Available online: https:// journal.uny.ac.id/v3/jpa
Jurnal Pendidikan Anak, 15(1), 2026, 23-33

Assessing STEAM's Impact on Marine Awareness: The Moderating Effect of Critical Thinking

Suharti[1], Hapidin[2], Yufiarti[3]
Program Studi Pendidikan Anak Usia Dini, Fakultas Ilmu Pendidikan, Universitas Negeri Surabaya
Surabaya, Jawa Timur, Indonesia[1]
Program Studi Doktor Pendidikan Anak Usia Dini, Universitas Negeri Jakarta, Indonesia[2]
Program Studi Psikologi, Universsitas Negeri Jakarta, Indonesia[3]

E-mail: suhartisuharti@unesa.ac.id

ARTICLE INFO
Article history:
Received: September, 27 2025
Revised: October, 10 2025
Accepted: January, 23 2026

Keywords:
STEAM,
Scientific Approach,
Critical Thinking,
Marine Awareness,
Early Childhood Education

ABSTRACT

Marine environmental awareness in early childhood is essential to fostering lifelong environmental responsibility. This study evaluates the comparative effectiveness of STEAM and scientific approaches on children's marine awareness, specifically examining the moderating role of critical thinking among second-grade students in West Java, Indonesia. Using a quasi-experimental design with a 2×2 factorial structure, the study involved 51 children aged 7–8 years. Data were collected using the New Environmental *Paradigm (NEP) Scale adapted for children and a critical thinking assessment rubric, then analyzed using Two-Way ANOVA. Results confirmed that the STEAM approach significantly outperformed the scientific approach in enhancing marine awareness (F(1, 45)=111.65, p<.001). Crucially, a significant interaction effect (F(2, 45)=3.49, p=.039) revealed that the efficacy of STEAM was amplified in students with higher critical thinking skills (M=136.27) compared to the scientific group (M=112.75). Practically, these findings advocate for shifting early environmental pedagogy from linear scientific inquiry to transdisciplinary STEAM models. Educators are recommended to integrate critical thinking scaffolding within STEAM activities to maximize marine literacy and environmental responsibility in young learners.*

INTRODUCTION

The escalating degradation of marine ecosystems necessitates educational strategies that foster environmental responsibility from an early age (Lee & Shin, 2025). In this study, marine awareness is conceptualized not merely as factual knowledge, but as an *ecological worldview*, a fundamental set of beliefs regarding the relationship between human beings and the environment. While early childhood is a critical period for forming these environmental attitudes, marine-specific education remains underrepresented in Indonesia, where national curricula often prioritize terrestrial over maritime ecosystems despite the nation's archipelagic nature.

Current instructional practices in Indonesian elementary schools predominantly rely on the Scientific Approach. In the context of lower primary education, this approach adheres to a structured sequence of observing, questioning, experimenting, associating, and communicating (Qolbi et al., 2025). While effective for foundational inquiry, this linear method often emphasizes rote procedural skills, potentially overlooking the transdisciplinary connections required for deep environmental awareness (Wei et al., 2020). In contrast, STEAM (Science, Technology, Engineering, Arts, and Mathematics) offers a holistic alternative. By integrating creative arts and design, STEAM bridges cognitive understanding with affective engagement, theoretically enhancing the cultivation of complex ecological values.

However, the efficacy of such complex pedagogical models depends on the learner's cognitive disposition, particularly Critical Thinking. For children aged 7–8, critical thinking is defined as the nascent ability to identify simple cause-and-effect relationships and question assumptions (Yulia et al., 2025). A logical link exists between these variables: while STEAM provides a rich learning environment, it demands higher-order processing to synthesize diverse disciplines (Kelly & Burr, 2019). Therefore, critical thinking is hypothesized to act as a moderator, a cognitive tool that enables students to navigate the complexity of STEAM activities, thereby amplifying their acquisition of marine awareness. Therefore, comparing STEAM against the standard Scientific Approach is essential to determine whether the transdisciplinary integration of Arts significantly amplifies marine awareness beyond standard inquiry methods.

The novelty of this research lies in two key areas that address gaps in existing literature. First, while previous studies have examined STEAM's impact on general academic outcomes or creativity, research focusing specifically on marine awareness such as encompassing ecological beliefs and environmental responsibility remains scarce in early childhood contexts. Second, and most importantly, this study introduces critical thinking as a moderating variable. Existing literature largely treats critical thinking as an outcome of learning. However, little is known about how a child's pre-existing level of critical thinking influences the effectiveness of different instructional strategies. It is hypothesized that children with higher critical thinking skills (Facione, 2015) might benefit disproportionately from the complexity of STEAM compared to the structured Scientific Approach. More importantly, the effectiveness of these strategies may be moderated by Critical Thinking, defined as the ability to evaluate evidence and make reasoned decisions (Ennis, 1996; Facione, 2015). While critical thinking is known to support sustainable attitudes (Aginako & Guraya, 2023; Merma-molina et al., 2022), its interaction with instructional methods in early childhood remains underexplored. Specifically, it is unclear whether STEAM amplifies marine awareness more effectively among students with higher cognitive dispositions compared to standard methods. Understanding these dynamics is vital for the Indonesian context, where marine education is underrepresented and often dominated by rote learning (McDonell, 2001), creating an urgent need for integrative pedagogies in coastal regions.

To address these gaps, this study employs a quasi-experimental design to investigate the effectiveness of STEAM versus scientific instructional approaches in promoting marine awareness among second-grade students in West Java. Through two-way ANOVA analysis, the study aims to answer three key inquiries: whether the STEAM approach yields higher marine awareness than the scientific approach; how critical thinking levels impact these outcomes; and, crucially, whether there is a significant interaction between the instructional approach and critical thinking skills in fostering marine awareness.

METODE

Research Design

This study employed a quasi-experimental design with a 2×2 factorial structure, integrating two independent variables: instructional approach (STEAM vs. Scientific) and critical thinking level (High vs. Low). The quasi-experimental method was chosen due to practical constraints in random assignment within natural school settings, a common practice in educational research involving intact classroom groups (Creswell, 2012; Fraenkel et al., 2012). This design facilitates the investigation of both main effects and interaction effects between the instructional strategies and students' cognitive dispositions. The specific factorial structure and the distribution of participants (N=51) across the four experimental conditions are detailed in Table 1.

Table 1. 2×2 Factorial Design of the Study

Variable	Instructional Approach (X1)	
Critical Thinking (X2)	STEAM (Experimental)	Scientific (Control)
High Level	Group A1 (n = 15)	Group B1 (n = 8)
Low Level	Group A2 (n = 15)	Group B2 (n = 13)
Total (N)	n = 30	n = 21

Participants and Sampling

The target population for this study comprised second-grade students enrolled in public

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

elementary schools in Cirebon Regency, West Java, Indonesia, specifically those located along the north coast of Java Island. This coastal setting was deliberately targeted to ensure the ecological relevance of marine awareness education to the students' immediate living environment. From this population, a purposive sampling technique was employed to select schools for the 2024–2025 academic year based on specific inclusion criteria: (1) proximity to the coast (less than 5 km) to minimize geographical variance, (2) the implementation of the national curriculum to ensure baseline comparability, and (3) similar school at the north coast of Java Island.

The determination of the sample size was based on the intact group technique, which is characteristic of quasi-experimental designs where randomization of individual subjects is not feasible due to institutional constraints (Leyrat et al., 2024; Miller et al., 2020). Consequently, three intact classes from the selected schools were recruited, resulting in a total sample of 51 students aged 7–8 years. These intact classes were assigned to the treatment and control groups based on the initial equivalency of their academic schedules and teacher readiness. This process resulted in 30 students assigned to the experimental group (STEAM) and 21 students to the control group (Scientific approach). The demographic composition included 28 females (54.9%) and 23 males (45.1%).

A purposive sampling technique was used to select schools with comparable demographic and academic characteristics. Within each school, classrooms were assigned to the experimental (STEAM) or control (scientific) group, depending on the readiness of teachers and school agreement. Students were then categorized into high and low critical thinking levels based on a validated critical thinking assessment adapted from Ennis, (1996) and contextualized for early primary learners. The use of purposive sampling is justified in intervention research where specific pedagogical conditions and cognitive traits are required for analysis (Campbell et al., 2020; Tajik et al., 2024).

Procedures

The research was implemented in three key phases over a six-week instructional period. First, phase 1: pre-intervention assessment. Participants completed a baseline test measuring marine awareness, which included subscales for knowledge, attitudes, and behaviors toward the marine environment. Additionally, students completed a critical thinking assessment adapted for early learners to categorize their cognitive level. Second, intervention implementation. Students were assigned to one of two instructional groups receiving the same marine ecosystem content but through different pedagogical methods. The STEAM Group engaged in integrated activities incorporating hands-on experiments, art projects like 3D coral dioramas, engineering challenges (e.g., oil spill filtration), and storytelling to boost emotional engagement. Conversely, the Scientific Group followed the national curriculum's standard 5M Scientific Approach. This linear process involved observing (*Mengamati*), questioning (*Menanya*), collecting information (*Mencoba*), associating (*Menalar*), and communicating (*Mengomunikasikan*). This control condition prioritized cognitive mastery and factual recall, excluding the interdisciplinary arts and engineering components found in the experimental group.

Both interventions were integrated into the standard school schedule as a dedicated 'Marine Life' thematic unit. The program ran for 90 minutes per week over a period of 6 weeks. Given that the participating schools operate under a double-shift system, a rotating schedule was implemented to accommodate classroom availability and minimize time-of-day bias. Specifically, Group A and Group B alternated shifts weekly; for instance, when Group A attended the morning session, Group B attended the afternoon session, and this order was reversed the following week. To ensure developmental appropriateness for 7–8-year-olds, the 90-minute sessions were not continuous but segmented into varied activities (e.g., introduction, hands-on experimentation, and reflection). All lessons were delivered by classroom teachers who were trained by the researchers to ensure fidelity across conditions. Third, phase 3: post-intervention assessment. At the end of the intervention, all participants completed a post-test on marine awareness using the same instrument as the pre-test. Post-test scores were used as the primary outcome measure for statistical analysis.

Instrument

The main dependent variable, marine awareness, was assessed using a comprehensive 41-item instrument developed by the researchers. This instrument was designed to capture three distinct

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

domains. First, attitudes toward the marine environment were measured using 12 items on a 4-point Likert scale; these items were adapted from the New Environmental Paradigm (NEP) Scale for Children (Dunlap, 2008) to specifically focus on the rights of nature and eco-crises within an oceanic context. Second, knowledge of marine issues was assessed through 17 multiple-choice items developed based on the local marine curriculum. Finally, behavioral tendencies were evaluated using 12 items on a 5-point frequency scale to measure reported conservation actions. Given the established construct validity of the original NEP scale and the specific sample size of this study (N=51), a Confirmatory Factor Analysis (CFA) was not feasible. Instead, content validity was rigorously established through expert review to ensure the adaptation to the marine context was conceptually accurate and developmentally appropriate. The internal consistency was robust, with a Cronbach's alpha reliability coefficient of $\alpha = 0.87$ for the overall scale. Critical thinking was assessed using a simplified and contextualized version of Ennis, (1996) critical thinking framework for children, adapted to include age-appropriate scenarios requiring interpretation, reasoning, and judgment. Students were categorized into high and low critical thinking groups based on median-split scores.

Data Analysis

A two-way analysis of variance (ANOVA) was employed to analyze the quantitative data. Specifically, this analysis evaluated the main effects of both the instructional approach and critical thinking levels on marine awareness, along with the interaction effect between the instructional method and students' critical thinking skills. Prior to conducting ANOVA, assumptions of normality and homogeneity of variance were tested using Kolmogorov–Smirnov and Levene's test, respectively. Results indicated that the data met both assumptions ($p > .05$), validating the use of parametric analysis. Post hoc comparisons using the Tukey HSD test were conducted where necessary to explore significant interaction effects. Effect sizes were calculated using partial eta squared (η^2) to determine the strength of the associations, with $\eta^2 \geq .14$ indicating a large effect (Cohen, 1988). All statistical analyses were conducted using SPSS version 26.

RESULT AND DISCUSSION

Results and discussion contain an explanation of the results of the research followed by analysis and synthesis carried out sharply and critically. The sharpness of analysis and synthesis at least includes a description of the findings of the work, a sharp discussion, and a critical comparison with the work of others. Results and Discussion can be written using sub-chapters if there are several variables used. The position and style of the sub-chapters follow the example below. The analysis was structured to address the three primary research questions regarding the effects of instructional approach and critical thinking on marine awareness. Descriptive statistics, assumption tests, and Two-Way ANOVA were conducted using SPSS version 26.

Descriptive Statistics and Assumption Testing

Table 1 presents the descriptive statistics for marine awareness scores. Preliminary assumption testing confirmed that the data met the requirements for ANOVA. The Kolmogorov–Smirnov test indicated a normal distribution ($p = .08 > .05$), and Levene's test confirmed the homogeneity of variance ($p = .583 > .05$).

Table 2. Mean Scores of Marine Awareness by Instructional Approach and Critical Thinking

Instructional Approach	Critical Thinking Level	N	Mean	SD
STEAM	High	15	149.86	6.84
	Low	15	136.27	11.39
	Total	30	144.03	12.92
Scientific	High	8	112.75	14.38
	Low	13	107.75	9.72
	Total	21	111.52	11.69

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

Results for RQ1: Effect of Instructional Approach

To answer the first research question *Does the STEAM instructional approach lead to higher marine awareness than the scientific approach?*, the main effect of the instructional approach was examined. The Two-Way ANOVA results (Table 2) revealed a statistically significant main effect, F (1, 45) = 111.65, p < .001.The effect size was substantial ηp^2= .713, indicating that the instructional method accounted for 71.3% of the variance in marine awareness scores. Descriptive data confirms that students in the STEAM group (M = 144.03, SD = 12.92) significantly outperformed those in the Scientific group (M = 111.52, SD = 11.69). Thus, regarding RQ1, the STEAM approach is significantly more effective in promoting marine awareness than the scientific approach.

Table 3. Tests of Between-Subjects Effects

Source	F	Sig.	Partial η^2
Instructional Approach (X1)	111.65	.000**	.713
Critical Thinking (X2)	3.20	.050*	.125
X1 * X2 Interaction	3.49	.039*	.134

Results for RQ2: Influence of Critical Thinking

Addressing the second research question *How does critical thinking influence the relationship between instructional approach and marine awareness?*, the analysis showed a significant main effect of critical thinking level, F(1, 45) = 3.20, p = .050.Generally, students with high critical thinking skills achieved higher marine awareness scores (M = 136.27, adjusted based on total grouping) compared to those with lower critical thinking skills. The effect size (η_p^2 = .125) suggests a moderate influence. This indicates that independent of the teaching method, a student's cognitive capacity for critical analysis positively contributes to their environmental awareness..

Results for RQ3: Interaction Effect

Regarding the third research question *Is there a significant interaction between instructional approach and critical thinking?*, the ANOVA revealed a significant interaction effect, F(1, 45) = 3.49, p = .039, η_p^2 = .134.This significant interaction implies that the effectiveness of the instructional approach is moderated by the student's level of critical thinking. To interpret this interaction, a Tukey's HSD post hoc test was conducted. The results showed that the performance gap between the two approaches was widest among students with high critical thinking skills. The STEAM + High Critical Thinking group achieved the highest overall scores, significantly outperforming the Scientific + High Critical Thinking group (Mean Difference > 23.52, p < .05). While STEAM was effective for all students, those with higher critical thinking capabilities derived the maximum benefit from the STEAM intervention, likely due to the approach's demand for problem-solving and inquiry.

Effect Size Interpretation

The partial eta squared (η^2) values indicate strong effects:

η^2 = .713 for instructional approach = very large effect
η^2 = .134 for interaction = moderate effect

These results confirm that the STEAM approach is highly effective, especially when combined with strong critical thinking skills. This study aimed to examine the comparative effectiveness of the STEAM instructional approach versus the Scientific approach in cultivating marine awareness among young children, with a specific focus on the moderating role of critical thinking. The discussion is structured to interpret the three key statistical findings: the main effect of the instructional approach, the main effect of critical thinking, and the interaction effect between the two.

The Effect of Instructional Approach on Marine Awareness (Addressing RQ1)

The statistical analysis yielded a compelling answer to the first research question: the STEAM approach significantly outperforms the Scientific approach in cultivating marine awareness (F(1, 45) = 111.65, p < .001). The magnitude of this difference is highlighted by the substantial effect size (ηp^2 =

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

.713), indicating that the instructional method accounted for over 71% of the variance in student outcomes. The mean score disparity based on data 144.03 for STEAM versus 111.52 for Scientificsuggests that for young children living in coastal communities, the integration of arts and engineering offers a distinct pedagogical advantage over standard inquiry methods.

This superiority can be attributed to the way STEAM facilitates a shift in children's ecological worldview. As defined in the instrument used, marine awareness reflects "primitive beliefs about the relationship between human beings and their environments". The standard Scientific approach, while effective for factual acquisition, often presents nature as an object of study or something to be subdued, a view historically linked to the *Dominant Social Paradigm*. In contrast, the STEAM intervention required students to construct representations of marine ecosystems, fostering a sense of harmony and connection. This aligns with Dunlap & Van Liere (1978) assertion that educational interventions, even short modules, are critical in stimulating an increase in ecological worldview scores among children.

Furthermore, the integration of the Arts component in STEAM likely served as the critical emotional hook (Kashaka, 2024; Morari, 2023). While the Scientific approach engages the cognitive domain through observation, STEAM bridges the gap to the affective domain (Montero-izquierdo et al., 2024; Tan et al., 2021). By creating artifacts, students are not just learning about the balance of nature abstractly; they are physically building it. This hands-on engagement is crucial because, as noted in the development of the NEP scale for children, younger audiences (1st and 2nd grade) process environmental attitudes effectively through games and tangible adaptations (Maric, F., Poto, M.P., Zimmermann, H.J., & Panieri, 2023; Zhbanova et al., 2019). The STEAM approach mirrors this developmental need by turning abstract ecological threats into concrete, solvable design challenges.

The results support the Value-Belief-Norm (VBN) theory (Stern et al., 1999), which posits that beliefs about ecological fragility are precursors to pro-environmental behavior (Soemantri et al., 2025). The STEAM activities provided a lived experience of these beliefs (Gossen, 2024; Mater et al., 2023). When students engineered solutions for marine problems, they actively rejected the human exemptionalism paradigm the belief that humans are exempt from ecological constraints. Instead, the collaborative and creative nature of STEAM reinforced the reality of ecological limits and the necessity of human stewardship (Sumida, 2022; Taylor & Taylor, 2019). Thus, the significantly higher scores in the STEAM group reflect not just better memory of facts, but a more profound restructuring of their beliefs regarding the ocean, confirming that pedagogies activating both intellect and emotion are superior for early environmental education.

The Role of Critical Thinking in Environmental Learning (Addressing RQ2)

The second major finding reveals a significant main effect of critical thinking on marine awareness ($F(1, 45) = 3.20$, $p = .050$, indicating that students with higher critical thinking capabilities consistently demonstrated higher marine awareness scores, independent of the instructional intervention. This result underscores that the capacity to process environmental information is just as crucial as the method by which it is delivered.

This finding can be explained by examining the nature of the New Environmental Paradigm (NEP) used to measure marine awareness. Dunlap & Liere (2010) characterizes the NEP not merely as an attitude, but as a measure of "primitive beliefs about the relationship between human beings and their environments. For young children, adopting a pro-marine worldview requires a cognitive shift away from the Dominant Social Paradigm (DSP) by Kilbourne (2014), which typically views nature as limitless and primarily for human use. Critical thinking acts as the cognitive catalyst for this shift (Kanthimathi & Raja, 2025; Vincent-Lancrin, 2024). Students with higher critical thinking skills are better equipped to question the anthropocentric view and adopt a more ecocentric perspective, engaging in what Dunlap describes as rejecting human exemptionalism.

Furthermore, the link between critical thinking and marine awareness aligns with the belief systems perspective discussed by Dunlap (2008) in the context of NEP research. They argue that a sophisticated ecological worldview is characterized by a high level of constraint or coherence among beliefs. In this study, children with high critical thinking likely possess a more organized belief system. They do not view marine issues like pollution or coral bleaching as isolated facts to be memorized, but as interconnected components of a larger system. Their ability to analyze cause-and-effect relationships

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

allows them to construct a coherent mental model where human actions and ocean health are intrinsically linked (Quan & Liamputtong, 2024).

Consequently, critical thinking serves as a necessary condition for deep ecological literacy. While the instructional approach STEAM or Scientific provides the content and experience, critical thinking provides the processing power to internalize this content into a stable worldview (Guamanga et al., 2025). This suggests that in early childhood environmental education, fostering the ability to evaluate evidence and recognize assumptions is a direct predictor of a child's potential to become an environmentally responsible agent

The Interaction Effect: When STEAM Meets Critical Thinking (Addressing RQ3)

The most novel finding of this study is the significant interaction between instructional method and critical thinking ($F(1, 45) = 3.49$, $p = .039$, $\eta_p^2 = .134$). This indicates that the efficacy of the STEAM approach is not uniform; rather, it is significantly amplified when paired with high critical thinking skills. Students with high critical thinking capabilities in the STEAM group achieved the highest marine awareness scores ($M = 149.86$), significantly outperforming their counterparts in the scientific group.

This relationship can be effectively interpreted through the belief systems perspective derived from political science and applied to environmental sociology. As noted by Dunlap (2008), research by Pierce and Lovrich suggests that individuals with higher cognitive engagement possess more coherent belief systems, characterized by a high level of constraint, defined as strongly correlated sets of beliefs (Rodriguez et al., 2016). In the context of this study, the STEAM approach presented students with multifaceted marine issues e.g., balancing economic needs with ocean conservation. Students with high critical thinking skills were cognitively equipped to navigate this complexity (Gü, 2023). They utilized their reasoning abilities to organize the diverse, interdisciplinary experiences offered by STEAM into a coherent, tightly constrained ecological worldview, rather than perceiving the activities as isolated tasks (Rodríguez de la Barrera & Genes Quintero, 2024).

Furthermore, the interaction highlights the cognitive demands required to shift from a Dominant Social Paradigm (DSP) to a New Environmental Paradigm (NEP). The DSP typically emphasizes material abundance, limitless growth, and faith in technology. The STEAM intervention likely induced cognitive dissonance by simulating the negative consequences of this paradigm e.g., ocean pollution models (Halimah et al., 2025). High critical thinking students were better positioned to resolve this dissonance by rejecting human exemptionalism, the belief that modern society is exempt from ecological laws (Kim et al., 2023). By critically analyzing the STEAM simulations, these students could logically deduce that human activities are indeed subject to ecological limits, thereby deepening their acceptance of the NEP.

In contrast, the Scientific approach, while structured, may not have provoked the same degree of paradigmatic questioning among high-ability learners. It often presents environmental facts linearly, which does not necessarily challenge the underlying anthropocentric assumptions of the DSP (Cruz & Manata, 2020; Upreti, 1994). Therefore, the combination of STEAM (which provides the complex, challenging context) and high critical thinking which provides the analytical tool creates the optimal condition for nurturing a robust marine awareness (Erlita & Sari, 2025; Torres-rivera et al., 2025).

However, this interaction also implies a critical pedagogical caveat. The gap in scores suggests that students with lower critical thinking skills may struggle to synthesize the interdisciplinary connections inherent in STEAM without support. If the organization of a belief system is dependent on cognitive stratification, then educators must provide scaffolding for learners with developing critical thinking skills (Li et al., 2024). This ensures that the transition to an ecological worldview is accessible to all students, not just those who are already cognitively predisposed to handle the complexity of transdisciplinary learning.

Limitations and Future Research

While the findings are robust, the study has several limitations. First, the sample size was relatively small (N = 51) and drawn from a limited geographic area, which may affect generalizability. Second, the study employed a quasi-experimental design using intact groups rather than random assignment of individual students. Although pre-tests were administered to check for initial equivalency,

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

the lack of randomization introduces the potential for selection bias or unmeasured baseline differences between the groups that could influence the intervention outcomes. Third, the assessment of critical thinking, although age-appropriate, may not capture the full complexity of children's reasoning processes. Future studies could employ longitudinal designs to explore the lasting impact of STEAM instruction on marine awareness and mixed-methods approaches to examine how children express their understanding through language, art, and action.

It would also be valuable to explore other moderating factors such as gender, socioeconomic background, and prior exposure to environmental content. Given the observed interaction between pedagogy and cognition, researchers should further investigate how personalized instructional strategies can be optimized for different learner profiles.

Contribution to the Literature

This study provides a distinct contribution by examining the impact of STEAM-based marine education among young learners a topic that has received limited empirical attention, particularly in the Indonesian context. While the effectiveness of STEAM is well-documented in general STEM disciplines, its application in cultivating ecological worldviews at the primary level remains underexplored. By offering one of the first empirical comparisons between STEAM and scientific instructional approaches, this research fills a critical gap in the literature regarding effective pedagogies for marine sustainability in the Global South.

Furthermore, positioning critical thinking as a moderating variable offers a novel analytical perspective rarely explored in early childhood environmental education. Unlike previous studies that predominantly examine critical thinking as a learning outcome, this study identifies it as a dynamic cognitive factor that influences how children benefit from instructional interventions. This reframing invites future research to consider learner characteristics not merely as dependent variables, but as active elements shaping the learning process. Ultimately, these findings enrich the theoretical and practical discourse on designing inclusive and responsive education for sustainability.

CONCLUSION

This study confirms the pedagogical strength of the STEAM approach in cultivating marine awareness among young children, especially when paired with strong critical thinking skills. Children who received STEAM-based instruction demonstrated significantly higher levels of marine knowledge, attitudes, and behaviors compared to those taught through a conventional scientific approach. Moreover, the positive effect of STEAM was amplified in students with higher critical thinking abilities, suggesting that instructional methods and cognitive dispositions interact to shape learning outcomes. These findings underscore the importance of integrated, developmentally appropriate, and cognitively engaging pedagogy in early environmental education. As the need for ocean literacy grows globally, implementing STEAM approaches in primary education, particularly in maritime nations like Indonesia offers a promising pathway toward building a more ecologically responsible generation.

REFERENCES

Aginako, Z., & Guraya, T. (2023). Critical Thinking To Embed Sustainability In Engineering Courses Activities . A Systematic Literature Review. *Education Adan New Developments*, *2011*, 134–138.

Campbell, S., Greenwood, M., Prior, S., Walkem, K., Young, S., & Bywaters, D. (2020). Purposive sampling : complex or simple ? Research case examples. *Journal of Research in Nursing 0(0)*, 1–10. https://doi.org/10.1177/1744987120927206

Creswell, J. W. (2012). *Educational Research Planning, Conducting, and Evaluating Quantitative and Qualitative Research* (P. A. Smith (ed.); 4th ed.). Pearson.

Cruz, S. M., & Manata, B. (2020). Measurement of Environmental Concern : A Review and Analysis. *Frontier in Psychology*, *11*(March), 1–14. https://doi.org/10.3389/fpsyg.2020.00363

Dunlap, R. E. (2008). The New Environmental Paradigm Scale: From Marginality to Worldwide Use. *The Journal of Environmental Education*, *40*(1), 3–19.

Dunlap, R. E., & Liere, K. D. Van. (2010). The " New Environmental Paradigm ". *The Journal of Environmental Education*, *40*(1), 19–28.

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

Dunlap, R. E., & Van Liere, K. D. (1978). The "new environmental paradigm." *Journal of Environmental Education*, *9*(4), 10–19. https://doi.org/10.1080/00958964.1978.10801875

Ennis, R. H. (1996). *Critical Thinking*. Prentice-Hall.

Erlita, D., & Sari, M. W. (2025). Effect of steam approach with engineering design process on students ' critical thinking in vibration topic. *Innovations in Science Education and Practice*, *2*(1), 1–7.

Facione, P. A. (2015). Critical Thinking : What It Is and Why It Counts. In *THINK_Critically* (pp. 1–28). Pearson Education. https://www.insightassessment.com/CT-Resources/Teaching-For-and-About-Critical-Thinking/Critical-Thinking-What-It-Is-and-Why-It-Counts/Critical-Thinking-What-It-Is-and-Why-It-Counts-PDF

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to desIgn and evaluate research In educatIon* (8th ed.). Mc Graw Hill.

Gossen, D. (2024). It Says STEM so it must Work for Everyone : Experiences , Beliefs , and Career Choices across the STEM Disciplines To cite this article : Gossen , D . (2024). It says STEM so it must work for everyone : Experiences , beliefs , and career choices across. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *12*(3), 660–681. https://doi.org/10.46328/ijemst.3450

Gü, F. (2023). Environmental Sustainability in Science Education in the Anthropocene : A View from STEAM Education. *Science Insights Education Frontiers*, *14*(2), 2129–2143. https://doi.org/10.15354/sief.23.re088

Guamanga, M. H., Saiz, C., Rivas, S. F., & 3, P. M. B. (2025). Critical Thinking and Metacognition : Pathways to Empathy and Psychological Well-Being. *Journal of Intelligence*, *13*(34), 1–17. https://doi.org/10.3390/jintelligence13030034

Halimah, S., Nurulpaik, I., & Supriatna, E. (2025). The Effectiveness of the STEAM Approach on Critical Thinking Skills in Science and Scientific Attitudes in IPAS Learning in Primary Schools. *Journal of Innovation and Research in Primary Education*, *4*(13), 1736–1747. https://doi.org/10.56916/jirpe.v4i3.1611

Kanthimathi, S., & Raja, B. W. D. (2025). Transforming education: from rote learning to critical thinking in modern classrooms. *EPH - International Journal of Educational Research*. https://doi.org/10.53555/ephijer.v9i1.150

Kashaka, N. D. (2024). Arts Integration in Stem Education : A Path to Steam. *Eurasian Experiment Journal of Humanities Anda Social Sciences (EEJHSS)*, *5*(3), 49–52.

Kelly, K., & Burr, E. (2019). *Emphasizing Transdisciplinary Prowess in the Evaluation of STEAM Programs BT - Converting STEM into STEAM Programs: Methods and Examples from and for Education* (A. J. Stewart, M. P. Mueller, & D. J. Tippins (eds.); pp. 259–283). Springer International Publishing. https://doi.org/10.1007/978-3-030-25101-7_17

Kilbourne, W. (2014). Dominant Social Paradigm. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 1687–1688). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_3368

Kim, J. J. H., Betz, N., Helmuth, B., & Coley, J. D. (2023). Conceptualizing Human – Nature Relationships : Implications of Human Exceptionalist Thinking for Sustainability and Conservation. *Topics in Cognitive Science*, *15*, 357–387. https://doi.org/10.1111/tops.12653

Lee, C., & Shin, Y. (2025). Exploring Young Children's Awareness of Respect for Life in the Context of Marine Ecological Experience Activities. *Journal of Children's Literature and Education*, *26*(1), 257–282. https://doi.org/10.22154/jcle.26.1.11

Leyrat, C., Eldridge, S., Taljaard, M., & Hemming, K. (2024). Practical considerations for sample size calculation for cluster randomized trials. *Journal of Epidemiology and Population Health*, *72*. https://doi.org/10.1016/j.jeph.2024.202198

Li, R., Cao, Y., Tang, H., & Kaiser, G. (2024). Teachers ' Scaffolding Behavior and Visual Perception During Cooperative Learning. *International Journal of Science and Mathematics Education*, *22*(2), 333–352. https://doi.org/10.1007/s10763-023-10379-6

Maric, F., Poto, M.P., Zimmermann, H.J., & Panieri, G. (2023). Ocean floor diorama. In G. P. & M. Stiller-Reeve (Ed.), *The Ocean Senses Activity Book* (pp. 85–87). Septentrio Educational. https://doi.org/10.7557/8.7058

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

Mater, N., Daher, W., & Mahamid, F. (2023). The Effect of STEAM Activities Based on Experiential Learning on Ninth Graders ' Mental Motivation. *European Journal of Investigation in Health, Psychology and Education*, *13*, 1229–1244.

McDonell, J. D. (2001). Best Practices in Marine and Coastal Science Education: Lessons Learned from a National Estuarine Research Reserve. *Marine Anda Coastal Science Education*.

Merma-molina, G., Gavilan, D. M., Baena-morales, S., & Urrea-Solano, M. (2022). Critical Thinking and Effective Personality in the Framework of Education for Sustainable Development. *Education Scie*, *12*(28), 1–16.

Miller, C. J., Smith, S. N., & Pugatch, M. (2020). Experimental and quasi-experimental designs in implementation research. *Psychiatry Research*, *283*(March 2019), 112452. https://doi.org/10.1016/j.psychres.2019.06.027

Montero-izquierdo, A. I., Jeong, J. S., & Gonz, D. (2024). A future classroom lab with active and gamified STEAM proposal for mathematics and science disciplines : Analyzing the effects on pre-service teacher ' s affective domain. *Heliyon*, *10*(September 2023). https://doi.org/10.1016/j.heliyon.2024.e35911

Morari, M. (2023). Integration of The Arts in STEAM Learning Projects. *Review of Artistic Education*, *26*, 262–277. https://doi.org/10.2478/rae-2023-

Qolbi, N., Adrias, A., & Zulkarnaen, A. P. (2025). Efektivitas Pendekatan Saintifik dalam Meningkatkan Hasil Belajar IPA Siswa SD. *Pentagon : Jurnal Matematika Dan Ilmu Pengetahuan Alam*, *3*(3), 35–42.

Quan, N. K., & Liamputtong, P. (2024). Human Behavior and One Health: A Framework for Change. In P. Liamputtong (Ed.), *Handbook of Concepts in Health, Health Behavior and Environmental Health* (pp. 1–23). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-0821-5_45-1

Rodríguez de la Barrera, A. E., & Genes Quintero, C. F. (2024). The STEAM Methodology: An Interdisciplinary Experience To Promote Students' Attitude Towards Learning Mathematics, Science And Technology. *Praxis*, *20*(2 SE-Artículo de investigación científica y tecnológica), 248–262. https://doi.org/10.21676/23897856.5622

Rodriguez, N., Bollen, J., & Ahn, Y. (2016). Collective Dynamics of Belief Evolution under Cognitive Coherence and Social Conformity. *PLoS ONE*, *11*(11), 1–15. https://doi.org/10.1371/journal.pone.0165910

Soemantri, T. S., Anzhari, K., Kosasih, O., & Murwani, I. A. (2025). Value-Belief-Norm Theory and Pro-Environmental Behavior : A Study on Blue Collar Workers in Jakarta. *Journal Research of Social Science, Economics, an Mnagement*, *5*(2), 3323–3330.

Stern, P. C., Dietz, T., Abel, T. D., Guagnano, G., Kalof, L., Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A Value-Belief-Norm Theory of Support for Social Movements : The Case of Environmentalism A Value-Belief-Norm Theory of Support for Social Movements : The Case of Environmentalism. In *Huxley College on the Peninsulas Publications.*

Sumida, M. (2022). Transformation of young children's minds, lives, and society through science, technology, engineering, arts and mathematics (STEAM) play about water. *Play and STEM Education in the Early Years*. https://doi.org/10.1007/978-3-030-99830-1_17

Tajik, O., Golzar, J., & Noor, S. (2024). Purposive Sampling. *Research Education| Non-Empirical Article*, *2*(November), 1–9.

Tan, W., Samsudin, M. A., Ismail, M. E., Ahmad, N. J., & Talib, C. A. (2021). Exploring the Effectiveness of STEAM Integrated Approach via Scratch on Computational Thinking. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(12).

Taylor, P. C. S., & Taylor, E. (2019). Transformative STEAM Education for Sustainable Development. *Proceedings of the Science and Mathematics International Conference (SMIC)*, *2018*, 1–6.

Torres-rivera, A. D., Alejandra, A., Peña, R., Díaz-torres, S. T., & Díaz-torres, L. A. (2025). Ethical Integration of AI and STEAM Pedagogies in Higher Education : A Sustainable Learning Model for Society 5 . 0. *Sustainability*, *17*, 1–37. https://doi.org/10.3390/su17198525

Upreti, G. (1994). Environmental Conservation and Sustainable Development Require a New Development Approach. *Environmental Conservation*, *21*(1), 18–29. http://www.jstor.org/stable/44521571

ISSN 2302-6804 (print), ISSN 2579-4531 (online)

Vincent-Lancrin, S. (2024). *Critical thinking*. Edward Elgar Publishing. https://doi.org/10.4337/9781035317967.ch27

Wei, C. A., Deaton, M. L., Shume, T. J., Berardo, R., & Burnside, W. R. (2020). A framework for teaching socio-environmental problem-solving. *Journal of Environmental Studies and Sciences*, *10*, 467–477.

Yulia, E. D., Hapidin, & Sarifah, I. (2025). Kemampuan berpikir kritis pada anak usia dini. *Jurnal Pelita PAUD, 9*(2), 583–590.

Zhbanova, K. S., Mississippi, Rule, A. C., & Tallakson, D. A. (2019). Ocean Underwater Scene Dioramas of First Graders with Submarine Porthole Views. *Journal of STEM Arts, Crafts, and Constructions*, *4*(1), 63–82.

ISSN 2302-6804 (print), ISSN 2579-4531 (online)