proposed model estimates three direct paths: STEM-PjBL learning experience to science process skills, STEM-PjBL learning experience to climate change knowledge, and science process skills to climate change knowledge. This combination offers a focused empirical contribution without claiming causal effects or assuming an untested mediation mechanism.

The urgency of this study arises from the need for science education to connect scientific understanding with practical investigation of environmental challenges. Junior high school students need opportunities to evaluate evidence, interpret scientific data, and distinguish scientifically supported explanations of climate change from common misconceptions. Examining the relationships among STEM-PjBL learning experience, science process skills, and climate change knowledge can provide evidence to inform the design and evaluation of climate-oriented physics learning. Accordingly, this study aims to analyze the relationships between STEM-PjBL learning experience and science process skills, between STEM-PjBL learning experience and climate change knowledge, and between science process skills and climate change knowledge. The study involves 200 junior high school students who have participated in STEM-PjBL-based learning and uses PLS-SEM to estimate the proposed direct relationships. The findings are expected to inform future instructional design and research while recognizing that a correlational design cannot establish causal effects.

2. RESEARCH METHOD

2.1. Research Design

This study employed a quantitative explanatory correlational design to examine the relationships among STEM-PjBL learning experience, science process skills, and climate change knowledge in junior high school physics education. The study focused on estimating the direct relationships among the three constructs rather than evaluating the causal effects of an instructional intervention. Data were collected from students who had previously participated in STEM-PjBL-based physics learning. Three hypothesized relationships were examined: STEM-PjBL learning experience with science process skills, STEM-PjBL learning experience with climate change knowledge, and science process skills with climate change knowledge. Partial least squares structural equation modeling (PLS-SEM) was used to evaluate the measurement properties of the constructs and estimate the hypothesized structural relationships [33]-[35]. This design was selected because it supports the simultaneous analysis of multiple relationships among latent constructs, subject to appropriate measurement specification and sample adequacy.

2.2. Participants and Sampling

The target population comprised junior high school students who had participated in STEM-PjBL-based physics learning. A target sample of 200 students was established for the analysis. Participants were selected using purposive sampling based on their prior experience with STEM-PjBL activities and their ability to complete the study instruments. The eligibility criteria included enrollment in junior high school, participation in a physics learning activity involving STEM-PjBL, and completion of the required research instruments. Students who did not meet the eligibility criteria or submitted substantially incomplete responses were excluded from the analysis. The final sample characteristics, including grade level, age distribution, gender, school representation, and prior STEM-PjBL experience, will be reported after the data have been verified.

2.3. Research Variables and Conceptual Model

The study examined three constructs: STEM-PjBL learning experience (X), science process skills (M), and climate change knowledge (Y). STEM-PjBL learning experience represented students' perceptions of their participation in integrated science, technology, engineering, and mathematics learning activities. Science process skills represented students' observable performance when conducting scientific investigations and interpreting evidence. Climate change knowledge represented students' demonstrated understanding of climate-related scientific concepts, causes, consequences, mitigation, and adaptation. The model specified three direct relationships among these constructs, as presented in Table 1.

Table 1. Research variables, operational definitions, and measurement methods

Variable	Operational definition	Dimensions	Measurement	Literature sources
STEM-PjBL Learning Experience (X)	Students' perceived experience of integrated STEM project-based learning	Scientific inquiry; technological application; engineering design; mathematical processing	16-item questionnaire, four-point Likert scale	Wan et al. [20]
Science Process Skills (M)	Students' observable performance in conducting scientific inquiry and interpreting evidence	Observation; question formulation; hypothesis formulation; experimental design; data collection and measurement; data interpretation; conclusion and	Observation rubric, four-point rating scale	Rosana et al. [36] and Darmaji et al. [37]

Variable	Operational definition	Dimensions	Measurement	Literature sources
Climate Change Knowledge (Y)	Students' demonstrated understanding of climate science and responses to climate change	scientific communication Greenhouse effect and climate system; causes; consequences; carbon footprint and mitigation; scientific evidence; collective mitigation and adaptation	24-item objective test, scored 1 for correct and 0 for incorrect responses	Labonté & Champagne St-Arnaud [17]

The proposed model was evaluated through three direct hypotheses:

- H1: STEM-PjBL learning experience is positively associated with science process skills.
- H2: STEM-PjBL learning experience is positively associated with climate change knowledge.
- H3: Science process skills are positively associated with climate change knowledge.

Science process skills were included as an explanatory construct with a direct path to climate change knowledge, not as a hypothesized mediator. Accordingly, no indirect-effect hypothesis was specified.

2.4. Research Instruments

Three instruments were used to measure the study variables. The STEM-PjBL learning experience questionnaire was designed to capture students' perceptions of scientific inquiry, technological application, engineering design, and mathematical processing. It contained 16 proposed items, with four items allocated to each dimension. Responses were recorded on a four-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree). Science process skills were assessed using a structured observation rubric containing 23 proposed indicators across seven dimensions: observation (3 indicators), question formulation (3), hypothesis formulation (3), experimental design and implementation (4), data collection and measurement (3), data interpretation and analysis (4), and conclusion and scientific communication (3). Each indicator was rated on a four-point scale, with behaviorally anchored descriptions distinguishing levels of performance. Observations were conducted during comparable STEM-PjBL activities, and individual student scores were calculated using a consistent scoring procedure.

Climate change knowledge was assessed using a proposed 24-item objective test, with four items allocated to each of six dimensions: greenhouse effect and climate system, climate change causes, climate change consequences, carbon footprint and individual mitigation, climate science and evidence, and collective mitigation and adaptation. Each correct answer received one point, whereas an incorrect answer received zero points. The test was intended to assess scientific understanding rather than students' self-reported confidence or perceived knowledge. The instruments were developed or adapted from relevant literature and aligned with the study context. Any adaptation of existing instruments was reviewed for linguistic suitability, age appropriateness, and conceptual relevance to Indonesian junior high school students. The proposed item counts represent the initial instrument blueprint; the final item counts should be reported only after expert review and pilot testing.

2.5. Instrument Validity and Reliability

Before the main data collection, the instruments were subjected to content review by experts in science education, physics education, and educational assessment. The review examined construct alignment, scientific accuracy, clarity of wording, age appropriateness, and suitability for the intended learning context. Feedback was used to revise ambiguous statements, improve the observation rubric, and ensure that the climate change test reflected accepted scientific explanations. A pilot study was then conducted with students who had characteristics comparable to those of the target participants but who were not included in the main analysis, where feasible. Pilot results were used to examine item clarity, response patterns, item difficulty, item discrimination, and preliminary reliability.

For the questionnaire, measurement quality was evaluated using indicator loadings, composite reliability, and average variance extracted where reflective measurement was theoretically appropriate. Discriminant validity was assessed using the heterotrait–monotrait ratio (HTMT). The observation rubric required clear performance anchors and, where more than one observer was involved, an assessment of inter-rater agreement or reliability. The objective climate change test was evaluated through item-level analysis and appropriate evidence of content validity and score reliability. Because objective test items may represent distinct areas of knowledge rather than interchangeable manifestations of a single latent trait, their measurement specification was determined from the construct definition and item structure instead of automatically treating every item as a reflective indicator. Correction to the observation rubric specification: the conclusion and scientific communication dimension should contain four indicators, not three. The intended total is therefore 24 indicators across seven dimensions, consistent with the initial instrument blueprint.

2.6. Data Collection Procedure

Data collection was conducted after the participating students had experienced STEM-PjBL-based physics learning. The learning context involved a project such as designing an energy-efficient house model to investigate thermal conditions, compare building materials, and discuss the relationship between energy consumption and greenhouse gas emissions. The project provided a common contextual reference for the three constructs, while the study itself remained correlational rather than experimental. Students completed the STEM-PjBL learning experience questionnaire and the climate change knowledge test, while their science process skills were assessed using the structured observation rubric during relevant learning activities. Instrument administration and observation procedures were standardized to minimize differences arising from instructions, timing, and scoring. Data were checked for completeness, coding accuracy, and consistency before statistical analysis. The project context requires an important scientific distinction: a lower temperature inside a model house demonstrates the thermal performance of that model under the tested conditions; it does not directly demonstrate a reduction in global temperature. The connection to climate change was therefore addressed through scientific explanations of energy demand, energy sources, and greenhouse gas emissions.

2.7. Data Analysis

Data analysis was conducted using a staged procedure. First, descriptive statistics were calculated to summarize participant characteristics and the distributions of the measured variables. Second, the dataset was screened for missing values, implausible responses, coding errors, and potential outliers. Third, the measurement properties of the questionnaire and latent constructs were evaluated before interpreting the structural model.

PLS-SEM was used to estimate the three hypothesized direct relationships. For reflective constructs, indicator reliability, internal consistency, convergent validity, and discriminant validity were examined using outer loadings, composite reliability, average variance extracted, and HTMT, respectively. Measurement specifications for the objective climate change test and the observation-based science process skills scores were determined according to their theoretical structure; formative or composite specifications were considered where the indicators represented distinct components rather than interchangeable manifestations of a latent construct.

The structural model was evaluated by examining path coefficients, bootstrapped confidence intervals, t-statistics, and p-values. Statistical significance was interpreted alongside the direction and magnitude of each estimated relationship. The coefficients of determination (R^2) were reported to describe the variance explained in the endogenous constructs, while effect sizes (f^2) were used to assess the relative contribution of individual predictors. Predictive relevance or out-of-sample predictive performance was evaluated where appropriate to the model and analytical objective. A significance level of 0.05 was used as a reference for hypothesis testing, and the number of bootstrap resamples and software version were documented in the final manuscript.

The three hypotheses were evaluated independently: H1 tested the relationship between STEM-PjBL learning experience and science process skills; H2 tested the relationship between STEM-PjBL learning experience and climate change knowledge; and H3 tested the relationship between science process skills and climate change knowledge. No mediation analysis was specified. Because the data were observational, the estimated paths were interpreted as statistical associations rather than evidence of causal effects.

2.8. Ethical Considerations

The study followed applicable institutional requirements for research involving school students. Permission was obtained from the relevant educational authorities and participating schools before data collection. Informed consent was obtained from parents or legal guardians, and student assent was obtained in an age-appropriate manner. Participation was voluntary, and students were informed that their decision to participate or withdraw would not affect their academic assessment. Data were anonymized or pseudonymized, stored securely, and used only for the stated research purposes. The final manuscript should identify the approving ethics committee and approval number, if applicable, and accurately report the consent procedures implemented in the study.

3. RESULTS AND DISCUSSION

3.1. Evaluation of the Measurement Model

The measurement model was first evaluated through indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. The outer loading results showed that all indicators exceeded the recommended threshold of 0.70. For the STEM-PjBL Learning Experience construct, the outer loadings ranged from 0.745 to 0.884. The Science Process Skills indicators showed loadings ranging from 0.817

to 0.876, while the Climate Change Knowledge indicators ranged from 0.844 to 0.890. These results indicate that all indicators demonstrated adequate indicator reliability and were retained for subsequent analysis.

Table 1. Outer Loading of the Measurement Model

Construct	Number of indicators	Outer loading range
STEM-PjBL Learning Experience	16	0.745–0.884
Science Process Skills	24	0.817–0.876
Climate Change Knowledge	24	0.765–0.881

Note: All indicators exceeded the 0.70 criterion.

Internal consistency and convergent validity were assessed using Cronbach's alpha, composite reliability, and average variance extracted (AVE). The results showed that Cronbach's alpha values ranged from 0.977 to 0.983, while composite reliability values ranged from 0.979 to 0.984. The AVE values were 0.745 for STEM-PjBL Learning Experience, 0.720 for Science Process Skills, and 0.689 for Climate Change Knowledge. Thus, all constructs demonstrated satisfactory internal consistency and convergent validity.

Table 2. Construct Reliability and Convergent Validity

Construct	Cronbach's Alpha	Composite Reliability	AVE
STEM-PjBL Learning Experience	0.977	0.979	0.745
Science Process Skills	0.983	0.984	0.720
Climate Change Knowledge	0.980	0.981	0.689

3.2. Discriminant Validity

Discriminant validity was assessed using the heterotrait–monotrait ratio (HTMT). The HTMT values among the three constructs ranged from 0.525 to 0.616. Specifically, the HTMT value between STEM-PjBL Learning Experience and Science Process Skills was 0.525, between STEM-PjBL Learning Experience and Climate Change Knowledge was 0.616, and between Science Process Skills and Climate Change Knowledge was 0.556. The upper bounds of the confidence intervals were below 0.708, indicating adequate discriminant validity among the constructs.

Table 3. HTMT Results

Construct Relationship	HTMT	97.5% CI
STEM-PjBL Learning Experience ↔ Science Process Skills	0.525	0.619
STEM-PjBL Learning Experience ↔ Climate Change Knowledge	0.616	0.708
Science Process Skills ↔ Climate Change Knowledge	0.556	0.646

3.3. Structural Model and Hypothesis Testing

After establishing the adequacy of the measurement model, the structural model was evaluated using path coefficients, t-statistics, and p-values obtained through bootstrapping. All three hypothesized relationships were statistically significant at the 0.05 level. The results of the PLS-SEM algorithm are presented in Figure 1, illustrating the outer loadings of the measurement indicators, the path coefficients between constructs, and the coefficients of determination (R^2) of the endogenous constructs.

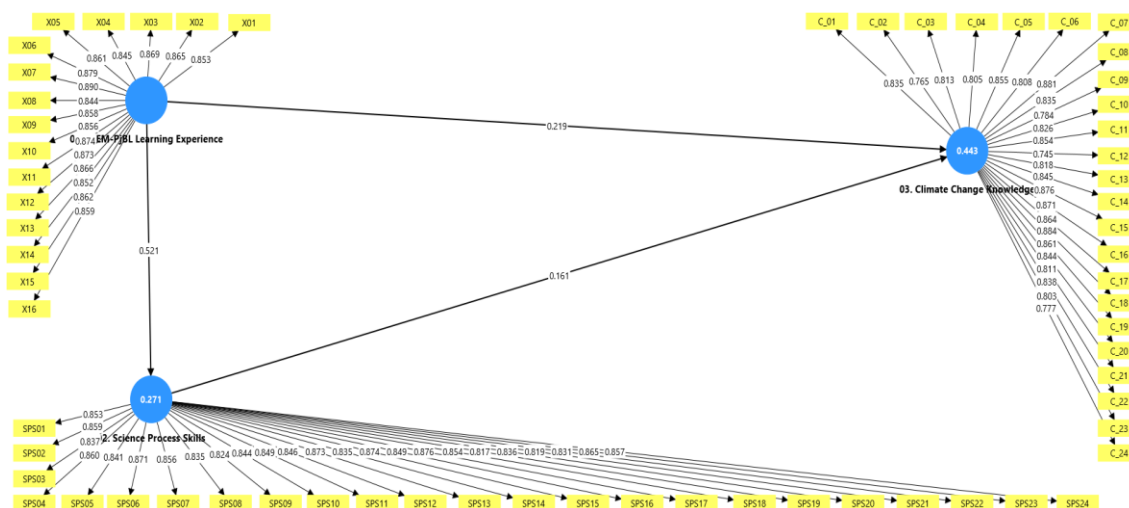


Figure 1. PLS-SEM Algorithm Results of the Measurement and Structural Models

Figure 1 presents the results of the PLS-SEM algorithm, including the outer loadings, structural path coefficients, and coefficients of determination (R^2). The path coefficient from STEM-PjBL Learning Experience to Science Process Skills was 0.521, while the path coefficient from STEM-PjBL Learning Experience to Climate Change Knowledge was 0.219. Science Process Skills also showed a positive relationship with Climate Change Knowledge, with a path coefficient of 0.161. The coefficient of determination was 0.271 for Science Process Skills and 0.443 for Climate Change Knowledge, indicating that the model explained 27.1% and 44.3% of the variance in these constructs, respectively.

To determine the statistical significance of the hypothesized relationships, a bootstrapping procedure was performed. Figure 2 presents the bootstrapping results, which provide the basis for evaluating the significance of the structural paths in the proposed model.

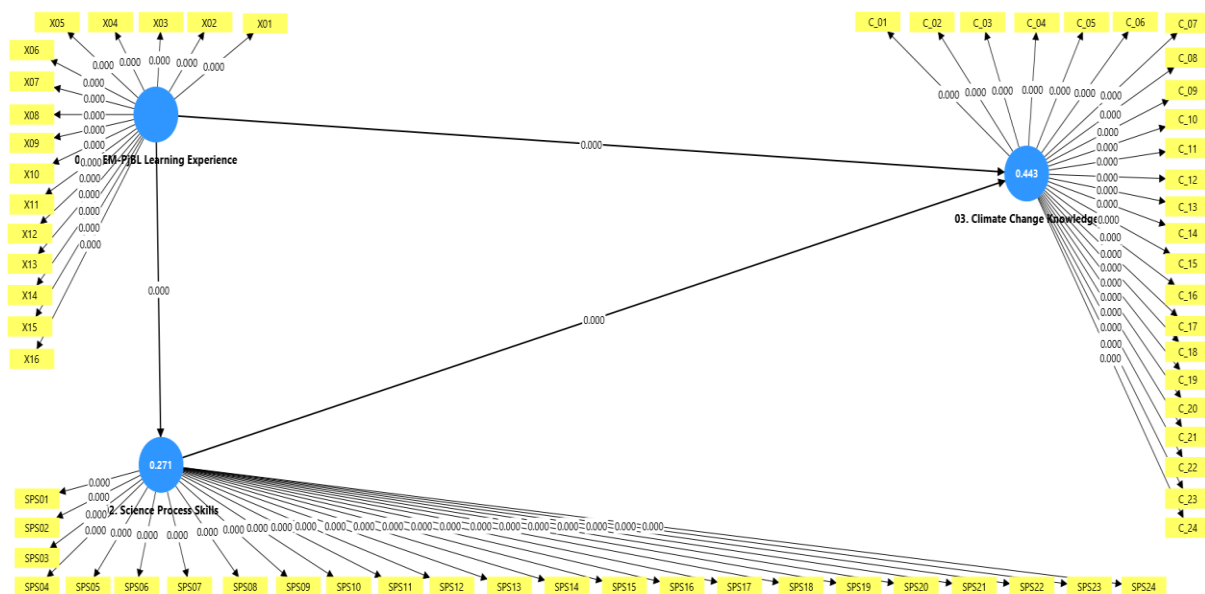


Figure 2. Bootstrapping Results of the Structural Model

Figure 2 presents the bootstrapping results used to assess the statistical significance of the hypothesized relationships. The p-values displayed on the structural paths were 0.000, which should be reported as $p < 0.001$. These results indicate that the relationships among STEM-PjBL Learning Experience, Science Process Skills, and Climate Change Knowledge were statistically significant at the 5% significance level. The detailed path coefficients, t-statistics, and p-values are presented in Table 4.

The first hypothesis (H1), concerning the relationship between STEM-PjBL Learning Experience and Science Process Skills, was supported. The path coefficient was $\beta = 0.521$, with a t-value of 10.498 and $p < 0.001$. This indicates a positive and statistically significant association between students' STEM-PjBL learning experience and their science process skills. The second hypothesis (H2), concerning the relationship between STEM-PjBL Learning Experience and Climate Change Knowledge, was also supported. The path coefficient was $\beta = 0.219$, with a t-value of 6.429 and $p < 0.001$, indicating a positive and statistically significant association between the two constructs. The third hypothesis (H3), examining the relationship between Science Process Skills and Climate Change Knowledge, was supported. The analysis produced a path coefficient of $\beta = 0.161$, $t = 4.856$, and $p < 0.001$, demonstrating a positive and statistically significant association.

Table 4. Structural Model and Hypothesis Testing

Hypothesis	Relationship	β	t-value	p-value	Decision
H1	STEM-PjBL $\rightarrow$ Science Process Skills	0.521	10.498	<0.001	Supported
H2	STEM-PjBL $\rightarrow$ Climate Change Knowledge	0.219	6.429	<0.001	Supported
H3	Science Process Skills $\rightarrow$ Climate Change Knowledge	0.161	4.856	<0.001	Supported

Among the three relationships, STEM-PjBL Learning Experience $\rightarrow$ Science Process Skills produced the largest standardized path coefficient ($\beta = 0.521$), indicating that this relationship was the strongest direct association in the proposed structural model.

3.4. Coefficient of Determination

The explanatory power of the structural model was assessed using the coefficient of determination (R^2). Science Process Skills obtained an R^2 value of 0.271, indicating that 27.1% of its variance was explained by STEM-PjBL Learning Experience. Meanwhile, Climate Change Knowledge obtained an R^2 value of 0.443, indicating that 44.3% of its variance was jointly explained by STEM-PjBL Learning Experience and Science Process Skills.

Table 5. Coefficient of Determination

Endogenous Construct	R^2	Explained Variance
Science Process Skills	0.271	27.1%
Climate Change Knowledge	0.443	44.3%

Thus, the model explained a greater proportion of variance in Climate Change Knowledge than in Science Process Skills.

3.5. Effect Size

The effect size analysis indicated that STEM-PjBL Learning Experience had an f^2 of 0.372 on Science Process Skills, an f^2 of 0.252 on Climate Change Knowledge, while Science Process Skills had an f^2 of 0.136 on Climate Change Knowledge. All three effects were statistically significant based on the bootstrapping results. Hasil analisis SEM PLS

Table 6. Effect Size of the Structural Relationships

Relationship	f^2	p-value
STEM-PjBL → Science Process Skills	0.372	<0.001
STEM-PjBL → Climate Change Knowledge	0.252	0.007
Science Process Skills → Climate Change Knowledge	0.136	0.024

The largest effect size was observed for the relationship between STEM-PjBL Learning Experience and Science Process Skills ($f^2 = 0.372$), followed by the effect of STEM-PjBL Learning Experience on Climate Change Knowledge ($f^2 = 0.252$).

The findings reveal three important relationships among STEM-PjBL Learning Experience, Science Process Skills, and Climate Change Knowledge. STEM-PjBL Learning Experience had the strongest direct relationship with Science Process Skills ($\beta = 0.521$, $t = 10.498$, $p < 0.001$). This finding suggests that students' engagement in integrated, project-oriented science learning is closely associated with their science process skills. STEM-PjBL activities may provide opportunities for students to formulate questions, investigate problems, interpret evidence, and develop solutions. Furthermore, STEM-PjBL Learning Experience was positively associated with Climate Change Knowledge ($\beta = 0.219$, $t = 6.429$, $p < 0.001$), while Science Process Skills also showed a positive relationship with Climate Change Knowledge ($\beta = 0.161$, $t = 4.856$, $p < 0.001$). The model explained 27.1% of the variance in Science Process Skills and 44.3% of the variance in Climate Change Knowledge. These findings indicate that the proposed model accounted for a greater proportion of variance in Climate Change Knowledge than in Science Process Skills. However, the remaining unexplained variance suggests that other factors may also be associated with these learning outcomes.

The positive relationship between STEM-PjBL Learning Experience and Science Process Skills is consistent with Markula and Aksela [1], who identified scientific investigation, collaboration, presentation of findings, and reflection as important characteristics of project-based learning in K–12 science education. These learning activities provide a plausible explanation for the strong association observed in the present study. In addition, Lu et al. [38], through an umbrella review of 22 meta-analyses, reported generally positive learning outcomes associated with STEM education. The present study complements this broader evidence by examining the specific relationship between STEM-PjBL Learning Experience and Science Process Skills within a single structural model. The path coefficient of 0.521 indicates that this was the strongest direct relationship among the three relationships examined.

The relationship between STEM-PjBL Learning Experience and Climate Change Knowledge is also relevant to previous research on climate change education. DeWaters et al. [39] examined project-based learning modules designed to improve climate literacy through educational activities that combine rigor and relevance. Their work highlights the importance of connecting climate-related content with meaningful learning experiences. Similarly, Kurup et al. [40] investigated high school students' informed decision-making regarding global warming and climate change, emphasizing the relevance of science education to students' understanding of climate issues. More recently, Kundariati et al. [41] examined problem-oriented project-based learning in secondary-school climate change education. These studies provide a relevant context for interpreting the positive relationship between STEM-PjBL Learning Experience and Climate Change Knowledge in the present study (β

= 0.219). Nevertheless, the current findings represent an association and should not be interpreted as definitive evidence of a causal effect.

The relationship between Science Process Skills and Climate Change Knowledge further highlights the relevance of scientific competencies in climate-related learning. Scientific processes, such as examining evidence, interpreting information, and evaluating explanations, may help students develop a more informed understanding of climate change. The findings of Kurup et al. [40] provide a relevant perspective because their study addressed students' understanding and decision-making regarding global warming and climate change. However, the path coefficient for Science Process Skills and Climate Change Knowledge in the present study was relatively smaller ($\beta = 0.161$) than the coefficient for STEM-PjBL Learning Experience and Science Process Skills ($\beta = 0.521$). This difference suggests that the relationship between learning experience and scientific skills was more pronounced than the direct relationship between scientific skills and climate knowledge in the proposed model. Further research is needed to examine whether science process skills mediate the relationship between STEM-PjBL Learning Experience and Climate Change Knowledge.

The novelty of this study lies in the integration of STEM-PjBL Learning Experience, Science Process Skills, and Climate Change Knowledge within a single PLS-SEM framework. Rather than examining these constructs separately, the study simultaneously evaluates their direct relationships and compares their relative strengths. The results identify STEM-PjBL Learning Experience as the construct with the strongest direct relationship with Science Process Skills, while both STEM-PjBL Learning Experience and Science Process Skills were positively associated with Climate Change Knowledge. In addition, the model explained 44.3% of the variance in Climate Change Knowledge. These findings provide empirical evidence concerning how students' STEM-PjBL learning experiences and scientific competencies are associated with climate-related knowledge. The contribution of the study therefore lies in the integration and quantitative examination of these relationships within the investigated context.

The findings have implications for science teaching and curriculum design. For teachers, the strong relationship between STEM-PjBL Learning Experience and Science Process Skills highlights the importance of providing learning activities that engage students in investigating authentic problems, collecting and interpreting data, evaluating evidence, and communicating solutions. Climate change can serve as a meaningful context for these activities because it connects scientific concepts with environmental challenges. For curriculum designers, the findings support the integration of STEM-oriented projects with explicit climate learning objectives. Project activities should be accompanied by accurate scientific explanations, evidence-based discussions, and opportunities for students to evaluate climate-related information. The positive relationship between Science Process Skills and Climate Change Knowledge also suggests that scientific competencies should be considered when designing climate change learning activities. For researchers, the findings provide a basis for further investigations into potential mediating mechanisms, additional explanatory variables, and the influence of different instructional approaches on climate-related learning outcomes.

The findings should be interpreted in light of the methodological scope of the study. The measurement model demonstrated satisfactory indicator reliability, internal consistency, convergent validity, and discriminant validity based on the reported results. Nevertheless, satisfactory measurement properties do not automatically establish the generalizability of the structural relationships. The available results do not provide sufficient information about the sampling strategy, sample size, or geographical distribution of participants to determine the extent to which the findings can be generalized to other student populations. Furthermore, PLS-SEM estimates statistical relationships among constructs but does not, by itself, establish causality. The model explained 27.1% of the variance in Science Process Skills and 44.3% of the variance in Climate Change Knowledge, indicating that other factors may also be relevant. Future studies should replicate the model with more diverse student samples, provide detailed information about sampling and instructional implementation, and consider longitudinal or quasi-experimental designs to investigate changes over time. Additional analyses of indirect effects and other explanatory variables may also help clarify the relationships among STEM-PjBL Learning Experience, Science Process Skills, and Climate Change Knowledge.

4. CONCLUSION

This study examined the relationships among STEM-PjBL learning experience, science process skills, and climate change knowledge among junior high school students in physics education. The PLS-SEM results demonstrated that all three hypothesized relationships were positive and statistically significant. STEM-PjBL learning experience had the strongest association with science process skills ($\beta = 0.521$, $p < 0.001$), followed by its association with climate change knowledge ($\beta = 0.219$, $p < 0.001$), while science process skills were also positively associated with climate change knowledge ($\beta = 0.161$, $p < 0.001$). The model explained 27.1% of the variance in science process skills and 44.3% of the variance in climate change knowledge. These findings highlight the relevance of integrating STEM-oriented project experiences, scientific investigation, and evidence-based climate learning in junior high school physics education. Future research should employ longitudinal or

quasi-experimental designs to examine changes in students' science process skills and climate change knowledge and to establish stronger evidence regarding the effects of STEM-PjBL. Further studies should also investigate potential mediating mechanisms and additional factors, such as prior scientific knowledge, environmental attitudes, and climate literacy, using more diverse student populations.

ACKNOWLEDGEMENTS

The authors would like to thank the participating schools and students for their cooperation and contribution to this study. The authors also acknowledge the support of all individuals who contributed to the research process. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

- [1] A. Markula and M. Aksela, "The key characteristics of project-based learning: How teachers implement projects in K-12 science education," *Discip. Interdiscip. Sci. Educ. Res.*, vol. 4, no. 1, p. 2, 2022, doi: 10.1186/s43031-021-00042-x.
- [2] A. Rumjaun and F. Narod, "Social Learning Theory—Albert Bandura BT - Science Education in Theory and Practice: An Introductory Guide to Learning Theory," B. Akpan and T. J. Kennedy, Eds., Cham: Springer Nature Switzerland, 2025, pp. 65–82. doi: 10.1007/978-3-031-81351-1_5.
- [3] T. Tanti, D. A. Kurniawan, K. Kuswanto, W. Utami, and I. Wardhana, "Science process skills and critical thinking in science: Urban and rural disparity," *J. Pendidik. IPA Indones.*, vol. 9, no. 4, 2020, doi: 10.15294/jpii.v9i4.24139.
- [4] S. Syahrial *et al.*, "Content analysis of student learning videos for teacher professional education programs based on Gagne's learning theory," *J. Ilm. Pendidik. Profesi Guru*, vol. 7, no. 3, pp. 552–563, 2024, doi: 10.23887/jippg.v7i3.84354.
- [5] Z. Ma, G. Jiang, and J. Chen, "Physics-informed ensemble learning with residual modeling for enhanced building energy prediction," *Energy Build.*, vol. 323, p. 114853, 2024, doi: <https://doi.org/10.1016/j.enbuild.2024.114853>.
- [6] T. Tanti, D. A. Kurniawan, N. Kurniawan, and L. Anggraini, "Attitudes toward science based on analysis and correlation: Learning enjoyment & leisure interest on science," *Form. J. Ilm. Pendidik. MIPA*, vol. 11, no. 1, 2021, doi: 10.30998/formatif.v11i1.5142.
- [7] R. S. Retno, P. Purnomo, A. Hidayat, and A. Mashfufah, "Conceptual framework design for STEM-integrated project-based learning (PjBL-STEM) for elementary schools," *Asian Educ. Dev. Stud.*, vol. 14, no. 3, pp. 579–604, May 2025, doi: 10.1108/AEDS-08-2024-0188.
- [8] R. A. Rochim, P. Prabowo, M. Budiyo, E. Hariyono, and B. K. Prahani, "The use of STEM-integrated project-based learning models to improve learning outcomes of junior high school students," in *Proceedings of the Eighth Southeast Asia Design Research (SEA-DR) & the Second Science, Technology, Education, Arts, Culture, and Humanity (STEACH) International Conference (SEADR-STEACH 2021)*, Atlantis Press, 2022, pp. 211–218. doi: 10.2991/assehr.k.211229.034.
- [9] D. A. Kurniawan, A. Astalini, Darmaji, Tanti, and S. Maryani, "Innovative learning: Gender perception of e-module linear equations in mathematics and physics," *Indones. J. Learn. Adv. Educ.*, vol. 4, no. 2, pp. 92–106, 2022, doi: 10.23917/ijolae.v4i2.16610.
- [10] R. Megawati, "Integration of project-based learning in science, technology, engineering, and mathematics to improve students' biology practical skills in higher education: A systematic review," *Open Educ. Stud.*, vol. 6, no. 1, p. 20240049, 2024, doi: 10.1515/edu-2024-0049.
- [11] M. Nuswowati, "Mapping research trends on STEM-integrated project-based learning in physics education: A bibliometric review," *J. Educ. Learn.*, vol. 19, no. 4, pp. 1859–1872, 2025, doi: 10.11591/edulearn.v19i4.22999.
- [12] S. Wildbichler, C. Haagen-Schützenhöfer, and T. Schubatzky, "Students' ideas about the scientific underpinnings of climate change: a systematic review of the literature," *Stud. Sci. Educ.*, vol. 61, no. 1, pp. 117–169, Jan. 2025, doi: 10.1080/03057267.2024.2395206.
- [13] R. D. Handayani and Triyanto, "Seventh-grade students' conceptions of climate change, global warming, and the greenhouse effect," *J. Geosci. Educ.*, vol. 70, no. 4, pp. 490–500, Oct. 2022, doi: 10.1080/10899995.2021.1989941.
- [14] T. Schubatzky, C. Haagen-Schützenhöfer, R. Wackermann, C. Wöhlke, and S. Wildbichler, "Navigating the complexities of student understanding: Exploring the coherency of students' conceptions about the greenhouse effect," *Sci. Educ.*, vol. 108, no. 4, pp. 1134–1161, Jul. 2024, doi: 10.1002/sce.21867.
- [15] K. Goniewicz, F. M. Burkle, and A. Khorram-Manesh, "Transforming global public health: Climate collaboration, political challenges, and systemic change," *J. Infect. Public Health*, vol. 18, no. 1, p. 102615, 2025, doi: <https://doi.org/10.1016/j.jiph.2024.102615>.
- [16] E. Gaisie and P. B. Cobbinah, "Planning for context-based climate adaptation: Flood management inquiry in Accra," *Environ. Sci. Policy*, vol. 141, pp. 97–108, 2023, doi: <https://doi.org/10.1016/j.envsci.2023.01.002>.
- [17] K. Labonté and V. C. St-Arnaud, "Development and validation of MACK-12: A short multidimensional climate knowledge scale," *PLOS Clim.*, vol. 4, no. 11, p. e0000600, Nov. 2025, doi: 10.1371/journal.pclm.0000600.
- [18] D. Pramesti, R. M. Probosari, and N. Y. Indiyanti, "Effectiveness of project based learning low carbon STEM and discovery learning to improve creative thinking skills," *J. Innov. Educ. Cult. Res.*, vol. 3, no. 3, pp. 445–456, 2022, doi: 10.46843/jiecr.v3i3.156.
- [19] C.-C. Chang and Y.-K. Chen, "Educational values and challenges of i-STEM project-based learning: A mixed-methods study with data-transformation design," *Front. Psychol.*, vol. 13, 2022, doi: 10.3389/fpsyg.2022.976724.
- [20] Z. H. Wan, W. M. W. So, and Y. Zhan, "Developing and validating a scale of STEM project-based learning experience," *Res. Sci. Educ.*, vol. 52, no. 2, pp. 599–615, 2022, doi: 10.1007/s11165-020-09965-3.

- [21] D. S. Vijayan, A. Sivasuriyan, P. Patchamuthu, and R. Jayaseelan, "Thermal performance of energy-efficient buildings for sustainable development," *Environ. Sci. Pollut. Res.*, vol. 29, no. 34, pp. 51130–51142, 2022, doi: 10.1007/s11356-021-17602-3.
- [22] M. Lackner *et al.*, "Energy Efficiency: Comparison of Different Systems and Technologies BT - Handbook of Climate Change Mitigation and Adaptation," M. Lackner, B. Sajjadi, and W.-Y. Chen, Eds., Cham: Springer Nature Switzerland, 2025, pp. 515–613. doi: 10.1007/978-3-031-84483-6_24.
- [23] G. B. Petersen, S. Klingenberg, R. E. Mayer, and G. Makransky, "The virtual field trip: Investigating how to optimize immersive virtual learning in climate change education," *Br. J. Educ. Technol.*, vol. 51, no. 6, pp. 2099–2115, Nov. 2020, doi: <https://doi.org/10.1111/bjet.12991>.
- [24] J. Bentz, "Learning about climate change in, with and through art," *Clim. Change*, vol. 162, no. 3, pp. 1595–1612, 2020, doi: 10.1007/s10584-020-02804-4.
- [25] R. R. Mohammadi, M. Saeidi, and A. Abdollahi, "Modelling the interrelationships among self-regulated learning components, critical thinking and reading comprehension by PLS-SEM: A mixed methods study," *System*, vol. 117, p. 103120, 2023, doi: 10.1016/j.system.2023.103120.
- [26] S. Kono and M. Sato, "The potentials of partial least squares structural equation modeling (PLS-SEM) in leisure research," *J. Leis. Res.*, vol. 54, no. 3, pp. 309–329, May 2023, doi: 10.1080/00222216.2022.2066492.
- [27] J. Hair and A. Alamer, "Partial Least Squares Structural Equation Modeling (PLS-SEM) in second language and education research: Guidelines using an applied example," *Res. Methods Appl. Linguist.*, vol. 1, no. 3, p. 100027, 2022, doi: <https://doi.org/10.1016/j.rmal.2022.100027>.
- [28] A. A. D. Peny, A. Widodo, and R. Solihat, "Project-based learning and problem-based learning in improving climate change literacy of junior high school students in disaster-prone areas," *J. Pendidik. MIPA*, vol. 23, no. April, pp. 692–700, 2022, doi: 10.23960/jpmipa/v23i2.pp692-700.
- [29] M. L. Hafitri and S. Efwinda, "Enhancing students' learning outcomes and science process skills through STEM project-based learning on global warming topics," *J. Penelit. Pengemb. Pendidik. Fis.*, vol. 10, no. 1 SE-Articles, pp. 147–160, Jun. 2024, doi: 10.21009/1.10113.
- [30] S. Feng, M. W. Mohd Shafiei, T. F. Ng, J. Ren, and Y. Jiang, "The intersection of economic growth and environmental sustainability in China: Pathways to achieving SDG," *Energy Strateg. Rev.*, vol. 55, p. 101530, 2024, doi: <https://doi.org/10.1016/j.esr.2024.101530>.
- [31] B. K. Singh *et al.*, "Climate change impacts on plant pathogens, food security and paths forward," *Nat. Rev. Microbiol.*, vol. 21, no. 10, pp. 640–656, 2023, doi: 10.1038/s41579-023-00900-7.
- [32] L. Mehner, S. Rothenbusch, and S. Kauffeld, "How to maximize the impact of workplace training: a mixed-method analysis of social support, training transfer and knowledge sharing," *Eur. J. Work Organ. Psychol.*, vol. 34, no. 2, pp. 201–217, Mar. 2025, doi: 10.1080/1359432X.2024.2319082.
- [33] S. A. Bozkurt, S. Aydoğan, F. Dursun Ergezen, and A. Türkoğlu, "A systematic review and sequential explanatory synthesis: Artificial intelligence in healthcare education, a case of nursing," *Int. Nurs. Rev.*, vol. 72, no. 2, p. e70018, Jun. 2025, doi: <https://doi.org/10.1111/inr.70018>.
- [34] N. Sardana, S. Shekoohi, E. M. Cornett, and A. D. Kaye, "Chapter 6 - Qualitative and quantitative research methods," A. D. Kaye, R. D. Urman, E. M. Cornett, and A. N. B. T.-S. U. and A. R. Edinoff, Eds., Academic Press, 2023, pp. 65–69. doi: <https://doi.org/10.1016/B978-0-323-98814-8.00008-1>.
- [35] C. Q. Nguyen, A. M. T. Nguyen, and L. Ba Le, "Using partial least squares structural equation modeling (PLS-SEM) to assess the effects of entrepreneurial education on engineering students's entrepreneurial intention," *Cogent Educ.*, vol. 9, no. 1, p. 2122330, Dec. 2022, doi: 10.1080/2331186X.2022.2122330.
- [36] D. Rosana, M. Ramadani, and K. Dewi, "The instrument for assessing the performance of science process skills based on Nature of Science (NOS)," *J. Cakrawala Pendidik.*, vol. 36, no. 3, pp. 435–445, 2017, doi: 10.21831/cp.v36i3.14731.
- [37] D. Darmaji, A. Astalini, D. A. Kurniawan, and E. Triani, "The effect of science process skills of students argumentation skills," *J. Inov. Pendidik. IPA*, vol. 8, no. 1, pp. 78–88, Jun. 2022, doi: 10.21831/jipi.v8i1.49224.
- [38] J. Lu, H. Si, J. Xu, and T. Xu, "An overview of applications and trends of STEM for learning effectiveness—An umbrella review based on 22 meta-analyses," *Educ. Res. Rev.*, vol. 48, p. 100712, 2025, doi: <https://doi.org/10.1016/j.edurev.2025.100712>.
- [39] J. E. DeWaters, C. Andersen, A. Calderwood, and S. E. Powers, "Improving climate literacy with project-based modules rich in educational rigor and relevance," *J. Geosci. Educ.*, vol. 62, no. 3, pp. 469–484, Sep. 2014, doi: 10.5408/13-056.1.
- [40] P. M. Kurup, R. Levinson, and X. Li, "Informed-decision regarding global warming and climate change among high school students in the United Kingdom," *Can. J. Sci. Math. Technol. Educ.*, vol. 21, no. 1, pp. 166–185, 2021, doi: 10.1007/s42330-020-00123-5.
- [41] M. Kundariati, I. Ibrohim, F. Rohman, and S. Nida, "Navigating climate change education: A problem-oriented project-based learning in secondary schools," *Sci. Act.*, vol. 62, no. 2, pp. 156–170, Apr. 2025, doi: 10.1080/00368121.2025.2463653.