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ORIGINAL RESEARCH ARTICLE

Measuring Ecoliteracy Outcomes: The Efficacy of The Kalimas-Yarra Steam Learning Reconstruction in Urban Elementary Schools

Dyka Septiana Putri[1], Salsabilla Az Zahroh [2], Kirana Ai[3], Dr. Ari Metalin Ika Puspita[4], Nurul Istiq'faroh[5]

1. [1245]Surabaya State University
2. [3]Malang State University

Correspondence: putridika49@gmail.com
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ABSTRACT

Background: Traditional elementary education often remains theoretical and isolated from local environmental challenges, necessitating contextual learning models that connect local realities with global perspectives. Purpose: This study aims to evaluate the efficacy of reconstructed aquatic-based STEAM learning using the Kalimas River ecosystem as an open laboratory, integrating global governance practices from Australia's Yarra River. Methods: A quantitative pre-experimental one-group pretest-posttest design was conducted with 30 elementary students at SDN Kaliasin 1, Surabaya, using validated cognitive tests (Aiken's V = 0.84–0.92; KR-20 = 0.81), structured observations, and interviews. Results: Paired sample t-test revealed a significant increase in learning outcomes from pretest (M = 75.07, SD = 14.16) to posttest (M = 88.40, SD = 8.41; t = -9.775, $p < 0.001$, r = 0.904), alongside reduced variance in student achievement and enhanced critical thinking, creativity, and ecological problem-solving skills. Conclusion: Reconstructing STEAM instruction with glocal river perspectives effectively bridges local environmental issues with global standards, serving as an impactful pedagogical model to foster 21st-century competencies and ecoliteracy in urban elementary education.

Keywords: STEAM, Kalimas River, contextual learning, environmental education, sustainability.

ABSTRAK

Latar Belakang: Pendidikan dasar tradisional sering kali bersifat teoretis dan terisolasi dari tantangan lingkungan setempat, sehingga diperlukan model pembelajaran kontekstual yang menghubungkan realitas lokal dengan perspektif global. Tujuan: Penelitian ini bertujuan untuk mengevaluasi efektivitas pembelajaran STEAM berbasis ekosistem perairan yang direkonstruksi dengan memanfaatkan ekosistem Sungai Kalimas sebagai laboratorium terbuka, serta mengintegrasikan praktik tata kelola global dari Sungai Yarra di Australia. Metode: Penelitian kuantitatif dengan desain pra-eksperimental *one-group pretest-posttest* dilakukan terhadap 30 siswa sekolah dasar di SDN Kaliasin 1, Surabaya, menggunakan tes kognitif yang telah divalidasi (Aiken's V = 0,84–0,92; KR-20 = 0,81), observasi terstruktur, dan wawancara. Hasil: Uji-t sampel berpasangan (*paired sample t-test*) menunjukkan peningkatan signifikan pada hasil belajar dari *pretest* (M = 75,07; SD = 14,16) ke *posttest* (M = 88,40; SD = 8,41; t = -9,775; p < 0,001; r = 0,904), disertai dengan berkurangnya varians dalam pencapaian siswa serta peningkatan kemampuan berpikir kritis, kreativitas, dan pemecahan masalah ekologis. Kesimpulan: Rekonstruksi pembelajaran STEAM dengan perspektif sungai yang bersifat "glokal" (menggabungkan unsur lokal dan global) secara efektif menjembatani isu lingkungan lokal dengan standar global, serta menjadi model pedagogis yang berdampak dalam menumbuhkan kompetensi abad ke-21 dan ekoliterasi dalam pendidikan dasar perkotaan.

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Keywords: STEAM, Sungai Kalimas, pembelajaran kontekstual, pendidikan lingkungan, keberlanjutan.

INTRODUCTION

The transformation of elementary education in the twenty-first century increasingly requires learning to move beyond the transmission of disciplinary knowledge toward the development of students' capacity to understand, evaluate, and respond to complex sustainability problems. Global education agendas now position climate change, biodiversity loss, unsustainable resource use, and environmental degradation as educational concerns requiring learners to develop knowledge, skills, values, attitudes, and the capacity to take informed action (UNESCO, 2021; OECD, 2022). UNESCO's recent Greening Curriculum Guidance further emphasizes that sustainability education should be action-oriented, scientifically grounded, interdisciplinary, context-sensitive, and connected with learners' lived environments rather than being restricted to abstract classroom knowledge (UNESCO, 2024; UNESCO, 2024). Similarly, the OECD conceptualizes environmental sustainability competence through interconnected cognitive, affective, behavioral, and attitudinal dimensions, indicating that environmental learning should enable students not only to know about ecological problems but also to interpret evidence and consider appropriate responses (Borgonovi et al., 2022; OECD, 2022). Within this global transformation, STEAM—Science, Technology, Engineering, Arts, and Mathematics—offers a particularly relevant pedagogical orientation because it connects disciplinary knowledge with authentic problems, design processes, creativity, and solution development (Asghar et al., 2024; Anggraini & Herwin, 2025). Consequently, the use of real urban ecosystems as learning environments represents an important pathway for translating global sustainability expectations into meaningful elementary learning experiences.

The urgency of such transformation becomes particularly visible in urban river environments, where ecological degradation is simultaneously an environmental, social, and educational problem. The Kalimas River in Surabaya, for example, passes through densely populated, commercial, industrial, and residential areas and therefore receives pressures associated with domestic and anthropogenic activities (Pambudi et al., 2022; Kurnianto et al., 2024). Empirical assessments have identified persistent water-quality concerns: Aristananda et al. (2023) found that the Kalimas was predominantly categorized as lightly polluted using the Pollution Index but substantially more concerning under the NSF-WQI classification, while Kurnianto et al. (2024) reported elevated BOD, COD, and TSS alongside reduced dissolved oxygen at several locations. Other investigations have identified microbial contamination and microplastic contamination, indicating that the river represents a multidimensional environmental problem rather than a single pollution issue (Rahmawati & Binawati, 2024; Fitriyah et al., 2022). At the same time, these environmental pressures expose a pedagogical challenge: students may learn ecological concepts without directly encountering the ecological systems to which those concepts refer. Studies of elementary ecoliteracy in Indonesia indicate that environmental knowledge and awareness do not automatically translate into environmentally responsible action, while classroom implementation remains constrained by limited contextualization and instructional integration (Safitri et al., 2023; Utari, 2025). The challenge, therefore, is not merely environmental degradation itself, but the absence of sufficiently contextual, interdisciplinary, and experiential learning mechanisms through which students can interpret and respond to such degradation.

Research conducted during 2020–2025 provides substantial evidence that contextual, project-based, and interdisciplinary learning can strengthen environmental and ecological learning outcomes, although the studies differ considerably in scope and methodological orientation. Mustafida and Wulandari (2021) profiled ecoliteracy among 92 first-grade elementary students and demonstrated the importance of measuring ecological competence at an early age, but their survey design primarily described students' existing profiles rather than evaluating a contextual intervention. Afiani et al. (2022) implemented contextual learning based on ecoliteracy with fourth-grade students and reported improved learning outcomes and student engagement, although the intervention focused specifically on poetry writing rather than interdisciplinary ecological problem-solving. Widyasmoro et al. (2022) examined ecosystem e-book-assisted PjBL and found positive effects on ecoliteracy and problem-solving, but the intervention remained mediated by classroom instructional materials rather than an actual urban ecosystem. Kusnadi et al. (2023) developed online PjBL-STEAM learning devices to improve environmental literacy, demonstrating the potential of integrating STEAM and project-based learning but emphasizing digital instructional development rather than direct environmental field engagement. Similarly, Chaesar and Andayani (2024) demonstrated that ecoliteracy-integrated PjBL improved elementary students' creative thinking compared with conventional instruction, while Setiadi et al. (2023) established the relevance of ecoliteracy competence to environmental sustainability among elementary students. Collectively, these studies substantiate the pedagogical value of ecoliteracy, contextual learning, PjBL, and STEAM, but they also reveal that these components have largely been investigated separately or within conventional classroom settings (Setiadi et al., 2023; Chaesar & Andayani, 2024).

Further evidence strengthens the case for an interdisciplinary environmental learning reconstruction but simultaneously exposes limitations in the existing research trajectory. Pratiwi and Supriatna (2022) reported that PjBL supported students' ecological knowledge and attitudes when students processed plastic waste through collaborative activities, indicating that authentic environmental tasks can make ecoliteracy more meaningful. Widyasmoro et al. (2022) similarly showed that PjBL combined with ecosystem-oriented digital resources could improve ecoliteracy and problem-solving, although the environmental context was still represented primarily through instructional media. Zahrawati et al. (2023) designed a project-based ecoliteracy learning trajectory to strengthen ecological intelligence, but the study was conducted with students in higher education rather than elementary pupils. Chaesar and Andayani (2024) found that ecoliteracy-integrated PjBL was more effective than conventional learning for creative thinking, yet their ecological context remained associated with explanatory-text instruction rather than direct investigation of an urban ecosystem. More recently, Anggraini and Herwin (2025) experimentally examined STEAM-PjBL with elementary students and found its relevance for improving environmental awareness, but the study did not integrate an actual river ecosystem or a comparative international environmental-governance perspective. The emerging literature therefore demonstrates that PjBL, STEAM, contextual learning, and ecoliteracy can produce meaningful educational effects, but the interventions generally remain focused on classroom projects, recycling, digital resources, urban farming, or generic environmental themes rather than using an urban river as an open laboratory (Aripin & Putri, 2021; Kusnadi et al., 2023; Anggraini & Herwin, 2025). This limitation becomes particularly important when the intended outcome extends beyond environmental awareness toward measurable ecological knowledge and twenty-first-century problem-solving competencies.

The distinctive novelty of the present study lies in reconstructing STEAM learning around an actual urban aquatic ecosystem while simultaneously connecting the local ecological context of the Kalimas River with a global-local learning perspective derived from the Yarra River in Melbourne, Australia. Existing Indonesian studies have demonstrated the effectiveness of environmental PjBL, ecoliteracy-based instruction, contextual learning, and STEAM, but their ecological settings have generally involved classroom simulations, waste utilization, digital media, urban farming, or generalized environmental issues rather than a river ecosystem functioning as an open laboratory (Aripin & Putri, 2021; Widyasmoro et al., 2022; Kusnadi et al., 2023; Anggraini & Herwin, 2025). The Yarra/Birrarung context provides an empirically observable reference because environmental management in Victoria combines scientific monitoring, community participation, water-quality assessment, biodiversity protection, and educational engagement (Commissioner for Environmental Sustainability Victoria, 2024; Melbourne Water, 2024). The Yarra Strategic Plan and related governance initiatives also conceptualize river health through interconnected environmental and community indicators rather than treating water quality as an isolated technical variable (Commissioner for Environmental Sustainability Victoria, 2024; Birrarung Council, 2025). Educational initiatives around the Yarra further demonstrate how river environments can become sites for field observation, water-quality investigation, biodiversity learning, and interdisciplinary engagement (Melbourne Water, 2021; Merri Creek Management Committee, 2025). The present study therefore introduces a Kalimas–Yarra glocal reconstruction, in which the Kalimas is retained as the students' immediate ecological reality while selected principles of Yarra environmental governance become a comparative stimulus for designing STEAM learning. This positioning distinguishes the study from interventions that merely add environmental content to an existing instructional model.

This reconstruction addresses a research gap that emerges at the intersection of three bodies of literature: ecoliteracy education, STEAM/PjBL, and river-based environmental learning. First, systematic reviews have shown that elementary ecoliteracy research has concentrated on ecological knowledge, contextual learning, teaching materials, project-based models, and environmental programs, while relatively few studies have developed and empirically evaluated comprehensive instructional models specifically designed to cultivate ecological competence (Safitri et al., 2023; Utari, 2025). Second, recent STEAM-PjBL research has demonstrated improvements in environmental awareness, creativity, critical thinking, and related competencies, but these interventions have generally been implemented through classroom projects or recyclable-material activities rather than through authentic urban aquatic ecosystems (Kusnadi et al., 2023; Anggraini & Herwin, 2025). Third, research concerning the Kalimas River has primarily concentrated on hydrological, chemical, microbiological, and pollution-management dimensions, including water-quality indices, pollutant loads, microplastics, and health risks (Pambudi et al., 2022; Aristananda et al., 2023; Kurnianto et al., 2024). Consequently, an important unexplored intersection remains: how an empirically documented urban river problem can be transformed into a structured STEAM learning environment and evaluated through measurable student learning outcomes. The present study fills this gap by connecting environmental evidence from the Kalimas with pedagogical reconstruction, rather than merely describing the river's ecological condition or evaluating an unrelated classroom intervention. The gap is therefore both contextual and methodological: the literature lacks sufficient evidence concerning whether a glocal, aquatic-based STEAM reconstruction can produce measurable improvement in elementary students' learning outcomes.

The theoretical foundation of this reconstruction is principally derived from constructivist learning theory, project-based learning, STEAM pedagogy, and Education for Sustainable Development, which together explain why direct engagement with a real ecological system can support meaningful learning. Constructivism conceptualizes learning as an active process in which learners construct and reorganize knowledge through interaction with phenomena, prior experience, social interaction, and reflection; contemporary environmental-learning research similarly emphasizes that everyday and place-based experiences can provide meaningful foundations for environmental understanding and behavioral change (Ardoin & Heimlich, 2021; UNESCO, 2024). Project-based learning extends this logic by organizing learning around authentic questions, investigation, design, production, reflection, and evaluation, thereby allowing students to connect disciplinary knowledge with concrete problems (Almulla, 2020; Chaesar & Andayani, 2024). STEAM adds interdisciplinary integration by requiring learners to mobilize scientific explanations, technological tools, engineering design, artistic representation, and mathematical reasoning when confronting complex real-world problems (Kusnadi et al., 2023; Anggraini & Herwin, 2025). Meanwhile, Education for Sustainable Development provides the broader normative framework by positioning knowledge, skills, values, attitudes, and action as interconnected learning outcomes for sustainability (UNESCO, 2021; UNESCO, 2024). Within this theoretical architecture, the Kalimas River becomes the experiential environment, the environmental problem becomes the learning stimulus, STEAM provides the interdisciplinary mechanism, PjBL structures the inquiry and production process, and ESD provides the sustainability orientation against which learning becomes educationally meaningful.

Conceptually, the study uses ecoliteracy outcomes as the central educational construct and interprets them as more than the accumulation of environmental facts. Contemporary literature conceptualizes ecoliteracy through interconnected dimensions involving ecological knowledge, systems thinking, critical evaluation, environmental awareness, practical application, and participation in ecological problem-solving (Setiadi et al., 2023; Murti et al., 2025). This conceptualization is compatible with the present study because the reconstructed learning environment requires students to investigate an actual river ecosystem, interpret environmental conditions, identify problems, and formulate possible solutions through STEAM processes. The concept of glocalization further connects the immediate Kalimas context with broader international environmental practices: instead of transferring Yarra governance practices mechanically into Surabaya, the reconstruction uses the Yarra as a global reference while adapting its educational principles to the ecological, cultural, and instructional characteristics of the Kalimas environment (UNESCO, 2024; Commissioner for Environmental Sustainability Victoria, 2024). The river-as-open-laboratory concept then positions the environment not simply as an object about which students receive information, but as a source of observable evidence that can generate questions, measurements, interpretations, designs, and creative responses (Melbourne Water, 2021; Merri Creek Management Committee, 2025). Thus, the conceptual relationship can be understood as Kalimas ecosystem → authentic environmental problem → glocal comparison with Yarra → STEAM inquiry and design → ecoliteracy and twenty-first-century learning outcomes. This integrated configuration is substantially different from approaches in which environmental content is inserted into an otherwise conventional lesson (Widyasmoro et al., 2022; Anggraini & Herwin, 2025).

What makes this study particularly important is the possibility of transforming an environmental liability of an urban city into a pedagogical resource while simultaneously addressing the persistent problem of unequal and fragmented learning outcomes. The Kalimas River presents students with an environment in which pollution, biodiversity, water quality, human activity, urban development, and sustainability can be interpreted as interconnected rather than as isolated textbook topics (Aristananda et al., 2023; Kurnianto et al., 2024). The Yarra experience demonstrates that urban rivers can also become platforms for environmental monitoring, community participation, educational activities, biodiversity engagement, and public understanding of river health (Melbourne Water, 2021; Commissioner for Environmental Sustainability Victoria, 2024). This creates an intellectually significant contrast: the same broad ecological problem—an urban river under human pressure—can be approached through different governance and educational contexts, allowing local learning to acquire global relevance without losing its contextual identity. Such a design also responds directly to UNESCO's call for environmental and climate learning that is action-oriented, experiential, interdisciplinary, and connected to learners' own contexts (UNESCO, 2024; UNESCO, 2024). Empirically evaluating the reconstruction is therefore important because evidence is still needed regarding whether this type of glocal aquatic STEAM intervention produces measurable improvements in elementary students' learning outcomes. Accordingly, this study aims to evaluate the efficacy of reconstructed aquatic-based STEAM learning using the Kalimas River ecosystem as an open laboratory while integrating selected global governance-learning perspectives from Australia's Yarra River, thereby examining its capacity to strengthen elementary students' learning outcomes and support critical thinking, creativity, ecological problem-solving, and ecoliteracy within an urban educational context.

RESEARCH METHODS

This study employed a quantitative pre-experimental approach using a one-group pretest–posttest design to evaluate the efficacy of a reconstructed aquatic-based STEAM learning intervention situated in the Kalimas River ecosystem and informed by the river-governance perspective of Australia's Yarra River. The methodological orientation was designed to preserve the central characteristic of the intervention: learning was not treated as the transmission of environmental information alone, but as a contextualized STEAM experience in which students encountered a local river ecosystem as an open laboratory, investigated environmental problems, and developed responses through project-based learning. Such an approach is consistent with recent empirical evidence showing that STEM/STEAM and project-based learning can strengthen environmental literacy, scientific literacy, environmental attitudes, reasoning, and problem-solving when learning is connected to authentic environmental problems (Adriyawati et al., 2020; Sigit et al., 2022; Baek, 2023; Pertiwi et al., 2024).

The study further incorporated methodological triangulation through a cognitive test, structured behavioral observation, and semi-structured interviews. The cognitive test served as the principal quantitative outcome measure, whereas observation and interview data provided contextual evidence concerning students' engagement, collaboration, creativity, critical thinking, and ecological problem-solving during the intervention. This combination is particularly appropriate for contextual environmental learning because recent river- and place-based studies have demonstrated the value of combining learning assessments with field observations, student reflections, interviews, and authentic environmental activities (Choi & Kim, 2025).

Table 1. Research Questions and Types of Analysis

No.	Research Question	Data Source	Type of Analysis	Main Output
RQ1	Does the reconstructed Kalimas–Yarra STEAM learning intervention improve students' learning outcomes/ecoliteracy?	Pretest and posttest	Descriptive statistics; paired-samples *t*-test	Mean difference, *t*, *p*
RQ2	What changes in students' critical thinking, creativity, collaboration, and ecological problem-solving are observable during the intervention?	Structured observations and interviews	Descriptive/qualitative interpretation and triangulation	Behavioral and contextual evidence
RQ3	Does the intervention produce more consistent student achievement after learning?	Pretest and posttest scores	Comparison of *SD* and score dispersion	Reduction in score variability
RQ4	What evidence supports the instructional efficacy of the reconstructed STEAM model as a contextual environmental-learning approach?	Test, observation, interview, intervention records	Convergent interpretation/triangulation	Integrated efficacy interpretation

Table 1 establishes the analytical architecture of the study and prevents the cognitive test from being interpreted as the sole evidence of instructional efficacy. The distinction is important because environmental literacy and STEAM competence involve more than factual knowledge; recent empirical studies have similarly combined cognitive assessments with observations, field notes, and learning products to capture environmental competencies more comprehensively (Baek, 2023; Sigit et al., 2022).

2.1 Research Design

The study used a one-group pretest–posttest pre-experimental design, represented as O_1–X–O_2, where O_1 represents the pretest, X represents the reconstructed Kalimas–Yarra STEAM learning intervention, and O_2 represents the posttest. The design was selected because the study sought to determine whether measurable changes occurred in the same group of elementary students before and after participation in the contextualized intervention. The pretest established students' baseline performance, the intervention exposed them to project-based aquatic STEAM learning, and the posttest assessed their performance after completing the learning experience. Similar pre-experimental designs have been used in recent environmental-literacy research, including studies examining STEM-PjBL, environmental modules, and project-based environmental education (Indrasari & Wulandari, 2024; Handayani et al., 2024). The design can be expressed as follows:

Figure 1. One-Group Pretest–Posttest Research Design

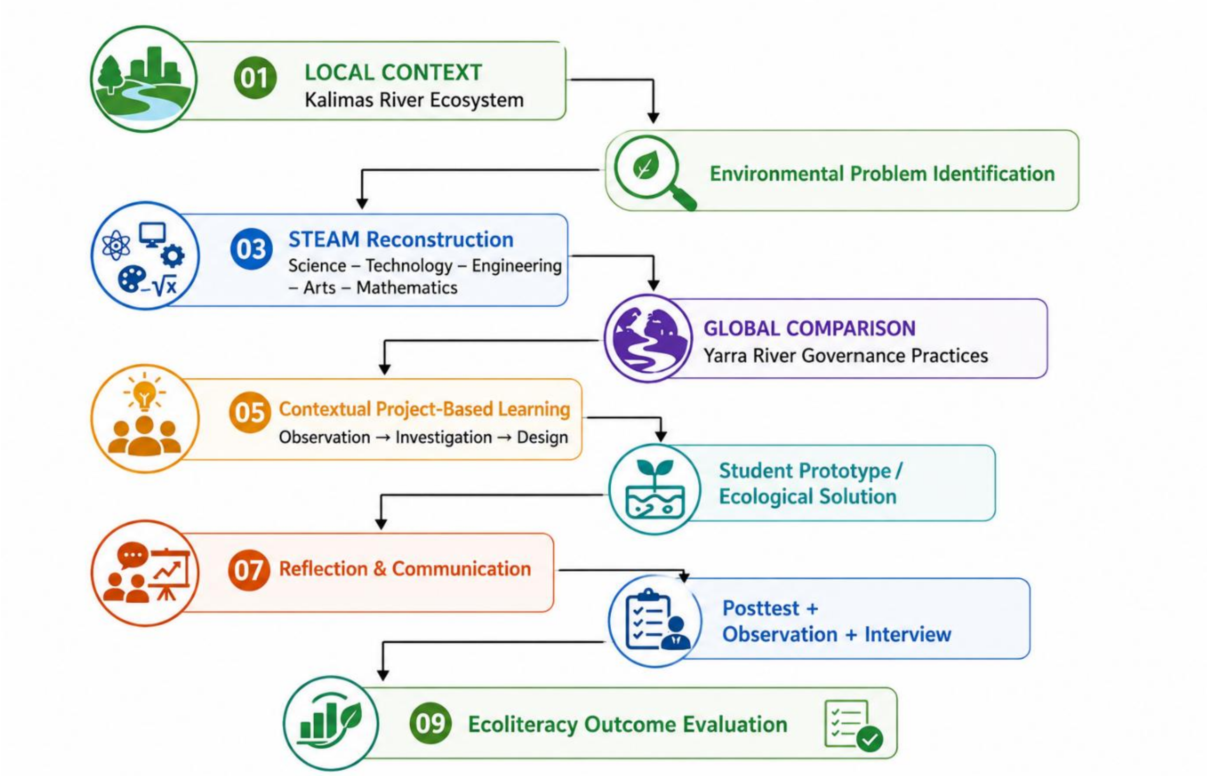


Figure 1 depicts the causal sequence represented by the supplied original method: baseline measurement, treatment via project-based learning in the Kalimas River open laboratory, and post-intervention measurement. The design is appropriate for detecting within-group change but does not provide the same level of causal control as a randomized control-group design; consequently, the interpretation should remain focused on instructional efficacy/evidence of improvement, rather than claiming definitive causal superiority over conventional instruction. This methodological caution is consistent with recent studies that use one-group pretest–posttest designs to evaluate environmental learning interventions (Indrasari & Wulandari, 2024; Febriliani & Budiyanto, 2025).

The design is subsequently operationalized through a clearly sequenced intervention and measurement procedure. Therefore, the next subsection explains how the learning reconstruction was positioned between the pretest and posttest.

2.2 Intervention Reconstruction and Research Procedure

The intervention was organized around the reconstruction of STEAM learning from a local–global river perspective. The Kalimas River functioned as the local ecological context and open laboratory, while the Yarra River provided a comparative governance perspective through which students could consider how an urban river may be understood, managed, protected, and connected to community responsibility. The reconstruction therefore did not replace the local context with an overseas context; rather, it connected local environmental observation with a global reference point. This logic is compatible with place-based environmental education, in which local ecological settings become meaningful learning environments, and with recent river-based elementary education research emphasizing field investigation, community mapping, environmental problem solving, and ecological citizenship (Choi & Kim, 2025). The learning process was conceptually structured as follows.

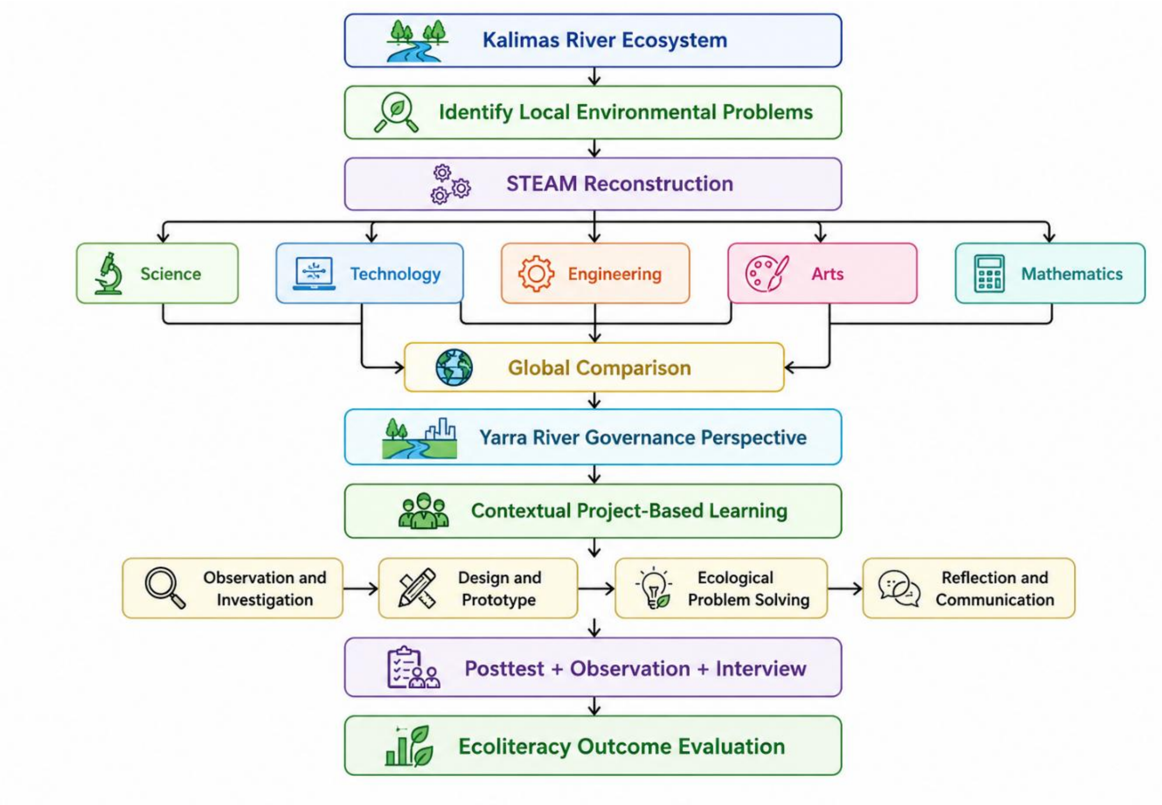


Figure 2. Kalimas–Yarra STEAM Learning Reconstruction Process

Figure 2 represents the methodological logic of the reconstructed intervention rather than introducing an additional empirical dataset. The reconstruction maintains the character of a STEAM product because students encounter a real environmental problem, integrate multiple disciplinary perspectives, develop a response, and communicate the resulting solution. Similar integration of STEAM/PjBL with environmental issues has been shown to support environmental literacy, ecological concept mastery, reasoning, and environmental competencies (Sigit et al., 2022; Baek, 2023; Pertiwi et al., 2024). This intervention sequence leads directly to the data that were generated from students' learning experiences; consequently, the next subsection clarifies the study's data structure and analytical framework.

2.3 Data Analysis Framework

The analysis framework was developed to distinguish between primary outcome data and supporting process data. The primary outcome was represented by students' cognitive test scores obtained before and after the intervention, whereas structured observations and semi-structured interviews were used to contextualize how students participated in the learning process. The quantitative analysis focused on changes in central tendency and dispersion and on testing whether the pretest and posttest scores differed significantly. This approach corresponds with recent environmental-learning studies in which pretest–posttest scores were combined with observation or contextual evidence to evaluate instructional effectiveness (Indrasari & Wulandari, 2024; Handayani et al., 2024).

The principal quantitative indicators were the mean, standard deviation, paired-samples *t*-test, significance level, and reported effect-size correlation. The observed increase from a pretest mean of 75.07 (SD = 14.16) to a posttest mean of 88.40 (SD = 8.41) was therefore interpreted as both an improvement in average performance and a reduction in score dispersion. The paired test yielded $t = -9.775$, $p < .001$, $r = .904$, indicating a statistically significant and large within-group association between the intervention period and the observed pre–post change. Recent studies applying one-group pretest–posttest designs in environmental literacy likewise use paired comparisons to establish whether post-intervention scores exceed baseline scores (Febriliani & Budiyanto, 2025; Indrasari & Wulandari, 2024).

Table 2. Data Sources and Analytical Functions

Data source	Data form	Primary purpose	Analysis
Cognitive test	25 multiple-choice items	Measure learning outcomes, critical thinking, ecological problem-solving	Mean, SD, paired *t*-test
Structured observation	Likert 1–5 rubric	Examine engagement, collaboration, creativity/prototyping	Descriptive scoring and interpretation
Semi-structured interview	Student/learning-process responses	Contextualize learning experience and problem solving	Thematic/descriptive interpretation
Pretest–posttest dataset	Paired student scores	Determine intervention-related change	Paired *t*, *p*, effect size *r*

The table clarifies that the study uses triangulation rather than methodological substitution: the test establishes measurable outcome change, while observations and interviews provide process-level evidence. This is particularly relevant because ecological literacy includes knowledge and cognitive skills but is also connected to environmental attitudes, behavior, and action; recent STEAM and environmental-learning studies similarly recommend multiple sources of evidence rather than relying on a single assessment modality (Sigit et al., 2022; Baek, 2023). The analytical framework is implemented through instruments that must first be defined in terms of content, structure, and scoring; therefore, the following subsection specifies the instruments used.

2.4 Research Instruments

Three data-collection instruments were employed: a cognitive achievement test, a structured behavioral observation rubric, and a semi-structured interview guide. The cognitive instrument consisted of 25 multiple-choice items designed to measure students' environmental understanding and higher-order learning outcomes, particularly critical thinking and ecological problem-solving. The observation instrument used a five-point Likert rubric (1–5) to document active engagement, collaboration, and creativity during project-based prototyping. Interviews were used to obtain complementary information concerning students' learning experiences and responses to environmental problems. This combination follows the principle that environmental and STEAM competencies should be assessed through cognitive, behavioral, and process evidence rather than through factual recall alone (Baek, 2023; Sigit et al., 2022).

Table 3. Instrument Blueprint

Instrument	No. of items/components	Respondent/source	Indicators	Sub-indicators	Scale
Cognitive test	25 items	30 elementary students	Environmental understanding	Ecological concepts; river ecosystem; environmental problems	Dichotomous
Cognitive test	Included within 25 items	30 students	Critical thinking	Identifying problems; interpreting evidence; evaluating alternatives	Dichotomous
Cognitive test	Included within 25 items	30 students	Ecological problem solving	Problem identification; solution selection; application	Dichotomous
Observation rubric	Structured rubric	Students during intervention	Active engagement	Participation, attention, initiative	1–5
Observation rubric	Structured rubric	Students during project	Collaboration	Communication, role sharing, teamwork	1–5
Observation rubric	Structured rubric	Students during prototype activity	Creativity	Idea generation, design modification, originality	1–5
Interview guide	Semi-structured	Students/learning participants	Learning experience	Environmental understanding, reflection, perceived problem solving	Qualitative

The instrument architecture is consistent with recent elementary STEAM research in which pre/post assessments are complemented by field notes, learning outcomes, and qualitative evidence (Baek, 2023; Adriyawati et al., 2020). The 25-item cognitive test also permits dichotomous scoring appropriate for KR-20 reliability estimation, while the observation rubric is retained as an ordinal behavioral measure rather than being treated as equivalent to the cognitive achievement test. This distinction is methodologically important because KR-20 is specifically associated with dichotomously scored items, and recent psychometric research continues to emphasize careful matching between reliability procedures and item characteristics (Foster, 2021; Ntumi et al., 2023).

The instruments therefore form a measurement system in which cognitive achievement is the principal pre–post outcome and behavioral/interview evidence provides triangulation. Their technical quality is addressed next.

2.5 Validity and Reliability

The cognitive test underwent technical feasibility assessment before being used as the principal measure of intervention outcomes. Content validity was established through expert judgment by two lecturers specializing in instructional design and science education, producing an Aiken's *V* range of 0.84–0.92. These values indicate strong agreement concerning the relevance of the test items to their intended content domains. Recent Indonesian educational research continues to employ Aiken's *V* as a quantitative method for evaluating content validity when experts judge the relevance of instrument items (Noviana et al., 2023).

Reliability was assessed using the Kuder–Richardson Formula 20 (KR-20) because the cognitive test consisted of multiple-choice items scored dichotomously. The resulting reliability coefficient was 0.81, indicating high internal consistency for the purposes of the intervention assessment. This procedure is consistent with recent instrument-development studies in education that employ KR-20 for dichotomously scored achievement tests; for example, Anggara et al. (2021) reported KR-20 reliability in elementary quantitative-literacy assessment, while Yurtyapan and Çirkinoglu Şekercioglu (2023) reported KR-20 = 0.88 for a science achievement test. The methodological relevance of KR-20 is also reinforced by Foster's (2021) discussion of Kuder–Richardson estimators and by Ntumi et al. (2023), who emphasize the role of item-level analysis in establishing the reliability of classroom tests.

Table 4. Instrument Quality Evidence

Quality criterion	Procedure	Result	Interpretation
Content validity	Expert judgment; 2 experts	Aiken's *V* = 0.84–0.92	Very strong content validity
Internal consistency	KR-20	0.81	High reliability
Test format	Multiple choice	25 items	Suitable for dichotomous scoring
Observation scoring	Structured Likert rubric	1–5	Process/behavioral evidence
Interview	Semi-structured	Qualitative	Contextual triangulation

Table 4 makes an important distinction between instrument validity/reliability and intervention effectiveness. The Aiken's *V* and KR-20 values establish the technical adequacy of the cognitive measurement instrument; they do not themselves demonstrate that the STEAM intervention was effective. Intervention effectiveness is established separately through the pretest–posttest comparison and triangulated learning evidence. This separation strengthens methodological transparency and follows current practice in environmental-literacy studies that report instrument validation independently from intervention analysis (Pertiwi et al., 2024; Baek, 2023). With the measurement quality established, the following subsection identifies the research participants and setting.

2.6 Participants and Research Setting

The study involved 30 elementary school students at SDN Kaliasin 1, Surabaya. The school served as the empirical setting for the implementation of the reconstructed aquatic-based STEAM learning intervention, with the Kalimas River ecosystem functioning as the open-laboratory context. Because the supplied original method does not specify the students' exact grade, age distribution, gender composition, sampling frame, or duration of the intervention, these details should not be added to the manuscript unless they can be verified from the original research records. This is preferable to retrospectively constructing participant characteristics that were not part of the reported dataset. The sample size of 30 nevertheless falls within the range of classroom-based intervention studies employing pre-experimental approaches, including recent environmental-literacy research using 30 students in one-group pretest–posttest designs (Handayani et al., 2024).

Table 5. Participants and Research Setting

Component	Description
Research approach	Quantitative pre-experimental

Participants	30 elementary students
School	SDN Kaliasin 1
City	Surabaya, Indonesia
Learning environment	Kalimas River ecosystem/open laboratory
Intervention orientation	Aquatic-based reconstructed STEAM
Local environmental context	Urban river ecosystem
Comparative/global perspective	Yarra River governance practices
Participant sampling details	Retained as reported in original study; no additional sampling claim added

The setting is substantively important because the intervention's novelty depends on connecting urban elementary education with a nearby aquatic ecosystem, rather than presenting environmental problems as abstract classroom content. Place-based environmental education research demonstrates that river-centered learning can support ecological knowledge, critical thinking, communication, and ecological citizenship when students investigate environmental issues in meaningful local contexts (Choi & Kim, 2025). The Yarra comparison also provides a global governance reference: the Victorian Yarra Strategic Plan explicitly emphasizes collaborative governance, public accountability, and protection of environmental and cultural values, making it a defensible comparative reference for the study's glocal learning rationale. The participant and setting description therefore establishes the ecological and educational context in which data were generated. The next subsection explains precisely how those data were statistically analyzed.

2.7 Data Analysis Techniques

Quantitative data from the cognitive test were analyzed through descriptive and inferential statistics. For both measurement occasions, the mean and standard deviation were calculated to describe students' achievement levels and score dispersion. The primary inferential procedure was a paired-samples *t*-test, which was selected because the same 30 students were measured before and after the intervention. The null hypothesis stated that there was no statistically significant difference between pretest and posttest achievement, whereas the alternative hypothesis stated that the posttest score differed from the pretest score. A significance threshold of $\alpha = .05$ was used. Recent environmental-learning studies using one-group pretest–posttest designs similarly employ paired comparisons or related pre–post procedures to establish whether an intervention is associated with significant improvement (Indrasari & Wulandari, 2024; Febriliani & Budiyanto, 2025).

The observed results were M = 75.07, SD = 14.16 at pretest and M = 88.40, SD = 8.41 at posttest, representing an increase of 13.33 score points. The paired-samples test produced $t = -9.775$, $p < .001$, indicating a statistically significant pre–post difference. The reported $r = .904$ provides an effect-size indicator showing a very strong within-group relationship associated with the pre–post change. The reduction in standard deviation from 14.16 to 8.41 was additionally considered descriptively as evidence of reduced achievement dispersion. Because the study has no comparison group, however, the analysis should avoid claiming that all observed change was caused exclusively by the intervention. The interpretation is instead framed as evidence of substantial instructional improvement within the participating group.

Table 6. Statistical Analysis Plan

Analysis	Formula/indicator	Purpose
Mean	$\Sigma X/N$	Describe average performance
Standard deviation	SD	Describe score dispersion
Mean difference	Mpost − Mpre	Quantify improvement
Paired-samples *t*-test	$t = \bar{D}/(SDD/\sqrt{n})$	Test pre–post difference
Significance	$p < .05$	Determine statistical significance
Effect size	Reported *r*	Estimate magnitude of pre–post association
Dispersion comparison	SDpre vs. SDpost	Examine consistency of achievement

The statistical procedure is therefore deliberately aligned with the study design: paired observations require paired analysis, and the descriptive reduction in variance is reported separately from the inferential test. This distinction is preferable to treating the observation data and cognitive test scores as statistically interchangeable. Recent pre-experimental environmental-literacy studies similarly distinguish descriptive improvement, significance testing, and gain/effect indicators (Indrasari & Wulandari, 2024; Handayani et al., 2024). The final methodological component specifies how the three data sources were actually collected during the research sequence.

2.8 Data Collection Techniques

Data collection was conducted through tests, structured observations, and semi-structured interviews, thereby providing triangulated evidence of the learning intervention. The cognitive test was administered twice: first as a pretest before the reconstructed STEAM intervention and subsequently as a posttest after the learning treatment. The same assessment framework was used at both measurement points so that students' performance could be compared within individuals. Structured observation was conducted during the project-based learning activities using a 1–5 rubric covering active engagement, collaboration, and creativity during prototyping. Interviews were used as a complementary source to capture students' experiences and perceptions that could not be fully represented by objective test scores. Comparable environmental and STEAM studies have used combinations of pre/post tests, observations, interviews, field notes, and student learning products to document both outcome and process dimensions (Adriyawati et al., 2020; Baek, 2023).

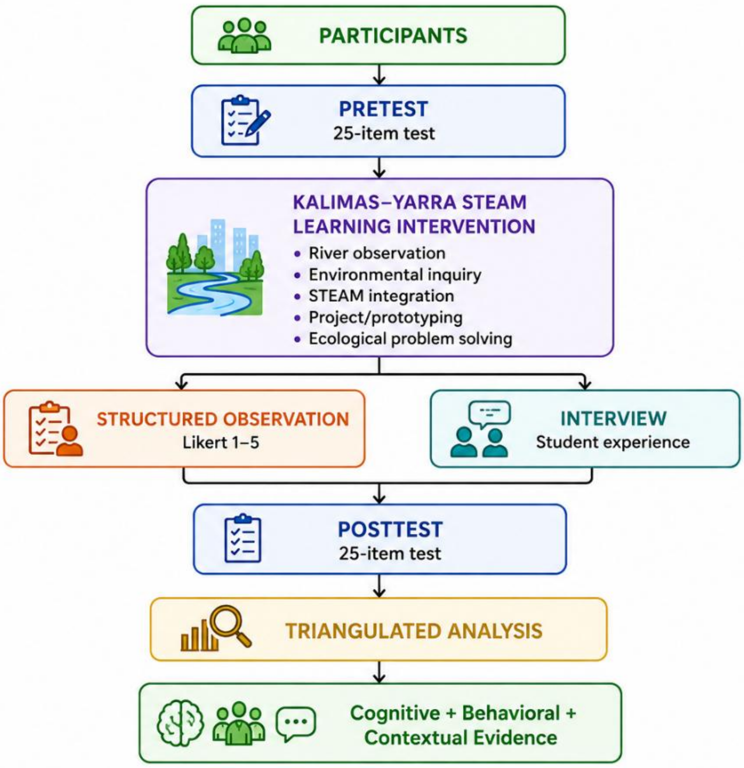


Figure 3. Data Collection Sequence

Figure 3 emphasizes that data collection was sequential rather than simultaneous: baseline cognitive performance was established first, the intervention was then implemented and observed, interviews provided contextual information, and the posttest provided the endpoint for quantitative comparison. This sequence is methodologically consistent with recent environmental-literacy interventions that collect pre/post measures alongside process evidence and subsequently integrate the different evidence streams (Sigit et al., 2022; Choi & Kim, 2025).

2.9 Methodological Alignment Between the Learning Product and Its Testing

Because the study evaluates a reconstructed learning model, the methodological process must remain consistent with the characteristics of the instructional product being evaluated. The product is not merely a worksheet or conventional lesson plan; its defining characteristics are contextuality, aquatic/ecological orientation, STEAM integration, project-based learning, local–global comparison, and ecological problem solving. Consequently, the intervention is tested through a combination of outcome measurement and authentic process evidence. This methodological alignment is supported by recent research showing that environmental STEAM/PjBL interventions are most meaningfully evaluated when students are required to engage with environmental problems, construct responses, and demonstrate learning through both cognitive outcomes and project processes (Baek, 2023; Pertiwi et al., 2024; Choi & Kim, 2025).

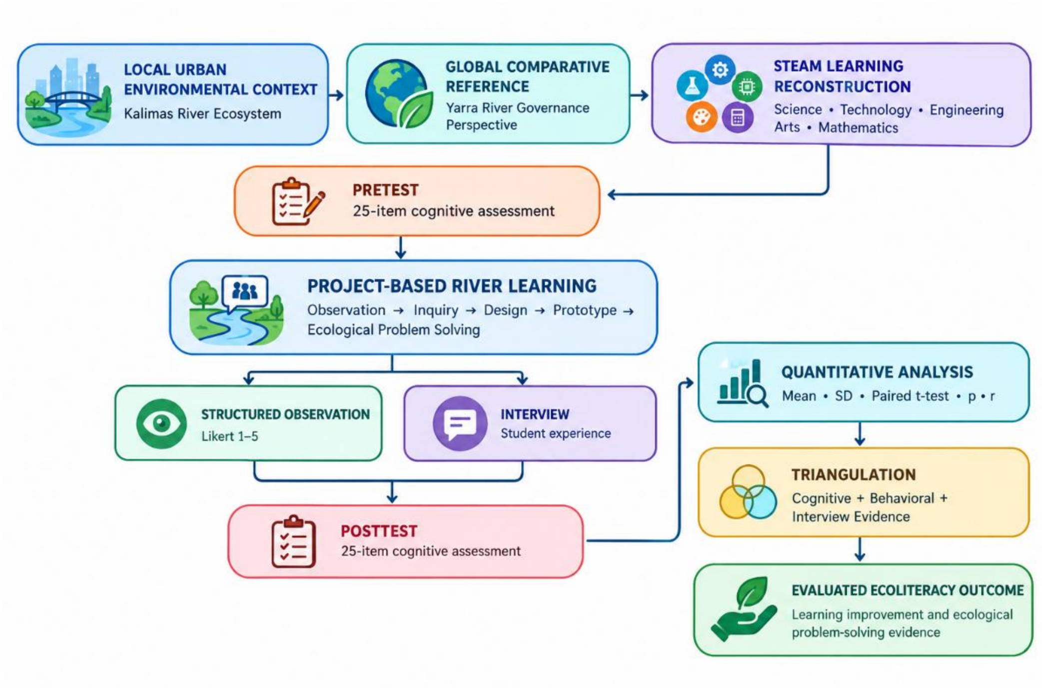
Table 7. Alignment of Product Characteristics, Learning Process, and Evaluation

Product characteristic	Learning process	Evidence collected	Evaluation
Local/contextual	Kalimas River as open laboratory	Observation + test	Ecological understanding
Global comparative	Yarra River governance perspective	Learning activity/interview	Contextual interpretation
STEAM-integrated	Science–Technology–Engineering–Arts–Mathematics	Observation + learning outcomes	Integrated competency
Project-based	Investigation, design, prototyping	Observation	Engagement, collaboration, creativity
Problem-oriented	Identification and response to ecological problems	Test + interview	Critical thinking/problem solving
Outcome-oriented	Pretest → intervention → posttest	Cognitive scores	Learning gain/effect
Reflective	Student reflection/interview	Interview	Contextual evidence

Table 7 makes explicit the fit between what the instructional product is designed to produce and how its efficacy is measured. The cognitive test captures measurable learning outcomes, while observation and interviews capture process characteristics that are central to project-based STEAM learning. Such alignment is preferable to evaluating a contextual STEAM intervention solely through conventional factual tests because recent research demonstrates that environmental competence develops through combinations of knowledge, reasoning, attitudes, collaboration, and engagement with authentic problems (Sigit et al., 2022; Baek, 2023; Gök & Boncukçu, 2023).

2.10 Overall Methodological Flow

To ensure that the entire procedure can be reproduced, the study can finally be represented as one integrated methodological flow. The flow begins with identification of the local environmental learning context, continues through reconstruction of STEAM learning using the Kalimas–Yarra glocal perspective, proceeds to pretest and intervention, and ends with posttest analysis and triangulated interpretation. This representation does not introduce a new research design; rather, it makes explicit the relationships among components that were previously described separately. The sequence is compatible with recent place-based river education and STEAM-PjBL research in which local environmental contexts are transformed into authentic learning laboratories and evaluated through multiple



forms of evidence (Choi & Kim, 2025; Sigit et al., 2022).

Figure 4. Integrated Methodological Flow of the Kalimas–Yarra STEAM Study

Figure 4 provides the final methodological synthesis and demonstrates the study's central methodological proposition: the efficacy of the reconstructed learning product is evaluated through correspondence between its intended characteristics and the evidence generated by its implementation. The statistically significant increase from M = 75.07 to M = 88.40, together with the reported $t = -9.775$, $p < .001$, and $r = .904$, constitutes the principal quantitative evidence, while the observation and interview components provide contextual support for interpreting critical thinking, creativity, collaboration, and ecological problem-solving processes. This integrated approach is consistent with recent empirical work positioning contextual STEAM/PjBL as a mechanism for connecting environmental literacy with authentic problem solving and 21st-century competencies (Baek, 2023; Pertiwi et al., 2024; Choi & Kim, 2025).

RESULTS AND DISCUSSION

Research result

3.1 Overview of Ecoliteracy Learning Outcomes

The evaluation of the Kalimas–Yarra STEAM learning reconstruction showed a clear improvement in students' learning outcomes following the intervention. The study involved 30 elementary school students at SDN Kaliasin 1 Surabaya, with the Kalimas River ecosystem serving as the contextual learning environment. The pretest was administered before the implementation of the reconstructed STEAM learning activities, while the posttest was administered after students had participated in environmental observation, inquiry, project-based learning, and ecological problem-solving activities. The resulting scores indicate not only an increase in students' average achievement but also a reduction in the dispersion of scores across students. This pattern is important for evaluating the instructional efficacy of the reconstructed model because the intervention was intended to connect environmental concepts with authentic local problems rather than treating ecological knowledge as purely theoretical. The original research results reported a pretest mean of 75.07 and a posttest mean of 88.40, representing an absolute improvement of 13.33 points. The accompanying reduction in standard deviation from 14.16 to 8.41 further indicates that post-intervention achievement became more homogeneous.

Table 1. Descriptive Statistics of Students' Pretest and Posttest Scores

Measurement	N	Mean	Standard Deviation	Interpretation
Pretest	30	75.07	14.16	Baseline learning outcome
Posttest	30	88.40	8.41	Post-intervention learning outcome
Mean improvement	30	13.33	—	Positive change

As shown in Table 1, students' mean scores increased from 75.07 before the intervention to 88.40 after the intervention. The increase of 13.33 points, equivalent to approximately 17.76% relative to the pretest mean, provides a substantial descriptive indication of improvement. At the same time, the standard deviation decreased from 14.16 to 8.41, indicating that the posttest scores were less dispersed than the pretest scores. The original analysis similarly reported that the initial student abilities were relatively heterogeneous and became more homogeneous after participation in the STEAM learning intervention.

The descriptive pattern is therefore consistent with the intended characteristics of the reconstructed learning model. Students did not only receive information about environmental problems but were engaged with the river ecosystem as a contextual learning resource. The original findings describe students as participating in observation, investigation, discussion, environmental problem analysis, and the development of simple solutions.

3.2 Distribution of Students' Learning Outcomes

The difference between the pretest and posttest distributions provides additional evidence concerning the consistency of students' learning outcomes. Before the intervention, the relatively large standard deviation (SD = 14.16) indicated considerable variation in students' baseline performance. Following the intervention, the standard deviation decreased to 8.41, a reduction of approximately 40.60%. This finding indicates that the improvement was not limited to a small number of high-performing students. Instead, the distribution of achievement became more concentrated around the posttest mean. The original research similarly interpreted this reduction in variability as evidence that students' achievement became more homogeneous following participation in the environment-based STEAM learning activities.

Figure 1. Comparison of Pretest and Posttest Learning Outcomes

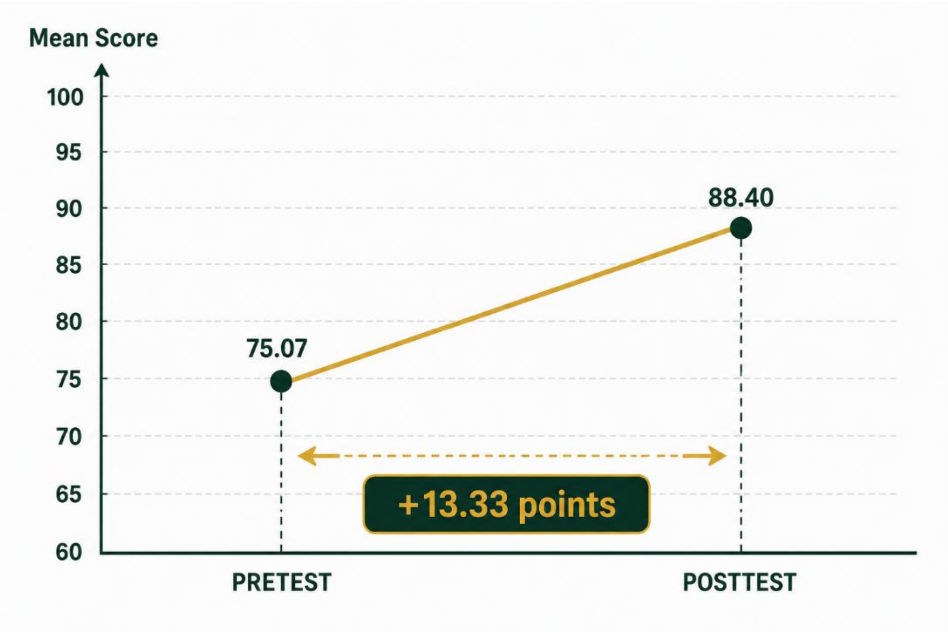


Figure 1 illustrates the increase in the average learning outcome following the reconstructed Kalimas–Yarra STEAM intervention. The posttest mean exceeded the pretest mean by 13.33 points. More importantly, the increase occurred together with a reduction in score variability, suggesting that students' achievement became more consistent after the learning intervention. This pattern supports the interpretation that the reconstructed learning experience was associated with broad improvement rather than merely an increase generated by a small subgroup of students. The original results explicitly reported that the lower posttest standard deviation indicated a more homogeneous distribution of learning outcomes. The next analysis examines whether the observed descriptive improvement was statistically significant.

3.3 Normality Test

Before conducting the paired-samples *t*-test, the distributional assumption required for parametric comparison was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The reported Shapiro–Wilk significance values were 0.310 for PRETESTA and 0.056 for PRETESTB. Both values were greater than the predetermined significance criterion of 0.05. Therefore, the relevant score distributions met the normality criterion required for the subsequent paired-samples analysis. The original research consequently proceeded with the paired-samples *t*-test as the principal inferential analysis.

Table 2. Normality Test Results

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PRETESTA	,136	30	,165	,960	30	,310
PRETESTB	,148	30	,094	,932	30	,056

a. Lilliefors Significance Correction

Table 2 demonstrates that both reported significance values exceeded 0.05. Thus, there was no statistical evidence in the reported normality tests that the score distributions deviated from normality. This supported the use of a parametric paired-samples comparison for evaluating the difference between students' pre-intervention and post-intervention scores. The normality assessment therefore functions as an assumption check preceding the principal hypothesis test rather than as evidence of intervention effectiveness itself.With the distributional assumption satisfied, the next stage was to determine the strength and significance of the relationship between the paired measurements.

3.4 Paired Samples Correlation

The paired-samples analysis produced a correlation coefficient of r = .904, with a reported significance value of p = .000 (reported by the statistical software; conventionally expressed as $p < .001$). This represents a very strong positive association between students' pretest and posttest scores. In practical terms, students who demonstrated relatively stronger performance before the intervention tended also to demonstrate relatively stronger performance after the intervention. The original analysis identified this association as evidence of consistency in students' performance across the two measurement occasions.

Table 3. Paired Samples Correlation

Paired Measures	N	Correlation (*r*)	Sig.
Pretest–Posttest	30	0.904	< .001

The high correlation should, however, be interpreted as an indicator of within-student score association, not as the statistical test of intervention effectiveness. A strong pretest–posttest correlation means that the relative ordering of students was substantially maintained across the two assessments. It does not by itself demonstrate that the STEAM intervention caused the improvement. The evidence for significant change is provided by the paired-samples *t*-test presented in the following section. This distinction produces a more rigorous interpretation of the original statistical output.

3.5 Paired-Samples *t*-Test of Learning Outcome Improvement

The principal inferential analysis was the paired-samples *t*-test because the same 30 students completed both the pretest and posttest. The analysis produced a t-value of −9.775 with a reported two-tailed significance value of 0.000, conventionally reported as p < .001. Because the probability value was substantially below the .05 criterion, the null hypothesis of no difference between pretest and posttest performance was rejected. The findings therefore demonstrate a statistically significant difference between students' learning outcomes before and after participation in the reconstructed STEAM learning intervention.

Table 4. Paired-Samples *t*-Test Results

Comparison	Mean Pretest	Mean Posttest	Mean Difference	*t*	*p*	Reported *r*
Pretest–Posttest	75.07	88.40	13.33	−9.775	< .001	.904

The negative sign of the *t*-value reflects the direction in which the difference was calculated rather than an unfavorable outcome. Because the posttest mean was higher than the pretest mean, the observed difference represents an improvement in students' scores after the intervention. The magnitude and direction of the mean difference therefore provide a clearer substantive interpretation than the sign of the *t*-statistic alone. The original research likewise noted that the negative *t*-value reflected the direction of the pretest–posttest calculation and that posttest performance exceeded pretest performance. The statistical evidence consequently supports the conclusion that the reconstructed STEAM learning intervention was associated with a significant improvement in measured learning outcomes. Because the design did not include a control group, the finding is appropriately described as statistically significant within-group improvement, rather than definitive proof of causal superiority over another instructional condition.

3.6 Ecoliteracy-Related Learning Outcomes

The statistical improvement is substantively relevant to the study because the assessed learning outcomes were connected to students' environmental understanding, critical thinking, and ecological problem-solving. The original research reported that students' engagement with the Kalimas River enabled them to move beyond theoretical environmental content toward direct observation, investigation, environmental-problem analysis, and the development of simple solutions. The reconstructed intervention consequently generated an instructional sequence in which ecological knowledge was connected with authentic environmental conditions. Students were exposed to problems associated with the river environment and were encouraged to analyze these problems and formulate responses through a STEAM-oriented project. The original findings further reported improvements in students' environmental awareness, critical thinking, and problem-solving, together with more active collaboration and creativity during environmental projects and campaigns.

Table 5. Outcome Pattern Associated with the Reconstructed STEAM Learning

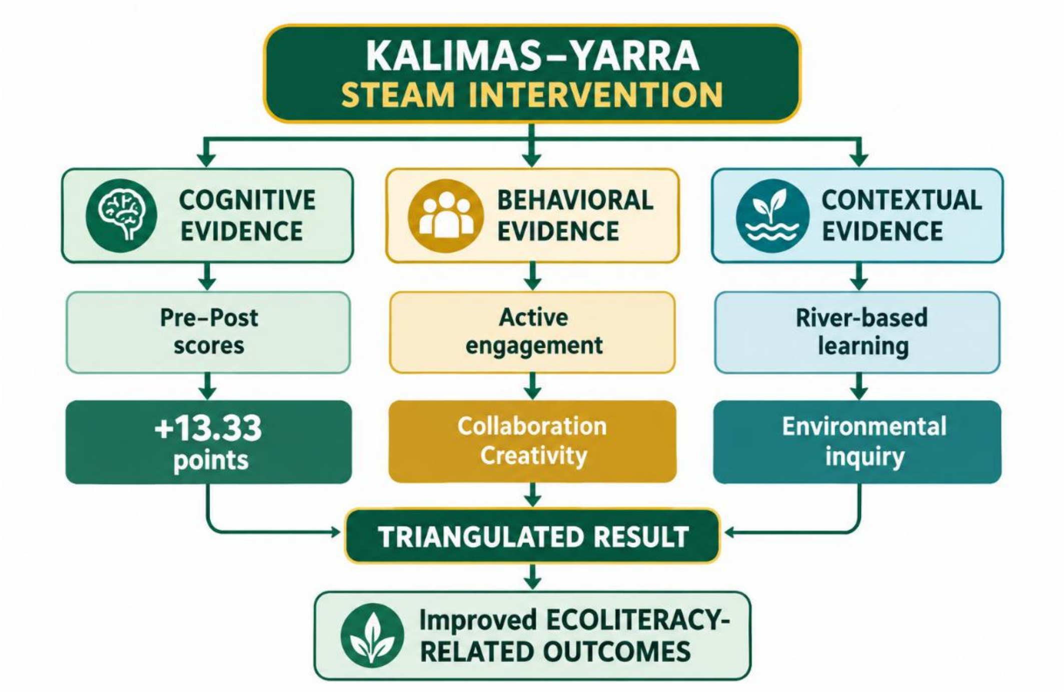
Outcome dimension	Evidence in the study	Result pattern
Environmental understanding	Pretest–posttest cognitive assessment	Improved
Critical thinking	Cognitive assessment + project activities	Improved
Ecological problem solving	Environmental investigation and solution design	Improved
Creativity	Project/prototyping activities	Enhanced
Collaboration	Group learning activities	Enhanced
Environmental awareness	Contextual river-based learning	Enhanced
Achievement consistency	Reduction in SD	Improved

Table 5 should be interpreted as an integrated outcome interpretation, rather than as a claim that separate numerical effect sizes were obtained for every listed dimension. The quantitative instrument provided the principal measurable pretest–posttest outcome, while the observation and project-learning evidence supported interpretation of students' behavioral and higher-order learning development. This distinction is important because the available original results do not provide separate numerical means for each individual dimension.

3.7 Behavioral and Process Evidence

In addition to the cognitive outcome measures, the learning implementation generated process evidence concerning students' engagement in contextual environmental learning. The original research reported that students became more active in environmental observation, group discussion, environmental analysis, and the development of solutions. The learning activities were characterized by direct interaction with environmental problems rather than exclusive dependence on classroom-based theoretical instruction. The observation component was particularly relevant to the reconstructed STEAM approach because the instructional model required students to participate in project-based activities. According to the original findings, students demonstrated greater activity, collaboration, and creativity during environmental projects and campaigns. These observations complement the cognitive results by indicating that the observed improvement was accompanied by changes in the learning process itself.

Figure 2. Integrated Evidence of the Kalimas–Yarra STEAM Learning Outcome



Discussion

Reframing STEAM efficacy through an urban river as a learning system

The central significance of this study is not simply that students performed better after the intervention, but that the learning architecture appears to have altered the relationship between scientific knowledge and the environmental world in which that knowledge is situated. The Kalimas–Yarra STEAM reconstruction positions the river not as an illustrative object added to an otherwise conventional lesson, but as a pedagogical environment through which scientific observation, technological interpretation, engineering-oriented problem solving, artistic representation, and mathematical reasoning can be coordinated around a shared ecological problem. This distinction matters because much of the STEAM literature continues to treat interdisciplinary integration primarily as a curricular configuration—combining several subject domains around a project—whereas the present study suggests that the stronger mechanism may lie in the reconfiguration of the learning environment itself. Santhosh et al. (2023), in a meta-analysis of 26 empirical studies involving 3,202 students, found that informal STEM project-based learning produced a moderate overall learning effect, while also showing that effectiveness depended on variables such as instructional model, assessment, group size, and course duration. The implication is that “project-based” or “STEM-based” cannot be treated as inherently effective pedagogical labels; the quality of the learning ecology mediates what students actually gain. Zhang and Ma (2023), using a much broader meta-analysis of 66 experimental and quasi-experimental studies, similarly found that project-based learning generally improved academic achievement, affective outcomes, and thinking skills, but their findings do not establish that every project environment produces comparable learning gains. The present study extends this literature by locating the project within an urban river ecosystem where the problem is neither simulated nor detached from students' everyday surroundings. The Kalimas becomes a "boundary object" between classroom knowledge and lived environmental experience: pollution, water quality, human activity, waste, river management, and ecological interdependence provide authentic phenomena against which abstract concepts can be tested. This helps explain why the intervention could generate not only cognitive improvement but also observable engagement, collaboration, creativity, and environmental inquiry. The result therefore supports, but also qualifies, the dominant project-based learning argument. The mechanism is unlikely to be project work alone; rather, it is the combination of interdisciplinary knowledge, authentic environmental problems, collective inquiry, and place attachment that creates conditions for deeper learning. Ardoin and Heimlich's (2021) concept of environmental "learningscapes" is particularly useful here because it conceptualizes environmental learning as social, relational, dynamic, and embedded within sociocultural and biophysical contexts rather than confined to formal instruction. From this perspective, the Kalimas–Yarra reconstruction represents an extension of STEAM from a disciplinary integration model into an ecological learning-system model. Its theoretical contribution is therefore not that STEAM "works," a proposition already well supported, but that STEAM may become pedagogically more consequential when the environment itself functions as an epistemic resource, a problem space, and a social context for knowledge construction.

Contextualization, place, and the transformation of environmental knowledge into ecoliteracy

The second objective of the study concerns whether a river-based learning environment can make ecological knowledge more meaningful and functionally connected to students' environmental understanding. The evidence suggests that contextualization is not merely a motivational device; it may operate as a cognitive and affective bridge through which students reinterpret environmental concepts as problems that belong to their own social world. This finding places the study in productive tension with earlier environmental-literacy research. Hamilton and Marckini-Polk (2023), studying 226 middle-school students, demonstrated that place-based education can strengthen environmental literacy and stewardship, while emphasizing that outcomes are shaped by school conditions, program design, community partnerships, and opportunities for students to make choices and share ideas. The present research extends this argument downward into the elementary-school context and into an intensely urbanized river setting. The significance lies in the fact that an urban river can function simultaneously as environmental problem, cultural landscape, scientific laboratory, and civic space. This is different from environmental education conducted in relatively pristine natural settings, where ecological relationships may be easier to observe but less connected to the contradictions of urban life. Phuetphian, Charnkonrawee, and Pongsophon (2023), working with Grade 3 students through place-based education on air pollution, found improvements across environmental knowledge, attitudes, and behavior, particularly when local problems were connected with evidence, creative design, and practical action. Chunphoon and Sawangmek (2023) likewise reported that place-based education could promote environmental literacy and sustainability understanding, although their study involved only seven Grade 12 students, highlighting the importance of context and sample characteristics when generalizing place-based effects. The current study therefore confirms the basic place-based proposition but extends it in two important directions. First, it demonstrates that the local environment does not have to be environmentally "ideal" to function pedagogically; an urban river with ecological pressures can become a more powerful learning resource precisely because it presents unresolved problems. Second, the Kalimas–Yarra model adds a glocal dimension: students encounter the Kalimas through a local experiential frame while using the Yarra River as a comparative reference for river governance, sustainability, and environmental stewardship. The Yarra component should not be interpreted as importing an Australian model wholesale. Rather, it functions as a comparative lens through which students can examine how different communities conceptualize and manage river ecosystems. This distinction is theoretically important because glocalization here is not a simple local-versus-global juxtaposition. It is a pedagogical process in which global knowledge is recontextualized through local ecological realities. The river therefore becomes a medium for epistemic translation: students learn that environmental problems are simultaneously local and planetary, while solutions are necessarily situated. Such a configuration may help explain why the intervention produced broader ecoliteracy-related outcomes rather than merely increasing factual knowledge. Ecoliteracy requires students to recognize relationships among ecological systems, human practices, values, and possible actions; the Kalimas provides those relationships in visible and investigable form. This interpretation is consistent with Ardoin and Heimlich's (2021) argument that environmental learning becomes meaningful through the interaction of people, place, experience, and social context.

From interdisciplinary activity to higher-order thinking, collaboration, and creative problem solving

The third objective was to determine whether reconstructed STEAM learning could support competencies extending beyond conventional academic achievement, particularly critical thinking, creativity, collaboration, and environmental problem solving. The findings are important because they suggest that the cognitive gains observed in the study should not be isolated from the behavioral and contextual dimensions of the intervention. The strongest interpretation is not that students simply learned more environmental content, but that they were placed in situations requiring them to use knowledge in socially and materially consequential ways. This interpretation corresponds with the broader evidence base for project-based learning but also exposes an important limitation in that literature: the label "PjBL" often conceals substantial variation in the quality and authenticity of student activity. Zhang and Ma's (2023) meta-analysis found positive effects of project-based learning across academic, affective, and thinking outcomes, yet such aggregate effects cannot explain which features of projects generate these gains. Santhosh et al. (2023) provide a more nuanced explanation by showing that informal STEM PjBL effectiveness is moderated by instructional model, assessment, group size, and duration. The present study adds another moderator that deserves greater theoretical attention: the ecological authenticity of the problem being investigated. When students investigate an actual river ecosystem, collaboration is not merely an instructional strategy imposed by the teacher. It becomes functionally necessary because environmental problems exceed the capacity of one learner and require multiple forms of evidence, interpretation, and representation. This helps explain the emergence of collaboration and creativity as behavioral evidence. Chaesar and Andayani (2024), for example, found that ecoliteracy-integrated project-based learning was more effective than conventional learning in developing creative thinking among elementary students, with the experimental group outperforming the control group. Widyasmoro, Sulianto, and Buchori similarly investigated project-based learning supported by ecosystem e-books and reported positive effects on elementary students' ecoliteracy and problem-solving capacities. Indrasari and Wulandari (2024) found significant improvement in ecoliteracy following STEM-based PjBL among junior-high students, again using a one-group pretest-posttest design. The present research converges with these findings but differs in its pedagogical architecture. Earlier studies often use environmental content as the theme of the project, whereas the Kalimas–Yarra reconstruction makes the environment itself the operational setting of inquiry. That distinction potentially changes the role of the learner from recipient of environmental information to investigator of an environmental system. It also explains why artistic and communicative components of STEAM matter: environmental problems require not only accurate measurement but the ability to visualize, communicate, persuade, and design. The STEAM framework therefore operates here as a form of epistemic coordination rather than subject accumulation. Science generates explanations, technology facilitates data and communication, engineering frames possible interventions, mathematics organizes evidence, and art gives ecological concerns communicative and affective form. The resulting competency profile is consequently broader than test-based achievement. Yet the interpretation should remain analytically cautious: because the study did not employ a control group or separate measures of each STEAM domain, the data cannot establish which disciplinary component was responsible for which competency gain. What can reasonably be argued is that the integrated learning architecture created conditions in which these competencies could be simultaneously exercised and observed.

The distinctive contribution of the Kalimas–Yarra reconstruction: from local environmental learning to glocal ecological pedagogy

A more distinctive contribution emerges when the local Kalimas context is placed in dialogue with the Yarra River reference. Existing environmental-learning studies strongly support place, authenticity, outdoor experience, and community engagement, but relatively few studies explicitly construct a pedagogical bridge between a local urban ecosystem in Indonesia and a globally recognized river-governance context. This makes the present study different at the level of curricular philosophy rather than merely instructional technique. Evidence from Victoria illustrates how the Yarra/Birrarung has been incorporated into educational programs through fieldwork, water-quality investigation, ecological observation, cultural history, sustainability, and community engagement. For example, Victorian school programs have used the Yarra as a setting for measuring river health, analyzing data, developing awareness campaigns, and producing collaborative artistic work, thereby integrating science, environmental inquiry, and creative expression. Contemporary Victorian Waterwatch programs likewise connect schools with waterways through hands-on water-quality monitoring and integrate science, mathematics, humanities, visual arts, and other curriculum areas. Educational resources concerning the Birrarung also explicitly connect river ecology with cultural heritage and Traditional Owner perspectives, presenting the river as a living entity rather than merely a physical watercourse. These examples provide an important comparative reference for the present study, but they should not be romanticized as a transferable "best practice." Their institutional infrastructure, environmental governance arrangements, community partnerships, and cultural history are not identical to those surrounding the Kalimas. The conceptual value of the Yarra therefore lies not in replication but in comparison. The reconstruction transforms international practice into a reflective mirror through which local students can ask why river problems are managed differently in different contexts, what counts as evidence of river health, who has responsibility for environmental protection, and how scientific knowledge interacts with cultural and civic values. This is where the study extends place-based education toward what may be called glocal ecological pedagogy: local environmental experience is retained as the primary site of meaning, while global cases provide comparative categories for interpretation. Such an approach avoids two opposite pedagogical failures. The first is localism without comparison, where students understand their immediate environment but have limited conceptual tools for relating it to broader environmental governance. The second is globalism without emplacement, where sustainability becomes an abstract discourse disconnected from students' lived realities. The Kalimas–Yarra reconstruction occupies the productive middle ground between these extremes. It also offers a potential explanation for the heterogeneity observed among students. Students enter the learning process with different academic abilities and environmental experiences, but a shared physical environment provides a common referent from which different forms of participation become possible. This may help explain why the dispersion of achievement decreased following the intervention. The learning environment potentially reduced dependence on prior classroom achievement by allowing students to contribute through observation, measurement, discussion, design, artistic production, or practical reasoning. The interpretation is consistent with Hamilton and Marckini-Polk's (2023) finding that student choice and opportunities to share ideas are consequential in place-based education. The broader theoretical implication is that glocalization should not be treated merely as adding international examples to local curricula; it should be understood as a process of pedagogical comparison through which local ecological knowledge becomes more conceptually powerful.

Interpreting the reduced achievement gap: a pedagogical mechanism rather than a statistical afterthought

One of the more theoretically interesting aspects of the findings is the reduction in score dispersion after the intervention. This pattern deserves greater attention than a simple statement that the posttest standard deviation was smaller because it raises a question about the distributional consequences of contextualized STEAM learning. Conventional classroom instruction often privileges students who already possess strong linguistic, conceptual, or academic resources because classroom participation is frequently organized around abstract explanation, reading, recall, and individual written performance. A river-based STEAM environment can redistribute opportunities to demonstrate competence because students encounter multiple modes of participation: observing environmental phenomena, collecting information, interpreting visual evidence, discussing hypotheses, constructing representations, designing solutions, and presenting ideas. The reduction in variability may therefore indicate that the intervention created more heterogeneous pathways into learning. This interpretation requires caution because a smaller standard deviation does not automatically mean that the learning process became more equitable; regression toward the mean, test characteristics, or ceiling effects could also contribute. Yet the pattern is theoretically meaningful when combined with the behavioral and contextual evidence reported in the study. The finding resonates with Hamilton and Marckini-Polk (2023), who emphasized that place-based learning is influenced by opportunities for students to exercise choice and contribute ideas, suggesting that participation structures are not peripheral to environmental learning outcomes. It also resonates with the 2023 meta-analysis by Santhosh et al., which demonstrated that PjBL effectiveness is shaped by instructional and organizational moderators rather than by the project label itself. The distinctive argument here is that contextual STEAM may partially compensate for differences in students' initial academic profiles because the environment supplies a shared experiential reference point. This possibility is particularly relevant to heterogeneous urban elementary classrooms, where students may differ considerably in prior exposure to scientific terminology, technology, or formal environmental education. The river creates a common object of inquiry without requiring every student to begin with identical conceptual resources. Such an interpretation also challenges a narrow understanding of differentiation. Differentiation is often framed as adapting content, tasks, or assessment to individual ability levels; the Kalimas–Yarra model suggests another form of differentiation through multiplicity of epistemic entry points. A student who struggles with abstract ecological definitions may nevertheless identify pollution patterns during field observation; another may excel in mathematical interpretation; another may contribute through visual design or communication; another may develop the engineering logic of a proposed solution. These forms of participation are not equivalent, but together they create a broader ecology of competence. This may explain why the intervention appears to have supported both higher achievement and greater homogeneity. Similar tendencies are visible in recent Indonesian research on STEAM and ecoliteracy. Ali, Ismail, and MY (2025), for instance, reported significant improvement in ecoliteracy following STEAM-based environmental learning in an elementary-school setting, while their reflective evidence emphasized the interaction of scientific reasoning, aesthetic production, environmental concern, and practical activity. The present study extends that finding by suggesting that interdisciplinary environmental learning may influence not only the mean level of achievement but also the distribution of participation and performance. Future research should test this proposition explicitly through interaction analyses, subgroup comparisons, and measures of equity rather than treating variance reduction as a secondary descriptive statistic.

Methodological critique and the boundaries of the efficacy claim

The statistical evidence supports the conclusion that student performance changed significantly across the two measurement occasions, but the design places clear boundaries around how that change should be interpreted. The one-group pretest-posttest structure is useful for detecting within-group change and is appropriate as an initial evaluation of an educational reconstruction, yet it cannot isolate the treatment effect from maturation, testing effects, history, teacher influence, novelty, or other concurrent experiences. The strong pretest-posttest correlation ($r = .904$) indicates that students' relative ordering across the two measurements was highly consistent; it does not demonstrate that the STEAM intervention caused the observed improvement. This distinction is essential for a rigorous discussion because correlation and causal effect answer different questions. Likewise, the negative paired-samples t statistic reflects the direction of the subtraction used by the statistical procedure; it should not be interpreted as evidence that the treatment is weak or strong. The strength of the inferential evidence lies in the statistical significance of the paired difference, while the practical magnitude of improvement requires an effect-size estimate and preferably a confidence interval. This methodological qualification does not invalidate the study; rather, it places the contribution at the correct evidentiary level. The study provides credible preliminary evidence that the reconstructed learning experience was associated with meaningful improvement in student outcomes, while the triangulation of cognitive, behavioral, and contextual evidence strengthens the interpretive plausibility of the mechanism. This triangulation is particularly important because recent literature warns against reducing environmental learning to cognitive scores alone. Ardoin and Heimlich (2021) conceptualize environmental learning as embedded in social, relational, and everyday contexts, while the 2026 meta-analysis of school-based outdoor environmental education found significant improvements in both environmental knowledge and attitudes across 29 knowledge studies and 19 attitude studies involving 7,359 participants. The present study therefore contributes to an emerging body of research that treats environmental learning as multidimensional. Its limitation is that the behavioral and contextual dimensions were not subjected to the same level of quantitative causal testing as the cognitive outcome. Future studies should move toward quasi-experimental or randomized designs with comparison groups, delayed posttests, validated multidimensional ecoliteracy scales, and longitudinal behavioral measures. A particularly important extension would be to compare the Kalimas-based model with a conventional STEAM project and with a non-river environmental project. Such a three-condition design would clarify whether the observed benefits derive primarily from STEAM integration, project-based learning, environmental contextualization, or the specific river-based setting. It would also test whether the Yarra comparative component adds value beyond local place-based learning alone. The present findings should therefore be understood as evidence supporting a promising pedagogical mechanism rather than as definitive proof of causal superiority. This critical positioning actually strengthens the contribution because it identifies the precise empirical question that future research must address: not whether contextual STEAM can produce improvement, but which configuration of context, interdisciplinarity, project structure, comparative global framing, and student agency produces the most durable forms of ecoliteracy.

Theoretical and practical implications: toward ecoliteracy as an enacted competence

Taken together, the findings suggest a conceptual shift from treating ecoliteracy as a body of environmental knowledge toward understanding it as an enacted competence produced through interaction among knowledge, place, inquiry, collaboration, creativity, and responsibility. This proposition extends recent empirical work in several directions. Chaesar and Andayani (2024) demonstrate that ecoliteracy-oriented project learning can strengthen creative thinking among elementary students. Indrasari and Wulandari (2024) demonstrate that STEM-based PjBL can improve ecoliteracy among secondary students. Phuetphian et al. (2023) show that place-based education can improve multiple components of environmental literacy among younger learners, particularly when local evidence, creative production, and practical engagement are integrated. Hamilton and Marckini-Polk (2023) demonstrate that student agency and community relationships influence whether place-based learning translates into environmental stewardship. Santhosh et al. (2023) demonstrate that the effectiveness of informal STEM PjBL is contingent upon design variables rather than guaranteed by the pedagogy itself. Ali et al. (2025) further indicate that STEAM-based environmental learning can strengthen elementary students' ecoliteracy through the interaction of scientific and creative activity. The present study brings these strands together through the Kalimas–Yarra reconstruction and thereby proposes a more integrated pedagogical logic: ecological literacy develops most meaningfully when students are required to know an environment, investigate an environment, represent an environment, negotiate problems within an environment, and imagine interventions for that environment. The river consequently functions as more than a teaching resource; it becomes a pedagogical infrastructure. This has practical consequences for curriculum design. Schools should not merely insert environmental topics into existing science units. They should identify accessible local ecosystems—rivers, drainage systems, wetlands, coastal zones, urban gardens, waste sites, or green corridors—and organize interdisciplinary learning around authentic questions emerging from those places. Teacher preparation must also change. The challenge is no longer simply knowing how to teach science, mathematics, art, or technology separately; teachers need capacity to orchestrate interdisciplinary inquiry, manage outdoor learning, interpret environmental data, facilitate collaborative problem solving, and connect local cases with global sustainability perspectives. The Yarra component demonstrates another practical possibility: international examples can be used not as decorative "global content" but as comparative governance cases that allow students to interrogate alternative ways of understanding and managing environmental systems. Such a strategy could support a form of global citizenship grounded in local ecological responsibility. At the policy level, the study suggests that environmental education should be supported through partnerships among schools, local government, environmental agencies, universities, and community organizations. This is not simply a logistical recommendation. The success of place-based environmental education depends partly on access to authentic places, data, expertise, and community participation, as Hamilton and Marckini-Polk (2023) also emphasize. The long-term implication is that urban schools should be conceptualized as nodes within local ecological systems rather than as institutions physically separated from them. Such a shift would reposition the river from a background feature of the city into a civic classroom. The ultimate contribution of the Kalimas–Yarra model therefore lies in demonstrating a pathway by which STEAM, place-based education, environmental literacy, and global comparative learning can be synthesized into an educational model that is simultaneously contextual, interdisciplinary, and oriented toward real-world ecological responsibility.

5. Conclusion and Recommendations

Conclusion

1. Core Finding and Conceptual Answer. This study concludes that the reconstruction of STEAM learning through the Kalimas River ecosystem, informed by comparative perspectives from the Yarra River, provides a meaningful pedagogical response to the limitations of decontextualized environmental learning in urban elementary education. The central contribution of the intervention is not merely the improvement of academic performance, but the integration of cognitive, behavioral, and contextual dimensions into a single ecological learning experience. By positioning the river as an open laboratory, students were encouraged to investigate authentic environmental problems, interpret evidence, collaborate with peers, formulate solutions, and communicate their understanding through multiple forms of representation. The findings therefore answer the central research problem by demonstrating that ecoliteracy-oriented STEAM learning becomes more pedagogically meaningful when environmental knowledge is constructed through direct engagement with a familiar ecosystem and connected to broader global perspectives. The Kalimas–Yarra framework consequently offers a contextual model for bridging local environmental realities with global sustainability learning in urban elementary schools.

2. Theoretical Contribution. The study contributes theoretically by extending conventional STEAM and project-based learning frameworks toward a **glocal ecological pedagogy**, in which interdisciplinary learning is organized around an authentic local ecosystem while global environmental practices provide comparative conceptual perspectives. This formulation positions place not simply as the setting in which learning occurs but as an epistemic component of the learning process. The study also conceptualizes ecoliteracy as an enacted competence involving the interaction of ecological knowledge, inquiry, critical thinking, creativity, collaboration, and environmental problem solving. In this sense, the Kalimas–Yarra reconstruction bridges three traditionally separated perspectives: interdisciplinary STEAM education, place-based environmental education, and global sustainability learning. Its theoretical significance lies in demonstrating how these perspectives can be integrated without displacing local ecological experience. The model suggests that global environmental education is potentially more meaningful when global knowledge is translated through locally recognizable ecological problems and when students are positioned as active interpreters of their own environmental context.

3. Policy and Practical Implications. The findings have practical implications for schools, teachers, curriculum developers, and education authorities seeking to strengthen environmental and 21st-century learning in urban elementary education. Schools can transform accessible local ecosystems—including rivers, wetlands, urban drainage systems, coastal areas, parks, and community gardens—into authentic learning laboratories rather than treating environmental education exclusively as classroom content. Teachers should be supported to design interdisciplinary projects that connect scientific investigation with technological tools, engineering-oriented solution design, mathematical analysis, and artistic communication. For education authorities, particularly those responsible for elementary curriculum development and environmental education, the study indicates the value of supporting place-based STEAM projects through teacher training, partnerships with universities and environmental organizations, access to local environmental data, and flexible curriculum structures. The practical priority is not to replicate the Kalimas–Yarra model mechanically, but to develop adaptable local versions in which students investigate real ecological challenges while engaging critically with wider national and global sustainability perspectives.

4. Limitations and Future Research Agenda. This study should be interpreted within the limitations of its pre-experimental one-group pretest-posttest design, single-school setting, relatively small sample, and limited duration of intervention. Although the findings provide meaningful evidence of learning improvement and are strengthened by cognitive, behavioral, and contextual observations, the design does not permit definitive causal attribution or establish whether the observed outcomes would persist over time. Future research should therefore employ quasi-experimental or randomized controlled designs involving multiple schools and comparison groups, including conventional learning, conventional STEAM, and locally contextualized STEAM conditions. Longitudinal studies are also needed to determine whether improvements in ecoliteracy translate into sustained environmental attitudes and behaviors beyond the classroom. Further research should examine which components of the Kalimas–Yarra framework—river-based inquiry, interdisciplinary integration, global comparison, student collaboration, or creative production—contribute most strongly to specific ecoliteracy outcomes. Such research would enable the model to move from a promising contextual intervention toward a more robust and transferable framework for urban environmental education.

Recommendations

Future implementation should focus on developing adaptable river- and ecosystem-based STEAM learning models that can be integrated into the regular elementary curriculum rather than treated as short-term enrichment activities. Schools and teachers should strengthen partnerships with local environmental institutions, universities, communities, and municipal authorities to provide authentic environmental data, field-based learning opportunities, and real-world problem contexts. Teacher professional development should prioritize interdisciplinary project design, environmental inquiry, data interpretation, collaborative learning, and assessment of ecoliteracy beyond conventional cognitive tests. For future researchers, the most important priority is to test the Kalimas–Yarra framework across different schools, socioeconomic contexts, ecological settings, and age groups using larger samples, control or comparison groups, longitudinal measurements, and multidimensional ecoliteracy instruments. Research should also examine whether the model produces sustained changes in students' environmental attitudes, everyday behaviors, civic participation, and capacity to design feasible ecological solutions, thereby addressing the central challenge of transforming environmental knowledge into durable ecological competence.

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