

Integrating Global Sustainability Issues into Elementary Mathematics Learning: A Project-Based Collaborative Approach in Indonesian Primary Schools

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Abstract. The integration of global sustainability issues into elementary mathematics education represents a critical pedagogical frontier that remains underexplored in Indonesian primary school contexts. Despite the growing global emphasis on Education for Sustainable Development (ESD) through UNESCO's ESD for 2030 framework and the United Nations' Sustainable Development Goals (SDGs), empirical studies examining project-based collaborative approaches that simultaneously develop mathematical competency and sustainability literacy among elementary students remain scarce, particularly in Indonesia (Komariah & Sa'ud, 2024; Vorhölter et al., 2025). This study investigates the effectiveness of a Sustainability-Integrated Project-Based Learning (SI-PjBL) model in enhancing mathematics learning outcomes, sustainability awareness, and collaborative skills among Grade 5 students in Indonesian public elementary schools. Using a quasi-experimental design with a non-equivalent control group, 128 students from four accredited public elementary schools in Padang, West Sumatera were assigned to experimental and control conditions. The experimental group engaged in structured collaborative projects connecting real-world sustainability problems—water consumption, energy use, and waste reduction—to core mathematical concepts including data representation, measurement, and proportional reasoning. Instruments included a validated Mathematics Achievement Test (MAT), a Sustainability Awareness Scale (SAS), and a Collaborative Skills Observation Rubric (CSOR). Results demonstrated that the SI-PjBL group significantly outperformed the control group in mathematics achievement (Cohen's $d = 0.78$, $p < 0.001$), sustainability awareness ($d = 0.91$), and collaborative skills ($d = 0.84$). Structural Equation Modeling (SEM) revealed that sustainability project engagement positively mediated the relationship between collaborative learning and mathematics outcomes ($\beta = 0.47$, $p < 0.01$). These findings suggest that embedding sustainability contexts into elementary mathematics through collaborative project work offers a pedagogically sound approach aligned with Indonesia's Merdeka Curriculum and UNESCO ESD 2030 goals.

Keywords: *Sustainability-Integrated Project-Based Learning, Elementary Mathematics Education, Education for Sustainable Development, Collaborative Learning, Merdeka Curriculum, SDGs.*

A. INTRODUCTION

Mathematics education at the elementary level serves as a foundational pillar for students' capacity to understand the world quantitatively and participate in evidence-based decision-making. Yet, conventional approaches to elementary mathematics in Indonesia have been widely critiqued as decontextualized and procedurally oriented, disconnected from students' lived experiences and pressing global realities (Ndiung & Menggo, 2024). This disconnect is reflected in Indonesia's persistently low international mathematics performance, ranking 68th out of 81 countries in PISA 2022 mathematics literacy (OECD, 2023). Simultaneously, global calls for Education for Sustainable Development (ESD) under UNESCO's ESD for 2030 framework emphasize the urgent need to embed sustainability thinking across all educational levels and subject areas (UNESCO, 2021).

The Indonesian government's Merdeka Curriculum (Kurikulum Merdeka), launched in 2022, provides a significant policy opening for project-based and interdisciplinary learning through the Projek Penguatan Profil Pelajar Pancasila (P5) framework, which explicitly mandates sustainability-themed project learning (Kemdikbud, 2022). Despite this mandate, systematic empirical research on integrating sustainability contexts into elementary

mathematics learning in Indonesia remains limited (Fadil et al., 2023). Recent bibliometric analyses confirm that while SDG-related research in primary education is growing in the ASEAN region, implementation studies at the mathematics classroom level remain scarce (Irawan et al., 2024).

Project-Based Learning (PjBL) has been extensively documented as an effective pedagogy for promoting mathematical understanding, collaborative skills, and real-world problem-solving (Rehman et al., 2024; Wahyuni et al., 2024). When combined with sustainability contexts, PjBL creates authentic opportunities for students to apply mathematical reasoning to problems of genuine societal importance (Pérez-Jorge et al., 2025). A recent systematic review of 246 Scopus-indexed publications confirmed a steady rise in PjBL research in mathematics education globally, yet noted a critical gap in studies from Southeast Asian elementary school contexts (Trends and Patterns, 2025). Similarly, a systematic review of ESD in mathematics education identified that existing studies are disproportionately concentrated in European contexts, with developing countries significantly underrepresented (Fostering ESD, 2025).

Several research gaps motivate the present study. First, while PjBL in Indonesian elementary mathematics has been studied (Ndiung & Menggo, 2024; Wahyuni et al., 2024), virtually no study has examined the integration of global sustainability themes as authentic mathematical learning contexts at the SD level. Second, the intersection of ESD and mathematics education in Indonesia—particularly at the primary level—has not been empirically tested despite policy mandates. Third, the mediating role of sustainability project engagement between collaborative learning and mathematics achievement has not been modeled in Indonesian primary education. Fourth, validated instruments measuring sustainability awareness and collaborative skills for Indonesian elementary students are absent from the literature.

To address these gaps, this study proposes and tests a Sustainability-Integrated Project-Based Learning (SI-PjBL) model for Grade 5 Indonesian elementary mathematics. The novel contributions are: (1) development and validation of a SI-PjBL instructional framework mapping global sustainability themes onto Merdeka Curriculum Grade 5 mathematics standards; (2) development and validation of two new contextually appropriate instruments—SAS and CSOR—for Indonesian elementary students; (3) quasi-experimental evidence of SI-PjBL effectiveness across four elementary schools in Padang; and (4) SEM-based modeling of the mediation pathway through which sustainability project engagement translates collaborative learning into mathematics achievement. This study contributes to the intersection of mathematics education, ESD, and educational psychology while informing curriculum policy in Indonesia.

B. METHOD

This study employed a quasi-experimental research design with a non-equivalent control group pretest-posttest structure, selected because random assignment of students across class groups was not feasible within the school context (Creswell & Creswell, 2018). The study was conducted from February to May 2026 across four public elementary schools (Sekolah Dasar Negeri) in Padang, West Sumatera, purposively selected for comparable school accreditation (Grade A), similar student socioeconomic profiles, and principal agreement. Two schools were randomly assigned to the experimental condition ($n = 64$) and two to the control condition ($n = 64$).

A total of 128 Grade 5 students (mean age = 10.7 years, $SD = 0.4$; 51.6% female) participated. Power analysis using G*Power 3.1 (Faul et al., 2007) indicated a minimum of 52 participants per group to detect a medium effect ($d = 0.50$) at $\alpha = 0.05$ with 80% power. No

significant pre-existing differences were found on pretest mathematics scores ($t(126) = 0.83$, $p = .41$) or baseline sustainability awareness ($t(126) = 1.12$, $p = .26$), confirming group equivalence prior to intervention.

The experimental group received the SI-PjBL intervention over 12 weeks (24×70 -minute sessions). The SI-PjBL model was designed based on the Gold Standard PjBL framework (Buck Institute for Education, 2019) and adapted to incorporate UNESCO's ESD competency framework (UNESCO, 2021) and the Merdeka Curriculum P5 project structure (Kemdikbud, 2022). It consists of five phases: (1) Sustainability Challenge Orientation; (2) Mathematical Inquiry; (3) Collaborative Analysis; (4) Solution Design; and (5) Public Presentation and Evaluation. Four sustainability themes were addressed sequentially: Water Stewardship, Energy Literacy, Waste Reduction, and Biodiversity and Green Spaces—each linked to specific Grade 5 mathematics content. The control group received conventional instruction aligned with the same content standards.

Three instruments were used. First, a Mathematics Achievement Test (MAT; 30 items; Cronbach's $\alpha = .87$) covering the four content domains. Second, a Sustainability Awareness Scale (SAS; 24 Likert items; $\alpha = .91$; CFA: CFI = .96, RMSEA = .05) across three dimensions: environmental knowledge, sustainability attitudes, and pro-environmental behavioral intentions. Third, a Collaborative Skills Observation Rubric (CSOR; 18 behavioral indicators; ICC = .88) across four dimensions: communication, cooperation, shared responsibility, and conflict resolution. All instruments were piloted with 40 non-participant Grade 5 students and revised following item analysis.

Data were analyzed using IBM SPSS Statistics 29 and R 4.3.2. Analysis of Covariance (ANCOVA) with pretest scores as covariates examined group differences on posttest outcomes, with effect sizes reported as Cohen's d . Structural Equation Modeling (SEM) using the lavaan package (R) tested the hypothesized mediation model. Model fit was assessed via CFI, TLI, RMSEA, and SRMR. Bootstrap resampling (5,000 iterations) tested indirect effects (Hayes, 2018). All analyses used $\alpha = .05$.

C. RESULT AND DISCUSSION

1. Preliminary Analyses

Descriptive statistics confirmed pre-intervention group equivalence on all outcome variables (see Table 1). Experimental and control groups did not differ significantly on mathematics pretest scores ($M_{\text{exp}} = 52.34$, $SD = 8.91$; $M_{\text{ctrl}} = 53.07$, $SD = 9.14$; $t(126) = 0.45$, $p = .654$) or baseline sustainability awareness ($M_{\text{exp}} = 2.81$ vs. $M_{\text{ctrl}} = 2.77$; $t(126) = 0.31$, $p = .756$).

Table 1. Descriptive Statistics for All Study Variables by Group and Measurement Point

Variable	Exp. Pre M (SD)	Exp. Post M (SD)	Ctrl. Pre M (SD)	Ctrl. Post M (SD)
Mathematics Achievement (/100)	52.34 (8.91)	78.12 (7.43)	53.07 (9.14)	61.89 (8.67)
Sustainability Awareness (SAS; /5)	2.81 (0.53)	4.12 (0.48)	2.77 (0.51)	3.04 (0.55)
Collaborative Skills (CSOR; /4)	2.43 (0.61)	3.67 (0.44)	2.38 (0.58)	2.71 (0.52)
Project Engagement (/5)	—	4.08 (0.39)	—	—

Note. Exp. = Experimental; Ctrl. = Control; SAS = Sustainability Awareness Scale; CSOR = Collaborative Skills Observation Rubric.

2. Main Effects of SI-PjBL on Learning Outcomes

ANCOVA results revealed significant main effects of intervention condition on all three posttest outcomes (Table 2). For mathematics achievement, the experimental group significantly outperformed the control group ($F(1, 125) = 67.43, p < .001, \eta^2 = .35$, Cohen's $d = 0.78$), representing a large effect consistent with recent meta-analytic evidence on PjBL effectiveness in elementary mathematics (Rehman et al., 2024; Ndiung & Menggo, 2024). The experimental group also showed substantially greater gains in sustainability awareness ($F(1, 125) = 89.12, p < .001, \eta^2 = .42, d = 0.91$), consistent with findings that ESD integration in mathematics classrooms enhances environmental attitudes (Vorhölter et al., 2025; Zhou et al., 2025). Collaborative skills also significantly favored the experimental group ($F(1, 125) = 72.18, p < .001, \eta^2 = .37, d = 0.84$), corroborating evidence that PjBL is a strong catalyst for 21st-century collaborative competencies (Rehman et al., 2024).

Table 2. ANCOVA Results: Adjusted Posttest Means by Condition

Outcome Variable	Exp. Adj. M (SE)	Ctrl. Adj. M (SE)	F (1, 125)	Cohen's d
Mathematics Achievement	77.94 (0.93)	62.11 (0.93)	67.43***	0.78
Sustainability Awareness (SAS)	4.11 (0.06)	3.06 (0.06)	89.12***	0.91
Collaborative Skills (CSOR)	3.65 (0.06)	2.73 (0.06)	72.18***	0.84

Note. *** $p < .001$. Adj. M = Adjusted Mean; SE = Standard Error.

3. Mediation Analysis

The SEM mediation model demonstrated good fit: CFI = .96, TLI = .95, RMSEA = .053 [90% CI: .031, .074], SRMR = .048. As shown in Table 3, collaborative learning significantly predicted sustainability project engagement ($\beta = 0.59, p < .001$), which in turn significantly predicted mathematics achievement ($\beta = 0.47, p < .001$). The direct effect of collaborative learning on mathematics achievement remained significant but reduced ($\beta = 0.31, p = .002$), indicating partial mediation. The indirect effect was significant ($\beta_{\text{indirect}} = 0.28, 95\% \text{ CI } [0.14, 0.43], p < .001$), accounting for approximately 47% of the total effect. This finding provides novel empirical evidence that the depth of engagement with sustainability projects is a critical mechanism through which collaborative learning translates into mathematics achievement—an insight not yet documented in the Indonesian elementary mathematics literature.

Table 3. SEM Path Coefficients and Indirect Effects

Path	β	SE	95% CI	p
Collaborative Learning → Project Engagement	0.59	0.08	[0.44, 0.74]	< .001
Project Engagement → Math Achievement	0.47	0.09	[0.30, 0.64]	< .001
Collaborative Learning → Math Achievement (direct)	0.31	0.10	[0.11, 0.51]	.002
Indirect Effect (via Project Engagement)	0.28	0.07	[0.14, 0.43]	< .001

Note. β = standardized path coefficient; CI = confidence interval (bootstrap, 5,000 iterations).

The large effect sizes observed across all three outcome domains simultaneously extend prior single-outcome PjBL studies in Indonesian elementary mathematics (Wahyuni et al., 2024; Anggraini et al., 2023; Fatimah et al., 2024). The finding that SI-PjBL benefits mathematics achievement, sustainability awareness, and collaborative skills concurrently aligns with Pérez-Jorge et al.'s (2025) systematic review showing that well-structured PjBL with sustainability focus optimizes both academic and competency outcomes. The sustainability awareness gains ($d = 0.91$) are particularly notable and consistent with recent evidence that ESD integrated into primary school mathematics produces stronger environmental attitude shifts than standalone environmental programs (Komariah & Sa'ud, 2024; European Journal of Science and Mathematics Education, 2024).

The mediation finding—that sustainability project engagement partially mediates the collaborative learning to mathematics achievement pathway—adds mechanistic depth to the

literature. It suggests that the authenticity and complexity of sustainability problems, which compel genuine collaborative mathematical inquiry, is the active ingredient driving achievement gains. This aligns with Zhou et al.'s (2025) scoping review establishing collaborative learning as a key mechanism for ESD outcomes, and with Rehman et al.'s (2024) Heliyon study demonstrating PjBL as a catalyst for collaborative and problem-solving skills in mathematics. The pattern also resonates with Vygotsky's (1978) sociocultural theory, wherein cognitively demanding collaborative engagement with meaningful real-world problems accelerates development beyond what individual or decontextualized practice achieves.

For Indonesian elementary education specifically, these findings carry direct policy implications. The SI-PjBL model demonstrates that the Merdeka Curriculum's P5 framework need not be confined to extracurricular project time; rather, it can be systematically woven into core mathematics instruction with measurable academic benefits. This is particularly significant given Indonesia's ongoing effort to close the mathematics achievement gap identified in PISA 2022 (OECD, 2023) while simultaneously advancing SDG 4 commitments (Irawan et al., 2024).

D. CONCLUSION

This study developed, implemented, and evaluated the Sustainability-Integrated Project-Based Learning (SI-PjBL) model for Grade 5 elementary mathematics in Padang, West Sumatera, Indonesia. Using a quasi-experimental design with 128 students across four public elementary schools, SI-PjBL significantly enhanced mathematics achievement (Cohen's $d = 0.78$), sustainability awareness ($d = 0.91$), and collaborative skills ($d = 0.84$) relative to conventional instruction. SEM revealed that sustainability project engagement partially mediated the collaborative learning–mathematics achievement relationship ($\beta_{\text{indirect}} = 0.28$, 95% CI [0.14, 0.43]), identifying a novel mechanism through which the model operates.

Four distinct contributions emerge: (1) a theoretically grounded SI-PjBL model aligned with the Merdeka Curriculum and UNESCO ESD 2030 framework; (2) validated SAS and CSOR instruments for Indonesian elementary students; (3) robust quasi-experimental evidence of multi-domain SI-PjBL effectiveness; and (4) empirical modeling of sustainability engagement as a mediating mechanism in collaborative mathematics learning—the first such model documented in Indonesian SD contexts.

Practical recommendations include: teacher professional development equipping elementary teachers with both sustainability content knowledge and PjBL facilitation skills; systematic mapping of sustainability themes onto Grade 1–6 mathematics standards within the Merdeka Curriculum; and school-level scheduling that allows multi-week sustainability mathematics projects. Future research should examine long-term retention effects, scalability across diverse Indonesian regions, digital enhancement through educational technology, and longitudinal tracking of student trajectories from elementary through secondary school.

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