The Mediating Role of Eco-STEM Learning in the Effects of Ethnoscience Integration and Islamic Ecotheological Values on Sustainability Thinking

Yunia Nabila Aziziy[1], Rony Harianto[2], and Ahmad Ramadhani[3]
[1,2,3]Tadris Ilmu Pengetahuan Alam, Universitas Islam Negeri Madura, Pamekasan, Indonesia
yunianabila@iainmadura.ac.id

Abstract. This study examines how Ethnoscience Integration and Islamic Ecotheological Values are associated with Sustainability Thinking through Eco-STEM Learning. A cross-sectional survey involved 400 Grade VIII and Grade IX students attending Madrasah Tsanawiyah in Madura. Four reflective constructs, measured using 40 indicators, were analyzed through partial least squares structural equation modeling in SmartPLS 4 with 5,000 bootstrap subsamples. The measurement model demonstrated satisfactory indicator reliability, internal consistency, convergent validity, and discriminant validity. Ethnoscience Integration and Islamic Ecotheological Values positively predicted Eco-STEM Learning, which was the strongest predictor of Sustainability Thinking. The model explained 39.8% of the variance in Eco-STEM Learning and 51.2% of the variance in Sustainability Thinking. Eco-STEM Learning partially mediated the associations of Ethnoscience Integration and Islamic Ecotheological Values with Sustainability Thinking, accounting for 59.3% and 69.0% of their respective total effects. These findings suggest that Eco-STEM Learning provides a pedagogical process through which cultural knowledge and Islamic environmental values are associated with sustainability-oriented reasoning among Madrasah Tsanawiyah students. The cross-sectional design supports an interpretation of these relationships as statistical associations but does not establish temporal causality.

Keywords: Eco-STEM learning, ethnoscience integration, Islamic ecotheology, sustainability thinking, PLS-SEM

1 Introduction

The accelerating ecological crisis requires science education to move beyond the transmission of environmental facts toward the cultivation of students who can interpret interdependent systems, anticipate future consequences, evaluate competing values, and design responsible courses of action. These capacities are integral to sustainability thinking because environmental problems are not related to a single set of variables. As such, sustainability thinking is not an extra subject in secondary education, but a way of structuring scientific reasoning around the relationship between ecological, social, cultural, economic, and ethical issues. Systems thinking is a cognitive basis for this

© The Author(s) 2026
U. Faruq et al. (eds.), *Proceedings of the 10th International Conference of Islamic Studies (ICONIS 2026) & 400th Anniversary of Shekh Yusuf Al-Makassari*, Advances in Social Science, Education and Humanities Research 1043,
https://doi.org/10.2991/978-94-6239-845-0_8

orientation. It allows learners to identify all of the components, interactions, feedback, hierarchy, and emerging consequences in a complex world.

Nevertheless, a synthesis of 255 empirical studies showed that systems thinking research in STEM education has remained concentrated in higher education and biology, while school-level applications and broader disciplinary integration are still comparatively limited [1]. A related study [2] similarly noted that active-learning approaches for fostering and assessing systems thinking across STEM disciplines remain underdeveloped. These findings indicate a need for learning designs that make complex environmental relationships accessible to younger learners through familiar and meaningful contexts.

STEM education offers a promising pedagogical basis because it integrates scientific inquiry, technological decision making, engineering design, and mathematical reasoning in the resolution of real-world problems. When combined with Education for Sustainable Development, STEM design thinking has been shown to improve students' scientific modeling skills and their capacity to address complex challenges [3]. Contextualized STEM instruction can also strengthen students' recognition of the causes, consequences, mitigation, and adaptation dimensions of environmental events. However, sustainability competences remain unevenly represented across STEM curricula, and students often demonstrate fragmented understandings of environmental problems and global sustainability frameworks [4].

Eco-STEM Learning extends conventional STEM integration by placing ecological responsibility and sustainability criteria at the center of problem identification, evidence gathering, technological selection, engineering design, quantitative evaluation, and reflection. Its educational value lies not merely in attaching an environmental topic to a STEM activity, but in requiring students to examine the environmental consequences of proposed solutions. Through Eco-STEM Learning, students investigate local problems, analyze scientific evidence, compare technological options, construct and test solutions, and evaluate whether those solutions are environmentally responsible and socially appropriate.

Integrating ethnoscience into Indonesian science education can strengthen the contextual relevance of Eco-STEM Learning. Ethnoscience Integration brings community knowledge, local practices, occupations, traditions, material culture, and ecological experience into dialogue with scientific concepts and evidence. A systematic review identified sustainable farming, fisheries, ethnobotany, local food knowledge, rituals, material culture, and ethnoecology as recurring contexts for conservation-oriented science education [5]. The review also described ethnoscience as an emerging field that requires further empirical investigation.

Existing studies demonstrate that ethnoscience can support both scientific learning and sustainability outcomes. Indigenous knowledge of botanical pesticides has been used as a starting point for green and sustainable chemistry learning [6]. Ethnoscience-integrated blended problem-based learning improved junior high school students' critical thinking, communication, creativity, engagement, and cultural appreciation [7]. Similarly, an Ethno-ESD engineering design model produced stronger sustainability knowledge, attitudes, and self-reported behavior than conventional learning [8]. These

findings suggest that ethnoscience can make environmental problems culturally recognizable while providing authentic resources for investigation and solution design.

Culturally grounded learning may also support sustainable environmental literacy when combined with digital and project-based pedagogies. An Ethno-SSI project integrated with virtual reality significantly contributed to students' sustainability knowledge, attitudes, and behavior [9]. Collectively, these studies show that local cultural knowledge can do more than increase contextual relevance. When reconstructed through scientific inquiry, ethnoscience can help students compare forms of evidence, evaluate the environmental implications of local practices, and adapt cultural resources to contemporary sustainability challenges.

In Islamic educational settings, environmental learning also involves a theological and moral dimension. Islamic Ecotheological Values position nature as part of an interconnected creation and frame human beings as khalifah who carry amanah for maintaining mizan and avoiding israf. Quranic ecological hermeneutics can support an ethical, ecological, and spiritual paradigm for responding to environmental challenges [10]. In educational practice, ecotawhid-based curricular, co-curricular, and extracurricular activities have been associated with the development of students' ecological awareness, responsibility, and religious character [11].

The presence of religious knowledge, however, does not automatically produce consistent environmental action. Analysis of 22,933 students from Islamic schools across Indonesia showed that students' understanding of ecotheology was generally high, while its implementation remained moderate because of limited programs, policies, and subject integration [12]. A recent critique [13] further argued that Islamic ecotheological discourse risks remaining within a general ethics of responsibility when it is not supported by deeper theological reflection and critical engagement with Anthropocene conditions. These findings reveal an educational gap between knowing religious environmental principles and applying them to the analysis and resolution of concrete ecological problems.

Ethnoscience Integration and Islamic Ecotheological Values thus provide two complementary resources for sustainability education. Ethnoscience supplies contextual knowledge, cultural experience, and locally grounded environmental practices, whereas Islamic ecotheology supplies normative direction, moral purpose, and spiritual accountability. Nevertheless, these resources may remain declarative unless they are translated into observable learning processes. Eco-STEM Learning is proposed in this study as the pedagogical mechanism that converts cultural and religious resources into inquiry, technological evaluation, engineering design, mathematical reasoning, and sustainability-oriented action.

Previous studies have often examined ethnoscience, ecotheology, STEM, and sustainability literacy as separate educational domains. Ethnoscience research has emphasized cultural relevance, learning outcomes, and environmental literacy, whereas Islamic ecotheology research has focused on awareness, values, and institutional implementation. STEM-ESD research has primarily investigated instructional effectiveness. Evidence remains limited on how Ethnoscience Integration and Islamic Ecotheological Values jointly relate to Sustainability Thinking through Eco-STEM Learning. Cultural and theological resources may support sustainability education, but

their presence alone does not ensure sustainability competence. This study addresses that gap by integrating the four constructs into a mediation model with both direct and indirect pathways to Sustainability Thinking. The model is examined among Madrasah Tsanawiyah students in Madura, where Islamic education intersects with local knowledge, cultural practices, and environmental concerns.

1.1 Hypothesis Development

Ethnoscience Integration can strengthen Eco-STEM Learning by providing authentic problems, materials, evidence, and design constraints for interdisciplinary learning. Scientifically reconstructing local knowledge can engage students in observation, measurement, experimentation, technological evaluation, and engineering design. Studies of ethnoscience-based green chemistry, problem-based learning, and Ethno-ESD engineering projects provide empirical support for this proposed relationship [6], [7], [8].

H1. *Ethnoscience Integration positively affects Eco-STEM Learning*

Islamic Ecotheological Values can also strengthen Eco-STEM Learning by providing moral criteria for selecting environmental problems and evaluating proposed solutions. Concepts such as khalifah, amanah, mizan, and the avoidance of israf can orient students toward responsible resource use, ecosystem balance, and the long-term consequences of technological decisions. The integration of ecotawhid within educational activities suggests that theological values can support ecological responsibility when they are connected to practical learning experiences[10], [11].

H2. *Islamic Ecotheological Values positively affect Eco-STEM Learning*

Ethnoscience Integration is expected to relate directly to Sustainability Thinking because it encourages students to examine interactions among community practices, ecosystems, culture, livelihoods, and scientific explanations. Such examination supports systems thinking, values-based judgment, and the adaptation of inherited knowledge to future environmental needs. Evidence from Ethno-ESD and culturally grounded environmental learning supports the contribution of local knowledge to sustainability literacy and behavior [8], [9].

H3. *Ethnoscience Integration positively affects Sustainability Thinking*

Islamic Ecotheological Values are likewise expected to relate directly to Sustainability Thinking. Theological principles encourage students to view environmental decisions in relation to responsibility, justice, balance, restraint, and accountability across generations. These principles can strengthen the values and strategic dimensions of sustainability thinking, although their effect depends on whether students move from general understanding to practical application [12].

H4. *Islamic Ecotheological Values positively affect Sustainability Thinking*

Eco-STEM Learning is expected to be positively related to Sustainability Thinking because it requires students to analyze environmental systems, anticipate the consequences of alternative solutions, apply ethical and ecological criteria, and formulate feasible actions. Contextualized inquiry and STEM design activities have

demonstrated potential for strengthening sustainability competences and the understanding of complex environmental challenges [3], [4], [12].

H5. *Eco-STEM Learning positively affects Sustainability Thinking*

The mediating proposition follows from the distinction between educational resources and educational processes. Ethnoscience and Islamic ecotheology provide culturally meaningful knowledge and normative orientation, but Eco-STEM Learning provides the activities through which students investigate, model, design, test, evaluate, and revise environmental solutions. Therefore, stronger Ethnoscience Integration and Islamic Ecotheological Values are expected to promote Sustainability Thinking partly through their contribution to Eco-STEM Learning.

H6. *Eco-STEM Learning mediates the relationship between Ethnoscience Integration and Sustainability Thinking*

H7. *Eco-STEM Learning mediates the relationship between Islamic Ecotheological Values and Sustainability Thinking*

Accordingly, this study examines the direct and indirect relationships among Ethnoscience Integration, Islamic Ecotheological Values, Eco-STEM Learning, and Sustainability Thinking using survey responses from 400 Grade VIII and Grade IX students enrolled in Madrasah Tsanawiyah across Madura. The proposed relationships are summarized in Fig. 1.

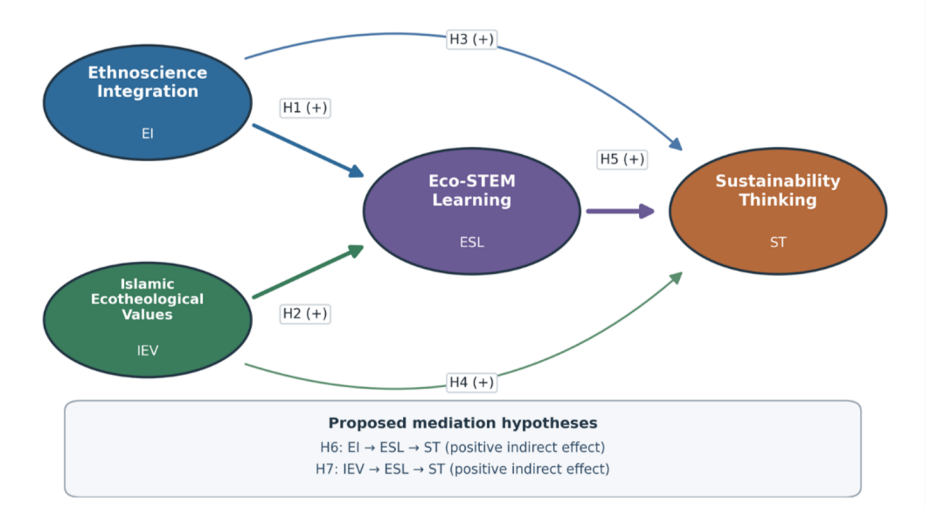


Fig. 1. Hypothesized Structural Model.

2 Method

2.1 Research Design and Participants

This study used a quantitative explanatory design with a cross-sectional survey to evaluate the direct and indirect relationships among Ethnoscience Integration, Islamic Ecotheological Values, Eco-STEM Learning, and Sustainability Thinking. Partial least squares structural equation modeling (PLS-SEM) was selected because the study emphasizes prediction, simultaneously estimates a mediation model with multiple latent constructs, and evaluates measurement quality before testing the structural relationships. Table 1 summarizes the methodological design.

Table 1. Research design and sampling framework

Component	Specification
Research approach	Quantitative explanatory survey analyzed using PLS-SEM
Temporal design	Cross-sectional
Population	Grade VIII and IX Madrasah Tsanawiyah students in Madura
Geographic coverage	Madrasah Tsanawiyah across Madura
Sampling	Multistage stratified cluster sampling
Analytical sample	400 student respondents
Unit of analysis	Individual student
Instrument	40-item self-report questionnaire; five-point Likert scale
Primary analysis	PLS-SEM using SmartPLS 4

The sample comprised Grade VIII and Grade IX students attending Madrasah Tsanawiyah across Madura. Multistage stratified cluster sampling used Madura's regencies as geographical strata, schools as clusters, and eligible classes as the final sampling units. The analytical sample included 400 students who completed a questionnaire containing 40 indicators, yielding a descriptive respondent-to-item ratio of 10:1.

2.2 Instrument and Measurement

The research instrument contained 40 positively worded items rated on a five-point scale from 1 (strongly disagree) to 5 (strongly agree). The indicators represented the four hypothesized constructs and were developed from the concepts discussed in the literature. Reliability and validity were evaluated using the responses of the 400 students. Table 2 presents the construct dimensions and indicator codes.

Table 2. Operationalization of the study constructs

Construct	Dimensions	Codes	n
Ethnoscience Integration (EI)	Local knowledge; scientific reconstruction; cultural relevance; critical appreciation; sustainable application	EI1-EI10	10
Islamic Ecotheological Values (IEV)	Tauhid; khalifah; amanah; mizan; avoidance of israf	IEV1-IEV10	10
Eco-STEM Learning (ESL)	Environmental problem orientation; scientific inquiry; technology use; engineering design; STEM integration	ESL1-ESL10	10
Sustainability Thinking (ST)	Systems thinking; anticipatory thinking; values thinking; strategic and action thinking	ST1-ST10	10

2.3 Data Collection and Ethical Safeguards

Data were collected from 400 Grade VIII and Grade IX students attending participating Madrasah Tsanawiyah schools in Madura. The questionnaire was administered at times agreed with the schools. Completed responses were coded and entered into the analytical dataset. Data collection followed educational research protocols for protecting minors, including consent and student-assent procedures. Participation was voluntary, responses were handled anonymously, and student names were excluded from the analytical file. Students were informed that participation or withdrawal would not affect their academic standing.

2.4 Data Analysis

Data analysis was conducted in SmartPLS 4 using a two-stage procedure recommended for PLS-SEM [14]. The first stage evaluated the reflective measurement model through indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. The second stage assessed collinearity, path coefficients, explanatory power, effect sizes, and overall model fit. The decision criteria are summarized in Table 3.

Table 3. PLS-SEM evaluation criteria

Stage	Assessment	Decision criterion
Measurement model	Indicator reliability	Outer loading ≥ .708
Measurement model	Internal consistency	Cronbach's alpha, rho_A, and CR = .70 to .95
Measurement model	Convergent validity	AVE ≥ .50
Measurement model	Discriminant validity	HTMT < .90

Stage	Assessment	Decision criterion
Structural model	Collinearity	Inner VIF preferably < 3; acceptable < 5
Structural model	Path significance	$p < .05$ and 95% bootstrap CI excludes zero
Structural model	Explanatory power	R^2 reported for ESL and ST
Structural model	Effect size	f^2: .02 small, .15 medium, .35 large
Model fit	Approximate fit	SRMR < .08; NFI closer to 1
Mediation	Specific indirect effects	5,000-subsample percentile CI excludes zero

The statistical significance of the direct and indirect effects was evaluated through bootstrapping with 5,000 subsamples, percentile confidence intervals, and two-tailed testing at the .05 significance level. A path was considered significant when its 95% percentile confidence interval did not include zero. Mediation was established from the significance and direction of each specific indirect effect. When both the indirect and corresponding direct effects were significant and pointed in the same direction, complementary partial mediation was inferred. When only the indirect effect was significant, indirect-only mediation was inferred [14]. Variance accounted for (VAF) was calculated as the specific indirect effect divided by the corresponding total effect and was reported descriptively.

3 Result and Discussion

3.1 Measurement Model

The reflective measurement model satisfied the requirements for indicator reliability, internal consistency, convergent validity, and discriminant validity. As shown in Table 4, the outer loadings ranged from .705 to .841 and were statistically significant at $p < .001$. ST5 had the lowest loading (.705), which was marginally below the preferred .708 benchmark but remained above .70. It was retained because the construct displayed strong reliability, an AVE above .50, and adequate conceptual coverage. Cronbach's alpha, rho_A, and composite reliability values were between .919 and .940, while AVE values ranged from .579 to .611.

Table 4. Measurement model results

Construct	Loading range	Alpha	rho_A	rho_C	AVE
ESL	.719-.841	.929	.930	.940	.611
EI	.719-.794	.919	.921	.932	.579
IEV	.713-.827	.926	.928	.938	.601
ST	.705-.815	.928	.930	.940	.609

Discriminant validity was also established. The HTMT values ranged from .385 to .767, with the highest value observed between Eco-STEM Learning and Sustainability Thinking. All values were below the .90 criterion[15]. The Fornell-Larcker criterion and cross-loading pattern similarly showed that each construct shared more variance with its own indicators than with the other constructs. Outer VIF values ranged from 1.705 to 2.716, indicating that indicator collinearity did not threaten the measurement estimates. Fig. 2 displays the reflective indicator structure and standardized loadings for all four constructs.

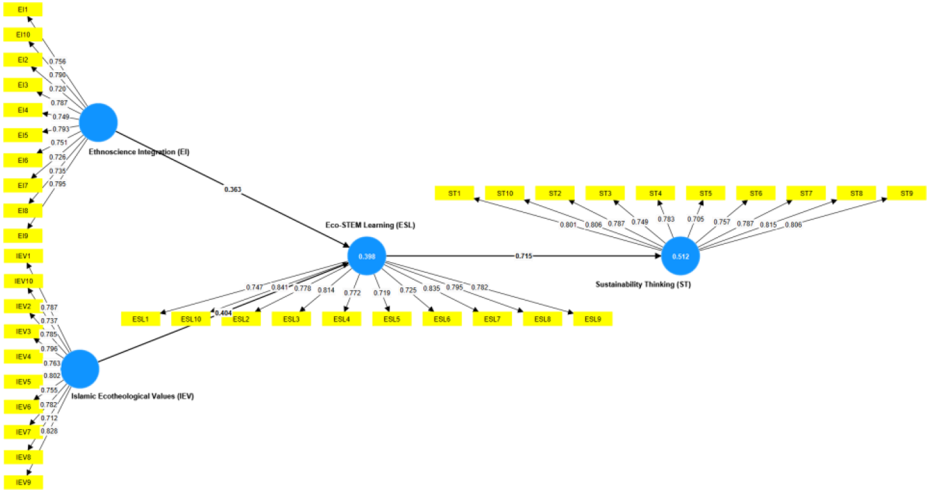


Fig. 2. Reflective measurement model with all 40 standardized outer loadings. Panels are redrawn from the final PLS-SEM estimates; structural paths are shown in Fig. 3.

3.2 Structural Model and Hypothesis Testing

After the measurement model was confirmed, the structural model was evaluated. Inner VIF values ranged from 1.145 to 1.660, indicating no problematic collinearity among predictor constructs. Eco-STEM Learning had an R^2 of .398 (adjusted R^2 = .395), while Sustainability Thinking had an R^2 of .512 (adjusted R^2 = .534). Thus, Ethnoscience Integration and Islamic Ecotheological Values explained 39.8% of the variance in Eco-STEM Learning, and the three predictors jointly explained 53.8% of the variance in Sustainability Thinking.

Table 5. Direct-effect hypothesis testing

H	Path	β	t	p	95% CI
H1	EI → ESL	.362	9.007	< .001	[.284, .440]
H2	IEV → ESL	.403	9.981	< .001	[.325, .482]
H3	EI → ST	.146	3.748	< .001	[.070, .224]
H4	IEV → ST	.106	2.454	.014	[.021, .189]
H5	ESL → ST	.585	14.087	< .001	[.502, .664]

Table 5 shows that all five direct hypotheses were supported. Eco-STEM Learning had the strongest direct relationship with Sustainability Thinking (β = .585, p < .001). Its effect size was large (f^2 = .446). Ethnoscience Integration (β = .362, f^2 = .190) and Islamic Ecotheological Values (β = .403, f^2 = .235) had medium effects on Eco-STEM Learning. For Sustainability Thinking, the direct effect of Ethnoscience Integration was small (f^2 = .034), whereas the direct effect of Islamic Ecotheological Values was below the conventional small-effect threshold (f^2 = .017). Fig. 3 presents the final structural model, including all five direct paths, endogenous R^2 values, and the two specific indirect effects.

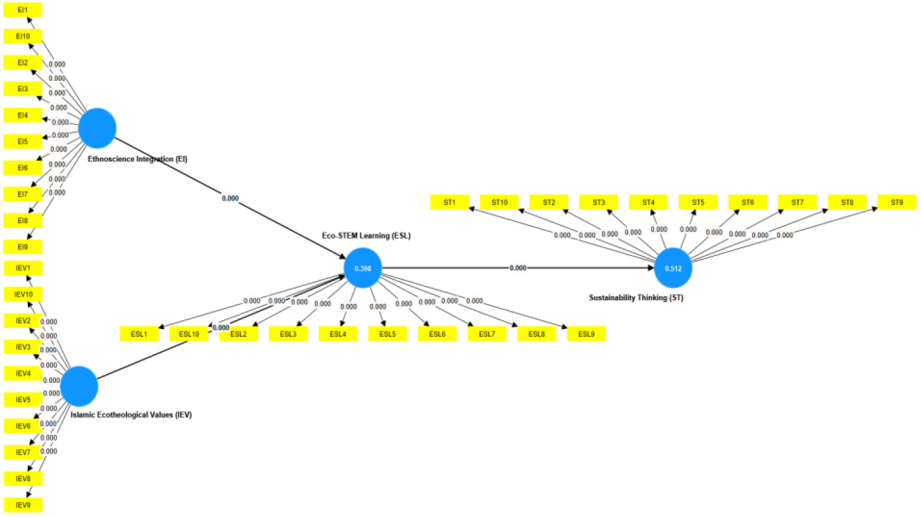


Fig. 3. Final structural model with standardized path coefficients, endogenous R^2 values, and specific indirect effects. Redrawn from the PLS-SEM and bootstrap results. * p < .05; *** p < .001.

3.3 Mediation Analysis

Both specific indirect effects were positive and significant. The indirect effect of Ethnoscience Integration on Sustainability Thinking through Eco-STEM Learning was $\beta = .212$, $t = 7.611$, $p < .001$, with a 95% percentile confidence interval of [.161, .269]. The corresponding direct effect remained significant and positive ($\beta = .146$, $p < .001$), indicating complementary partial mediation. The variance accounted for was 59.3%. Similarly, Islamic Ecotheological Values affected Sustainability Thinking indirectly through Eco-STEM Learning ($\beta = .236$, $t = 7.885$, $p < .001$, 95% CI [.182, .297]). Its direct effect also remained positive and significant ($\beta = .106$, $p = .014$), producing complementary partial mediation with a variance accounted for of 69.0%. Therefore, H6 and H7 were supported.

Table 6. Specific indirect effects and mediation

H	Indirect path	βind	t	p	95% CI	Type
H6	EI → ESL → ST	.212	7.611	< .001	[.161, .269]	Partial; VAF 59.3%
H7	IEV → ESL → ST	.236	7.885	< .001	[.182, .297]	Partial; VAF 69.0%

3.4 Explanatory Power and Model Fit

The model also demonstrated acceptable approximate fit. The estimated-model SRMR was .038, which was below the .08 threshold, and NFI was .907. The post hoc minimum-sample-size output indicated that 400 observations were sufficient for the principal paths at 80% power, except for the very small direct path from Islamic Ecotheological Values to Sustainability Thinking, which required 549 observations at $\alpha = .05$ and 80% power. Although H4 was statistically significant, its very small effect size and the reported sample-size requirement warrant cautious interpretation.

Table 7. Explanatory power and model quality

Criterion	Value	Interpretation
R^2 ESL	.398	Moderate explanatory power
Adjusted R^2 ESL	.395	Limited shrinkage
R^2 ST	.512	Moderate explanatory power
Adjusted R^2 ST	.534	Limited shrinkage
Inner VIF	1.145-1.660	No problematic collinearity
SRMR	.038	Below .08
NFI	.907	Acceptable approximate fit

3.5 Discussion

The results indicate a clear hierarchy among the relationships in the proposed model. Ethnoscience Integration and Islamic Ecotheological Values were modeled as educational resources, while Eco-STEM Learning had the strongest association with Sustainability Thinking. All seven hypotheses were statistically supported, but the magnitudes of the relationships differed substantially. The ESL to ST path was strong ($\beta = .585$, $f^2 = .446$), the EI and IEV paths to ESL were moderate ($\beta = .362$ and .403), the EI to ST direct effect was small ($\beta = .146$, $f^2 = .034$), and the IEV to ST direct effect was below the conventional small-effect threshold ($\beta = .106$, $f^2 = .017$). This pattern is consistent with the proposition that cultural knowledge and religious environmental values are educationally relevant when connected to inquiry, technological assessment, engineering design, quantitative reasoning, and reflection. This interpretation aligns with research on active, interdisciplinary, and systems-oriented learning for addressing complex sustainability problems [1], [2], [15]

The medium EI to ESL effect indicates that local knowledge is not merely a motivational background for science lessons. It can supply observable phenomena, locally available materials, community explanations, design constraints, and criteria for assessing whether a solution is culturally workable. This interpretation converges with evidence from green chemistry, ethnoscience-based problem-based learning, Ethno-ESD engineering projects, and Ethno-SSI learning, which connect cultural contexts with scientific reasoning, design, and environmental literacy[5], [6], [15]. More recent studies also show that students' science reconstruction, critical thinking, and contextual understanding improve when ethnoscience is integrated with socioscientific issues, inquiry, creative learning, and explicit reconstruction of indigenous science [5], [15]–[19]. For Madrasah Tsanawiyah students in Madura, this association is consistent with the view that culturally situated experience can support Eco-STEM when learners compare community explanations with evidence, identify mechanisms, test claims, and evaluate ecological consequences.

The medium IEV to ESL effect was numerically larger than the EI to ESL effect, although the study did not test whether the two coefficients differed significantly. The result is consistent with the proposition that tauhid, khalifah, amanah, mizan, and avoidance of israf can serve as operational criteria within Eco-STEM rather than remaining devotional statements. These values can shape which environmental problem deserves attention, whose interests must be considered, how resource efficiency is judged, and whether a technical solution preserves balance or transfers harm to another group or generation. This interpretation is supported by Qur'anic ecological hermeneutics, ecotawhid-oriented environmental education, and evidence from Islamic schools [10]–[13] . It is also compatible with newer ecotheological scholarship that connects divine unity, stewardship, balance, climate action, planetary health literacy, forest protection, Prophetic environmental ethics, and responsible technology use [20]–[25]. The important qualification is that values do not replace scientific evidence. Their distinctive role is to provide normative direction for choosing and evaluating evidence-based solutions.

The ESL to ST relationship is the pivotal empirical finding. Its large effect shows that Sustainability Thinking is closely associated with students' reported engagement in environmentally oriented STEM learning. Students must trace interactions and feedback, anticipate delayed consequences, compare technological alternatives, quantify trade-offs, justify value-based choices, and formulate feasible action. This interpretation extends findings that STEM design thinking, GreenComp-oriented instruction, and active systems-learning tasks improve modeling, awareness, and the analysis of complex environmental phenomena [22], [23], [26]. It is also consistent with evidence that structured STEM applications can strengthen scientific creativity and that K-12 STEM pedagogies can produce substantial gains in higher-order thinking [24], [25]. However, general higher-order thinking and Sustainability Thinking are not identical. The latter requires learners to connect analytical quality with ecological limits, intergenerational consequences, social acceptability, and action. One possible explanation for the strong ESL association is that Eco-STEM combines cognitive, design, and normative demands within the same learning process.

The small EI to ST direct effect requires a critical reading of culturally responsive science education. Local knowledge should not be presumed to be scientifically valid or environmentally sustainable simply because it is inherited. Cultural practices can contain valuable ecological insight, but they can also be context-bound, incompletely explained, or environmentally ambivalent. Studies of science reconstruction, woven-fabric production, batik-based sustainable education, and augmented reality show that cultural content becomes educationally productive through reconstruction, visualization, investigation, and reflection [16], [19] [20], [21], [24], [25]. The small direct coefficient is therefore theoretically meaningful. It warns against using ethnoscience as decorative cultural illustration or romanticizing tradition. For culture to support systems, anticipatory, values, and strategic thinking, students need structured opportunities to identify which elements should be preserved, scientifically reinterpreted, modified, or rejected in light of current sustainability evidence.

The IEV to ST direct effect was the smallest structural relationship ($\beta = .106$, $f^2 = .017$) and fell below the conventional $f^2 = .02$ benchmark for a small effect. Although its p value was .014, the post hoc analysis indicated that 549 observations would be required for 80% power, which exceeds the actual sample of 400. H4 should consequently be interpreted as a weak association that merits replication, not as evidence that religious understanding alone produces sustainability-oriented judgment or behavior. This caution aligns with the observed gap between high ecotheological understanding and only moderate practical implementation in Indonesian Islamic schools [12]. It also answers critiques that ecotheology can remain at the level of general responsibility unless it develops deeper theological reasoning and concrete engagement with Anthropocene conditions[13], [21] . Evidence from Muslim organizations, planetary health, forest protection, Prophetic ethics, and urban technology further suggests that practical enactment depends on institutional programs, situated problems, and explicit pathways from belief to collective action [22]–[26].

The EI mediation result is a central contribution of this study. Based on the reported unrounded SmartPLS estimates, the total effect of EI on ST was .357; the direct and indirect components, rounded separately to three decimal places, were .146 and .212,

respectively. Eco-STEM Learning accounted for 59.3% of the total association. Both components were positive and significant, indicating complementary partial mediation. Ethnoscience Integration therefore retained a small direct association with Sustainability Thinking, while a larger share of the modeled association operated through Eco-STEM Learning. This result connects evidence on ethnoscience, inquiry, engineering design, digital learning, and environmental literacy[5], [9], [19], [20] . Culturally grounded knowledge can provide problem contexts and initial explanations, while Eco-STEM activities offer opportunities to evaluate those explanations through systems analysis and solution design.

The IEV mediation result is even more revealing. IEV had a total effect of .342 on ST, of which .236 was indirect through ESL and only .106 was direct. Eco-STEM Learning therefore carried 69.0% of the total association. The larger mediated share suggests that Islamic environmental values are most strongly related to Sustainability Thinking when learners apply them to concrete scientific and technological decisions. In theoretical terms, Eco-STEM operationalizes ecotheology. Khalifah becomes responsibility for problem definition, amanah becomes accountability for evidence and consequences, mizan becomes a criterion for balancing system components, and avoidance of israf becomes a constraint on material and energy use. This interpretation connects theological foundations with the practical and institutional emphasis found across recent Islamic ecotheology studies [10], [12], [15], [17], [18]. This interpretation suggests a need to examine whether lessons that connect theological reflection with practical inquiry support stronger outcomes than lessons focused on moral instruction alone.

The model explained 39.8% of the variance in ESL and 53.8% of the variance in ST, leaving substantial variation unaccounted for. Potential additional factors include teacher support, prior science achievement, exposure to environmental problems, school sustainability culture, family practices, perceived behavioral control, and access to materials. The SRMR of .038 and NFI of .907 indicate acceptable approximate fit under the criteria used in this study, but these indices do not establish the causal ordering of the constructs. Because all variables were measured through student self-reports at a single time point, reciprocal relationships and common method effects remain possible. The coefficients should therefore be interpreted as associations that require further examination using longitudinal or intervention studies.

The findings support a conceptual distinction among cultural knowledge as an educational resource, Islamic ecotheology as a normative orientation, Eco-STEM as a process of inquiry and design, and Sustainability Thinking as the intended competence. This distinction helps identify potential weaknesses in curriculum integration: cultural content may remain descriptive, religious values may remain declarative, and technically successful STEM tasks may overlook ecological consequences. A proposed learning sequence would reconstruct a locally meaningful environmental practice, investigate it scientifically, compare alternatives using Islamic ecological principles, design and test a feasible response, and assess its systemic and future implications. The mediation results are consistent with this integrated approach, although its instructional effectiveness requires direct evaluation.

4 Conclusion

This study examined an integrated mediation model linking Ethnoscience Integration, Islamic Ecotheological Values, Eco-STEM Learning, and Sustainability Thinking among 400 Madrasah Tsanawiyah students in Madura. The reflective measurement model demonstrated satisfactory reliability and validity, and all seven structural hypotheses were statistically supported. Ethnoscience Integration and Islamic Ecotheological Values had moderate positive associations with Eco-STEM Learning, which was the strongest predictor of Sustainability Thinking. Eco-STEM Learning accounted for 59.3% of the total effect of Ethnoscience Integration and 69.0% of the total effect of Islamic Ecotheological Values. These findings suggest that inquiry, technological evaluation, engineering design, quantitative reasoning, and environmental reflection are relevant processes through which cultural and theological resources may support Sustainability Thinking. The cross-sectional results do not establish causal effects.

4.1 Theoretical Implications

The model contributes to sustainability-oriented science education by distinguishing educational resources from pedagogical processes. Ethnoscience Integration supplies contextual and culturally grounded knowledge, while Islamic Ecotheological Values provide moral purpose and criteria for responsible environmental judgment. Eco-STEM Learning functions as the intervening process that converts these resources into observable scientific and design activities. This mediation perspective extends studies that have previously examined ethnoscience, Islamic ecotheology, STEM, and sustainability outcomes as separate domains.

4.2 Practical Implications

Madrasah Tsanawiyah science teachers can organize learning around locally relevant environmental problems, examine ethnoscientific knowledge using scientific evidence, and apply Islamic ecotheological principles when evaluating proposed solutions. Eco-STEM activities can then guide students through inquiry, design, testing, and reflection. Assessment should address systems thinking, anticipation of consequences, values-based judgment, and strategic planning alongside environmental knowledge. Teacher preparation can support this approach through local knowledge documentation, ecotheological reflection, interdisciplinary STEM planning, and authentic sustainability assessment.

4.3 Limitations and Future Research

The cross-sectional, self-report design does not establish temporal causality and is susceptible to common method bias and socially desirable responses. The sample was drawn from Madrasah Tsanawiyah in Madura, which limits generalization to other

school types, regions, and cultural settings. The reported post hoc sample-size analysis estimated that 549 observations would be required for 80% power to detect the very small IEV to ST path at $\alpha = .05$, exceeding the sample of 400. Future research should use larger probability samples, assess measurement invariance across regencies and student groups, account for school-level clustering, and employ longitudinal or quasi-experimental designs with behavioral and performance-based measures of sustainability.

Acknowledgments. The authors acknowledge the scholarly sources and methodological guidance that supported the development of the Eco-STEM mediation model.

Disclosure of Interests. The authors declare no competing interests.

Data Availability. The de-identified data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and school data-protection requirements.

References

[1] T. Bielik, I. Delen, M. Krell, and O. B. Z. Assaraf, "Characterising the Literature on the Teaching and Learning of System Thinking and Complexity in STEM Education: a Bibliometric Analysis and Research Synthesis," *J. STEM Educ. Res.*, vol. 6, no. 2, pp. 199–231, 2023.

[2] R. Lavi and L. B. Bertel, "The System Architecture-Function-Outcome Framework for Fostering and Assessing Systems Thinking in First-Year STEM Education and Its Potential Applications in Case-Based Learning," *Educ. Sci.*, vol. 14, no. 7, 2024.

[3] H. E. Kurniawan, S. Saputro, and M. Ramli, "THE EFFECTS OF INTEGRATING STEM DESIGN THINKING INTO EDUCATION FOR SUSTAINABLE DEVELOPMENT ON STUDENTS' SCIENTIFIC MODELING SKILLS," *J. Balt. Sci. Educ.*, vol. 24, no. 5, pp. 935–955, 2025.

[4] J. L. del Río-Rodríguez, S. Campos Fernández, and M. Calero Llinares, "Enhancing GreenComp Sustainability Skills in STEM Disciplines: A Didactic Proposal for Extreme Weather Preparedness in Secondary Education," *Sustain.*, vol. 18, no. 5, 2026.

[5] S. Fathonah, S. Fatimah, E. F. Sari, and A. M. Fadilah, "Ethnoscience and local wisdom in science education for conservation: A systematic review with bibliometric mapping," *Multidiscip. Rev.*, vol. 9, no. 7, 2026.

[6] R. Zidny and I. Eilks, "Learning about Pesticide Use Adapted from Ethnoscience as a Contribution to Green and Sustainable Chemistry Education," *Educ. Sci.*, vol. 12, no. 4, 2022.

[7] D. Fitria, A. Asrizal, and L. Lufri, "Enhancing 21st-Century Skills through Blended Problem-Based Learning with Ethnoscience Integration: A Mixed-Methods Study in Indonesian Junior High Schools," *Int. J. Learn. Teach. Educ. Res.*, vol. 24, no. 1, pp. 464–480, 2025.

[8] A. Rahmawati and T. Wibowo, "Reconstruction of the Engineering Design Project

(EDPj) Learning Model based on Ethno-ESD to Actualize Students' Sustainable Environmental Literacy," *LUMAT*, vol. 12, no. 4, 2024.

[9] A. Permanasari, F. D. Hutagalung, S. E. Pujiastuti, D. S. Sari, and H. P. Asmaningrum, "Evaluating the Validity and Effectiveness of the Ethno-SSI Project–Integrated Virtual Reality in Improving Sustainable Environmental Literacy," *Eur. J. STEM Educ.*, vol. 11, no. 1, 2026.

[10] H. Amin, M. Djawas, A. Nurdin, and R. Akbar, "Environmental Paradigm Transformation through Integrative Interpretation: Perspective of Quranic Ecological Hermeneutics," *Int. J. Islam. Thought*, vol. 28, pp. 52–63, 2025.

[11] S. Suraijiah, R. Rusdiah, and S. Surawardi, "Implementation of Environmental Education in the Concept of Ecotawhid and Ecotheology in Students," *Kharisma*, vol. 4, no. 2, pp. 232–245, 2025.

[12] D. S. Maylawati *et al.*, "Data-Driven Insights of the Ecotheology Implementation at Islamic Schools in Indonesia using Machine Learning," *J. Appl. Sci. Eng. Technol. Educ.*, vol. 8, no. 1, pp. 175–195, 2026.

[13] S. Öztürk, "Islamic Ecotheology and the Anthropocene Challenge: Ethical Limits and Theological Possibilities," *Zygon*, vol. 61, no. 2, pp. 375–396, 2026.

[14] J. F. Hair, G. T. M. Hult, C. M. Ringle, and M. Sarstedt, *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, 3rd ed. Thousand Oaks: SAGE Publications, 2022.

[15] J. Henseler, C. M. Ringle, and M. Sarstedt, "A new criterion for assessing discriminant validity in variance-based structural equation modeling," *J. Acad. Mark. Sci.*, vol. 43, no. 1, pp. 115–135, 2015.

[16] A. Khoiri, B. Saputro, B. Parikesied, M. F. Sedon, and N. Nasokah, "SCIENCE LEARNING STRATEGY BASED ON ETHNO-SOCIOSCIENTIFIC ISSUES (ESSI): ANALYSIS OF CREATIVE THINKING ABILITY IN STUDENTS' SCIENCE RECONSTRUCTION," *J. Pendidik. IPA Indones.*, vol. 15, no. 2, pp. 292–306, 2026.

[17] S. Prayogi, S. Ahzan, J. Rokhmat, and N. N. S. P. Verawati, "Dynamic blend of ethnoscience and inquiry in a digital learning platform (e-learning) for empowering future science educators' critical thinking," *J. Educ. e-Learning Res.*, vol. 10, no. 4, pp. 819–828, 2023.

[18] A. Harjono, N. N. S. P. Verawati, S. Gummah, and S. Prayogi, "Integrating ethnoscience in inquiry-creative learning: a new breakthrough in enhancing critical thinking," *Int. J. Eval. Res. Educ.*, vol. 14, no. 1, pp. 636–647, 2025.

[19] M. Khusniati, A. P. Heriyanti, N. P. Aryani, T. R. Fariz, and D. Harjunowibowo, "Indigenous science constructs based on Troso woven fabric local wisdom: a study in ethnoscience and ethnoecology," *J. Turkish Sci. Educ.*, vol. 20, no. 3, pp. 549–566, 2023.

[20] M. Yasir, T. Hartiningsih, and A. A. Rahma, "Bridging Sustainable Science Education and Culture: The Role of Educational Augmented Reality Media in Ethnoscience and Cultural Literacy," in *Journal of Physics: Conference Series*, 2025, vol. 3148, no. 1.

[21] M. Anggaryani, S. Atmoko, M. Satriawan, U. A. Deta, and A. Zakariah, "Uniting cultures and promoting sustainable education: Batik diplomacy for Indonesian students in Taiwan to Support the SDGs," in *E3S Web of Conferences*, 2024, vol. 568.

[22] J. A. Cordaro, C. Murphy, and E. Redman, "Bridging STEM Education and

Sustainability: Insights from Pennsylvania Educators," *Educ. Sci.*, vol. 15, no. 3, 2025.
[23] E. Ingram and J. Keshwani, "Prairie Protector: student development of systems thinking habits in the context of agroecosystems," *Front. Educ.*, vol. 8, 2023.
[24] M. A. Kurtuluş, "The effect of STEM applications based on the OCIPSE learning model on primary school students' academic achievement and scientific creativity," *Think. Ski. Creat.*, vol. 62, 2026.
[25] M. Cheng, X. Lai, W. Zeng, S. Bai, C. Duan, and D. Sun, "Unlocking the Power of Gamification in K-12 STEM Education: A Meta-analysis of the Effects On Domain Knowledge, Higher-order Thinking, and Affective Outcomes," *Educ. Psychol. Rev.*, vol. 38, no. 1, 2026.
[26] M. Erol, A. Erol, and G. Tabaru Örnek, "The impact of place-based STEM education on primary school students' environmental awareness," *Innov. Eur. J. Soc. Sci. Res.*, 2026.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

