

STEAM Education and Sustainable Development in Thailand: Achievements, Challenges, and Future Directions

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Abstract

Aim/Purpose: The purpose of this paper was to provide a clearer and more comprehensive understanding of how Science, Technology, Engineering, Arts, and Mathematics (STEAM) education in Thailand supports the United Nations (UN) Sustainable Development Goals. Although STEAM has gained national attention for promoting interdisciplinary learning and 21st century skills, challenges remain, including uneven regional implementation, limited arts integration, and weak alignment with sustainability frameworks. This study aimed to examine current progress, identify implementation barriers, and determine conditions that can strengthen STEAM education's contribution to sustainable development in Thailand.

Introduction/Background: This paper addresses the challenges described above by investigating how STEAM education policies and practices across Thailand correspond to UN Sustainable Development Goals. The study evaluated the extent to which educators perceive progress in policy formulation, the method and depth of sustainability integration, and the role of interdisciplinary learning in fostering the skills needed to respond to environmental and social issues. By situating the analysis within Thailand's diverse institutional and regional contexts, the study sheds light on variations that shape STEAM implementation. These variations, which include differences in resource access, professional development, leadership support, and curriculum interpretation, create conditions that influence both equity and effectiveness. Understanding these dynamics is essential for refining national policy strategies and developing interventions that can strengthen STEAM education nationwide.

Methodology: In this study, a sequential explanatory mixed methods design was employed to examine the relationship between STEAM education and sustainable development in Thailand. Quantitative data were collected through structured surveys from a sample of 387 educators across a range of educational institutions, representing different instructional levels and geographical regions nationwide. The survey covered perceptions of policy clarity, institutional readiness, resource availability, the integration of arts components, and the use of sustainability-oriented frameworks. Following this phase, qualitative data were gathered through semi-structured interviews with 42 participants selected to represent diverse institutional settings. These interviews provided nuanced insights into local experiences, contextual challenges, variations in regional support systems, and the influence of socio-cultural conditions on STEAM practices. The combination of quantitative and qualitative approaches allowed for a deep understanding of measurable trends while also capturing the lived experiences and interpretations of educators. This methodological structure ensured that numerical findings were supported by contextual explanations, strengthening the overall validity and interpretive depth of the study.

Findings: The findings reveal several important outcomes. First, STEAM-related policy development in Thailand is showing forward movement, with increased attention to interdisciplinary learning and recognition of sustainability as an important educational theme. Despite this progress, significant discrepancies remain across institutions and regions. These include uneven distribution of resources,

inconsistent administrative support, and varying levels of teacher preparedness. The second major finding is that environmental sustainability dimensions are relatively well integrated into STEAM activities, partly due to national focus on ecological awareness. However, the arts component is often incorporated inconsistently or superficially, preventing STEAM from functioning as a fully holistic interdisciplinary model. Another finding is that policies, lesson plans, and instructional practices generally lack explicit references to formal sustainability frameworks, including the UN Sustainable Development Goals. Finally, the study confirms that STEAM learning environments, when supported with sufficient resources and appropriately designed curricular structures, have strong potential to foster critical thinking, creativity, collaboration, and environmental awareness among students, all of which are essential to sustainable development.

Contribution/Impact on Society: This study contributes significantly to academic discourse on STEAM education in Southeast Asia by providing empirical evidence grounded in Thailand's unique socio-cultural and institutional environment. It reveals structural, pedagogical, and regional factors that influence the success of STEAM initiatives and clarifies how well these initiatives align with the Sustainable Development Goals. The findings demonstrate that improving STEAM education can strengthen workforce readiness, enhance environmental responsibility, and support interdisciplinary problem-solving. These implications extend beyond the educational sector, as a strong STEAM foundation can help prepare future generations to navigate social, economic, and environmental challenges in a rapidly changing world. Policymakers, educators, school leaders, and curriculum developers can all benefit from the insights offered by this study.

Recommendations: This research highlights the need to strengthen the integration of arts components in STEAM programs to ensure the framework achieves its full interdisciplinary potential. Additional emphasis should be placed on reducing regional disparities by increasing institutional support, expanding professional development opportunities, and improving resource distribution. Policymakers should clearly embed Sustainable Development Goal elements into curriculum documents, teacher training programs, and instructional guidelines to enhance strategic alignment. Furthermore, investments should focus on teacher preparation, collaborative networks, community engagement, and leadership development to reinforce sustainable and effective STEAM implementation across Thailand.

Research Limitations: The study had several limitations. It focused exclusively on educators within Thailand, limiting the generalizability of findings to other countries. Institutional variation across regions may also have created inconsistencies in participants' responses. Additionally, the study relied on self-reported data, which can be influenced by personal perception, subjective interpretation, and limited recall, potentially affecting the accuracy of results. The cross-sectional nature of the data also restricts conclusions about long-term outcomes.

Future Research: The long-term effects of STEAM education on student development, especially in areas such as creativity, problem-solving, and sustainability awareness, warrant further investigation. Comparative studies across ASEAN countries could provide insight into different policy models and implementation frameworks. Further research should also investigate effective strategies for arts integration, the influence of school leadership on STEAM outcomes, and the role of digital tools in enhancing STEAM-aligned sustainability education.

Keywords: *Environmental education, STEAM education, sustainable development, Thailand*

Introduction

Over the last ten years, the country's education landscape has been transformed significantly in response to global educational trends and national development imperatives defined by the Thailand 4.0 Policy Framework (Buasuwan, 2018). As a result, the policy framework emphasizes innovation-driven development and human resource enhancement, thereby shifting Thailand toward a value-

based economy (World Bank, 2021). In this light, STEAM (Science, Technology, Engineering, Arts, Mathematics) integrated education has become a pivotal strategy for building both creative problem-solving capabilities and the technical competencies essential for sustainable national development (Land, 2013).

The pedagogical shift to include the Arts is significant, as it acknowledges how innovation within the domain of STEM is key to solving complex sustainability issues in the interplay between scientific and creative fields (Techakosit & Wannapiroon, 2015). This multidisciplinary approach aligns with Thailand's expectations regarding the UN Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action) (National Economic and Social Development Council, 2023).

This research was guided by four primary research questions:

- (1) How is STEAM education currently implemented across different educational levels and regions in Thailand?
- (2) To what extent are sustainable development principles integrated into STEAM educational practices in Thailand?
- (3) What impact does STEAM education have on students' knowledge, skills, and attitudes regarding sustainability issues?
- (4) What factors facilitate or impede effective STEAM education implementation within Thailand's educational environment?

Literature Review

STEAM Education: Conceptual Evolution and Global Context

STEAM education represents an essential change in educational ideology because it represents a fundamental paradigm shift from STEM (Land, 2013). While STEM education originated in the US during the early 2000s as a response to declining student interest and achievement in science and mathematics (Bybee, 2018; Gonzalez & Kuenzi, 2013), infusing arts in STEAM education acknowledges the roles of creativity, design thinking, and cultural context as sources for promoting innovation (Katz-Buonincontro, 2018; Quigley & Herro, 2019). This merging recognizes that complex global challenges need both technical expertise and creative problem-solving approaches (Land, 2013).

International research has demonstrated that effective STEAM education develops critical thinking, collaboration, communication, and creativity, essential competencies for 21st-century workforces (Liao, 2019). Studies have also revealed STEAM education's potential for developing systems thinking and ethical reasoning capabilities necessary for addressing sustainability challenges (Colucci-Gray et al., 2019; Perignat & Katz-Buonincontro, 2020).

STEAM Education in Southeast Asia

Southeast Asian countries increasingly utilize STEAM education as a strategy for economic development and workforce preparation (SEAMEO INNOTECH, 2020). Singapore's STEAM initiatives emphasize design thinking and technological literacy through programs such as the STEM Applied Learning Programme (Tan et al., 2019). Malaysia has developed STEM-specialized laboratories in schools, focusing on hands-on learning experiences and industry partnerships (Marzuki et al., 2026). Vietnam has also incorporated STEAM-related competencies into national STEM educational reform efforts (Nguyen, 2024). Similarly, South Korea's STEAM teacher education has evolved through community of practice models (Jho et al., 2016).

Thailand's approach to STEAM education has been shaped by its unique socioeconomic context and cultural values (UNDP, 2024). The Sufficiency Economy Philosophy, derived from the teachings of King Bhumibol Adulyadej, promotes balanced development emphasizing moderation, reasonableness, and sustainability (Mongsawad, 2010). This philosophy has influenced Thailand's interpretation of sustainable development and subsequent integration into STEAM education approaches.

Sustainable Development in Thai Educational Policy

Since ratifying the United Nations Sustainable Development Goals in 2015, Thailand has explicitly aligned its educational policies with sustainable development frameworks (Ministry of Foreign Affairs, 2021). The 2017–2036 National Education Plan emphasizes “Education for Sustainable Development” as a core principle, promoting environmental awareness, social responsibility, and economic consciousness (Office of the Education Council, 2017). The Basic Education Core Curriculum, revised in 2020, integrates sustainability principles across subject areas, emphasizing environmental education, cultural heritage conservation, and responsible consumption. Nevertheless, the implementation of sustainability education in schools remains uneven, with variations in leadership support, teacher capacity, and instructional practices affecting the extent to which sustainability principles are enacted in classrooms (Jean-Francois, 2022).

STEAM Education and Sustainable Development Integration in Thailand

The integration of STEAM education with SDGs represents an emerging research area in Thailand (Jean-Francois, 2022). Preliminary studies show promising results, with STEAM-based learning experiences enhancing students’ environmental awareness and problem-solving capabilities (Techakosit & Wannapiroon, 2015). STEAM projects addressing local environmental issues can effectively engage students while developing both subject-specific knowledge and sustainability competencies (Land, 2013).

However, significant gaps exist in understanding how STEAM education is implemented across different educational levels and geographical regions in Thailand, particularly regarding explicit connections to sustainable development frameworks (UNESCO, 2020). This study addressed these gaps by comprehensively examining STEAM educational practices and their alignment with sustainability principles across diverse Thai educational contexts.

Methodology

Research Design

In this study, a sequential explanatory mixed methods design was employed to investigate STEAM education implementation in Thailand and its relationship to sustainable development (Creswell & Creswell, 2018). The research was conducted in two phases: (a) a quantitative phase examining implementation patterns, pedagogical approaches, and perceived outcomes; and (b) a qualitative phase exploring implementation experiences, challenges, and success factors in depth.

Participants and Sampling

A total of 387 educators from various educational institutions across Thailand participated in the quantitative phase, including primary schools ($n=152$), secondary schools ($n=138$), vocational colleges ($n=45$), and universities ($n=52$). Participants were recruited through stratified random sampling to ensure representation across six geographical regions (North, Northeast, Central, East, West, and South) and institutional types (urban/rural, public/private).

For the qualitative phase, 42 participants were purposively selected from among survey respondents who indicated a willingness to participate in follow-up interviews. Selection criteria ensured diversity in geographical location, institutional type, teaching experience, and STEAM implementation approaches. Participant demographics are shown below in Table 1.

Table 1 *Participant Demographics*

Characteristic	Quantitative Phase (n=387)	Qualitative Phase (n=42)
Gender		
Female	216 (55.8%)	24 (57.1%)
Male	168 (43.4%)	18 (42.9%)
Non-binary/Prefer Not to Say	3 (.8%)	0 (.0%)
Educational Level		
Primary School	152 (39.3%)	14 (33.3%)
Secondary School	138 (35.7%)	16 (38.1%)
Vocational College	45 (11.6%)	5 (11.9%)
University	52 (13.4%)	7 (16.7%)
Geographical Region		
North	68 (17.6%)	7 (16.7%)
Northeast	73 (18.9%)	9 (21.4%)
Central	103 (26.6%)	11 (26.2%)
East	52 (13.4%)	5 (11.9%)
West	38 (9.8%)	4 (9.5%)
South	53 (13.7%)	6 (14.3%)
Institutional Setting		
Urban	218 (56.3%)	24 (57.1%)
Rural	169 (43.7%)	18 (42.9%)
Teaching Experience		
0–5 Years	86 (22.2%)	7 (16.6%)
6–10 Years	102 (26.4%)	12 (28.6%)
11–15 Years	89 (23.0%)	10 (23.8%)
16+ Years	110 (28.4%)	13 (31.0%)

Data Collection Instruments

Quantitative Phase. The survey instrument was developed based on existing STEAM education research (Liao, 2019; Perignat & Katz-Buonincontro, 2020) and adapted to the Thai educational context through expert review and pilot testing. The final questionnaire comprised five sections:

1. Demographic Information (8 items)
2. STEAM Conceptualization and Implementation Practices (15 items)
3. Sustainable Development Integration (12 items)
4. Perceived Outcomes and Impacts (18 items)
5. Implementation Facilitators and Barriers (14 items)

Items were rated on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) with additional open-ended questions. The instrument demonstrated strong internal consistency, with Cronbach's alpha coefficients ranging from .78 to .92 across subscales.

Qualitative Phase. Semi-structured interviews were conducted using a protocol developed from survey findings. The interview guide explored:

1. STEAM Education Conceptualization and Implementation Approaches
2. Sustainable Development Principles Integration
3. Observed Student Outcomes and Impacts
4. Success Factors and Challenges
5. Professional Development Needs and Support Systems
6. Future Directions and Recommendations

Interviews lasted 45-60 minutes, were conducted in Thai, and were audio-recorded and transcribed for analysis.

Data Collection Procedures

Quantitative data were collected from September to December 2024 through an online survey platform. Survey invitations were distributed through official educational networks with support from the Office of the Basic Education Commission and the Office of the Higher Education Commission. Three follow-up reminders were sent, achieving a response rate of 68.4%. Qualitative interviews were conducted face-to-face ($n=28$) or via video conference ($n=14$) from January to March 2025, based on participants' preferences and geographical considerations.

Data Analysis

Quantitative data were analyzed using descriptive statistics, inferential tests, and exploratory factor analysis in SPSS, with minimal missing data addressed through multiple imputations. Qualitative data were examined through thematic analysis, with two researchers coding independently before finalizing themes together. Member checking enhanced credibility through participant verification of interview summaries. Quantitative and qualitative findings were integrated during interpretation to clarify and enrich the overall results.

Ethical Considerations

This study received ethical approval from the institutional review board. All participants provided informed consent, and data were anonymized to ensure confidentiality. Participants were informed of their right to withdraw at any stage without consequence.

Results

STEAM Education Conceptualization

Survey responses revealed considerable variation in educators' conceptualization of STEAM education. While most participants (83.7%) recognized the integration of the arts with STEM fields as a defining characteristic, significant differences emerged in their understanding of underlying principles and implementation approaches. Factor analysis revealed three dominant conceptualizations: (a) interdisciplinary problem-solving (39.2%), (b) arts-enhanced STEM learning (34.6%), and (c) creativity-driven innovation (26.2%).

Interview data provided deeper insights into these conceptualizations. Educators emphasizing interdisciplinary problem-solving described STEAM as "an approach that integrates knowledge and methods from multiple disciplines to address real-world problems" (P7, university educator, Central region). Advocates of arts-enhanced STEM learning viewed arts integration primarily as a mechanism to make STEM subjects more engaging and accessible. "The arts component helps students connect with STEM concepts that might otherwise seem abstract or difficult" (P15, secondary school teacher, Northern region).

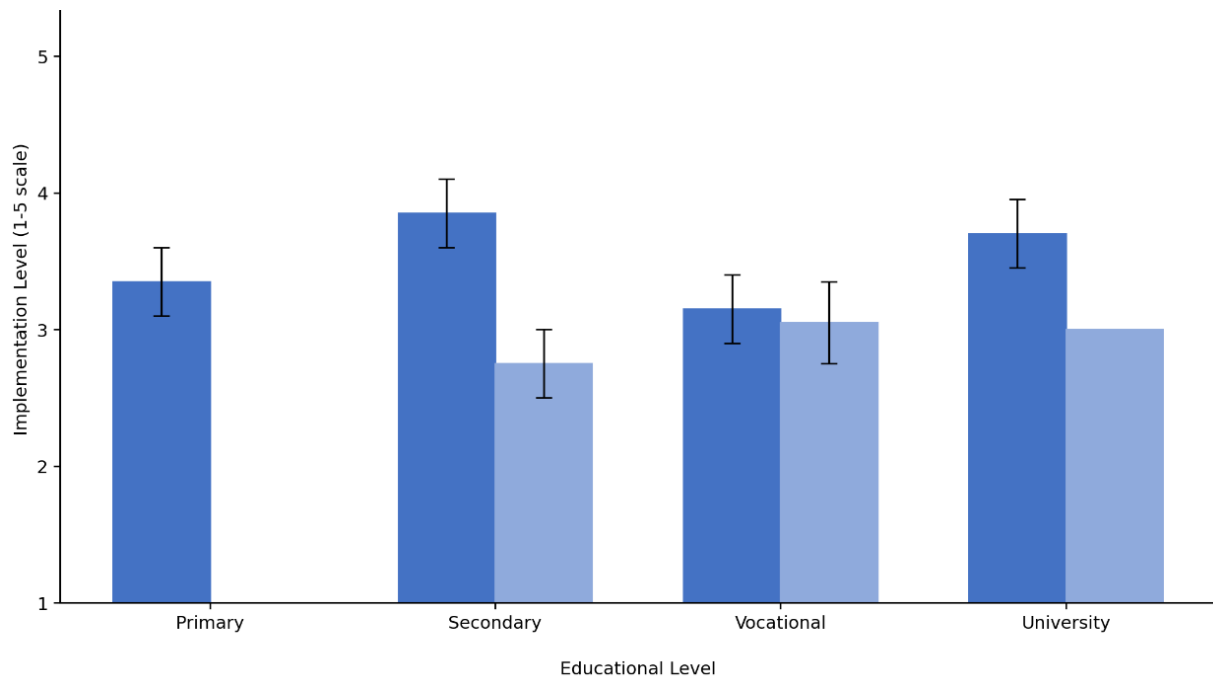
Creativity-focused perspectives emphasized innovation and design thinking. "STEAM education is a framework that prioritizes developing creative thinking and design skills that can be applied to any problem-solving situation" (P23, vocational college instructor, Southern region).

Implementation Patterns. Survey results revealed a substantial variation in STEAM education implementation across educational levels and regions. Figure 1 illustrates implementation levels by education level and institutional setting, with dark blue representing urban schools and light blue representing rural schools.

Urban schools reported significantly higher implementation levels ($M = 3.78$, $SD = .82$) than rural schools ($M = 2.95$, $SD = .91$), $t(385) = 4.73$, $p < .001$, $d = .86$. By educational level, secondary schools demonstrated the highest implementation ($M = 3.86$, $SD = .78$), followed by universities ($M = 3.72$, $SD = .85$), primary schools ($M = 3.28$, $SD = .93$), and vocational colleges ($M = 3.15$, $SD = .88$), $F(3,383) = 8.97$, $p < .001$, $\eta^2 = .09$.

Qualitative findings explained these disparities by highlighting resource constraints in rural areas. “We understand the importance of STEAM education, but lack the necessary equipment, materials, and professional development opportunities” (P29, primary school teacher, Northeast region).

Figure 1 STEAM Implementation Levels by Educational Level and Setting



The most common approach was dedicated STEAM subjects or modules (42.1%), followed by interdisciplinary project-based learning (37.6%), extracurricular activities (33.8%), integration into existing subjects (30.2%), and special events/competitions (26.9%). Most institutions adopted multiple approaches, with secondary schools showing greater use of combined implementation strategies.

Sustainable Development Principles Integration

Integration Extent. Survey results indicated moderate integration of sustainable development principles within STEAM education practices ($M = 3.42$, $SD = .88$ on a 5-point scale). However, significant variations were observed across different sustainability dimensions. Environmental sustainability received the highest ratings ($M = 3.86$, $SD = .79$), followed by economic sustainability ($M = 3.28$, $SD = .92$) and social sustainability ($M = 3.12$, $SD = .97$). Table 2 presents the percentage of respondents reporting different levels of sustainable development integration across key dimensions.

Table 2 Sustainable Development Dimensions Integration in STEAM Education

Sustainability Dimension	No Integration	Minimal Integration	Moderate Integration	High Integration	Comprehensive Integration
Environmental Sustainability	4.7%	12.1%	24.8%	39.3%	19.1%
Resource Conservation	7.2%	17.3%	30.5%	33.1%	11.9%
Climate Change	11.6%	20.7%	29.2%	27.6%	10.9%
Biodiversity	15.8%	23.3%	31.5%	22.0%	7.4%
Economic Sustainability	8.5%	18.6%	35.2%	27.6%	10.1%
Responsible Consumption	7.0%	19.9%	34.6%	28.4%	10.1%
Sustainable Production	12.4%	24.5%	31.8%	23.0%	8.3%
Economic Development	6.2%	17.3%	38.8%	27.9%	9.8%
Social Sustainability	9.8%	23.5%	31.8%	27.1%	7.8%
Cultural Preservation	8.3%	19.9%	33.9%	28.7%	9.2%
Social Equity	15.0%	26.9%	32.3%	20.4%	5.4%
Community Development	6.2%	23.8%	29.2%	32.0%	8.8%

Interview data revealed that while many educators recognize sustainability's importance, their explicit connections to formal sustainable development frameworks such as the UN SDGs remain limited. One participant explained, "We integrate environmental concepts and projects that address local issues, but we don't specifically reference the SDGs or use that terminology with our students" (P11, secondary school teacher, Eastern region).

Integration Approaches. The most common approaches for integrating sustainability into STEAM education included:

1. Project-based learning addressing local environmental issues (58.7%)
2. Resource conservation design challenges (47.3%)
3. Community-based initiatives addressing local sustainability challenges (39.5%)
4. Integration of traditional knowledge and practices (36.4%)
5. Green technology and innovation projects (33.1%)

Qualitative findings illustrated these approaches in practice. One exemplary case involved high school students designing a water filtration system for a rural community using locally available materials. "This project combined engineering principles, materials science, and artistic design while addressing a real societal need for clean water access" (P37, high school teacher, Northeast region).

Another significant example involved Thailand's Sufficiency Economy Philosophy. "Our STEAM projects are guided by Sufficiency Economy Philosophy principles, encouraging students to develop solutions that are not only technically sound, but also balanced, reasonable, and sustainable" (P5, primary school teacher, Central region).

Impact on Student Outcomes

Knowledge and Skills Development. Survey respondents reported positive impacts of STEAM education across various student outcomes. Table 3 presents mean impact ratings across cognitive, skills-based, and attitudinal domains.

Table 3 Educators' Perceived Impacts of STEAM Education on Student Outcomes ($n = 387$)

Competency Domain	Student Outcome	Mean	SD	Rank
Cognitive Skills	Critical Thinking	4.18	.72	1
	Creativity	4.15	.75	2
Social Skills	Collaboration Skills	4.12	.78	3
Content Knowledge	Environmental Awareness	3.96	.83	4
	Science Knowledge	3.95	.82	5
	Technology Skills	3.91	.85	6
Sustainability Competencies	Sense of Agency	3.78	.87	7
	Systems Thinking	3.73	.89	8
	Engineering Concepts	3.68	.89	9

Note. Ratings used a 5-point scale (1 = No Impact; 5 = Substantial Impact). M = Mean; SD = Standard Deviation. Items are ranked by mean score.

The highest reported impacts were for critical thinking ($M = 4.18$, $SD = .72$), creativity ($M = 4.15$, $SD = .75$), and collaboration skills ($M = 4.12$, $SD = .78$). Subject-specific knowledge impacts showed greater variation, with the strongest effects reported for science ($M = 3.95$, $SD = .82$) and technology ($M = 3.91$, $SD = .85$), followed by engineering ($M = 3.68$, $SD = .89$), arts ($M = 3.65$, $SD = .94$), and mathematics ($M = 3.52$, $SD = .96$). These patterns were consistent with STEAM models developed to improve creative thinking competencies in Thai students (Wannapiroon & Pimdee, 2022). Interviewees consistently emphasized transferable skills development. "The most significant impact I've observed is students' ability to approach complex problems systematically, consider multiple perspectives, and work collaboratively with their peers" (P18, secondary school teacher, Central region).

Sustainability Awareness and Attitudes. STEAM education demonstrated positive impacts on sustainability-related outcomes, with the strongest effects on environmental awareness ($M = 3.96$, $SD = .83$), local community connection ($M = 3.78$, $SD = .87$), and systems thinking ($M = 3.73$, $SD = .89$). Educators implementing STEAM programs with explicit sustainability connections reported significantly stronger impacts on all sustainability-related outcomes compared to programs without such connections, $t(385) = 5.87$, $p < .001$, $d = .92$.

Qualitative findings revealed transformative experiences for some students. “Following our river conservation project, students became passionate environmental advocates in their community. They initiated additional projects and even engaged with local authorities” (P33, secondary school teacher, Southern region).

Facilitators and Barriers

Implementation Facilitators. Survey responses identified several factors supporting effective STEAM education implementation. Table 4 shows the percentage of respondents rating various facilitating factors as “important” or “very important.”

Table 4 STEAM Education Implementation Facilitating Factors

Facilitating Factor	Percentage Rating (Important or Very Important)
Administrative Support and Leadership	87.6%
Adequate Material Resources and Equipment	84.2%
Teacher Collaboration Opportunities	82.7%
Professional Development and Training	81.4%
Flexible Curriculum Structure	76.2%
Community Partnerships and Engagement	72.6%
Student Interest and Motivation	70.0%
Supportive Policy Framework	67.2%
Integration with Assessment Systems	61.8%
External Funding Opportunities	58.7%

Interview data elaborated on these factors, highlighting the crucial role of school leadership. “Our principal champions STEAM education and allocates resources for interdisciplinary projects. This administrative support creates conditions for teachers to experiment and collaborate” (P22, primary school teacher, Western region).

Community partnerships proved particularly valuable for sustainability-focused STEAM initiatives. “Collaborating with local environmental groups and businesses provides real-world context for projects and additional resources our school couldn’t provide alone” (P9, secondary school teacher, Southern region).

Implementation Barriers. Despite growing support for STEAM education, significant barriers constrain effective implementation. The most frequently reported challenges included:

1. Limited time for interdisciplinary project preparation (76.5%)
2. Insufficient material resources and equipment (72.4%)
3. Inadequate teacher training (68.7%)
4. Rigid curriculum requirements and time constraints (65.9%)
5. Assessment and evaluation difficulties (62.3%)
6. Limited cross-subject teacher collaboration (57.6%)

Rural institutions reported significantly higher barriers related to material resources ($p < .001$) and professional development opportunities ($p < .01$) compared to urban institutions, consistent with broader research on STEM education in rural schools (NASEM, 2025).

Interviewees highlighted systemic challenges within Thailand’s educational context: “The examination-driven system pressures us to focus on content coverage rather than deep learning

experiences. This makes it challenging to implement time-intensive STEAM projects” (P4, secondary school teacher, Central region).

Cultural factors also emerged as important considerations. “Thai culture emphasizes following established procedures rather than open inquiry. We need to create safe spaces for students to take risks and for teachers to try new approaches” (P41, university educator, Northern region).

Discussion

STEAM Education in Thailand: Emerging Patterns and Implications

This study demonstrates that STEAM education in Thailand exists along an implementation continuum, with significant variations across educational levels, regions, and institutional types. The three distinct conceptualizations identified were interdisciplinary problem-solving, arts-enhanced STEM learning, and creativity-driven innovation, reflecting both global STEAM education evolution and Thailand’s unique cultural interpretations and educational contexts (Perignat & Katz-Buonincontro, 2020).

The uneven implementation patterns, particularly urban-rural disparities, highlight equity concerns requiring policy attention. These disparities may be explained by unequal access to qualified teachers, digital infrastructure, instructional resources, and institutional support, which can limit the capacity of rural and underserved schools to implement interdisciplinary and technology-supported STEAM learning. These findings align with previous research on educational inequality in Thailand (Chairassamee et al., 2024), which found that differences in household resources, digital access, and school readiness intensified disparities in educational opportunities. Therefore, their findings support the present study’s conclusion that contextual and resource constraints contribute to uneven STEAM implementation. These findings underscore the need for targeted resource allocation and capacity building in underserved areas. The diverse implementation approaches (ranging from dedicated STEAM subjects to integration within existing curricula) reflect educators’ adaptive responses to contextual constraints while maintaining core STEAM principles.

The relatively stronger STEAM education in secondary schools compared to other educational levels reflects developmental considerations in implementation. This pattern aligns with international trends showing stronger STEAM integration at secondary levels (Quigley & Herro, 2019), where learners are more likely to possess the disciplinary foundations, cognitive readiness, and exposure to project-based learning needed for complex interdisciplinary tasks. However, this pattern highlights the importance of vertical alignment across educational levels to build cumulative competencies.

STEAM Education and Sustainable Development: Connections and Gaps

The moderate integration of sustainable development principles within STEAM education represents both an opportunity and a challenge. The emphasis on environmental sustainability aligns with Thailand’s pressing environmental concerns and cultural values that emphasize harmony with nature (UNDP, 2024). However, limited attention to social equity and inclusion reveals a clear gap in comprehensive sustainability education.

Although STEAM activities addressed sustainability issues, explicit links to the UN Sustainable Development Goals remain limited (UNESCO, 2020), potentially restricting students’ understanding of connections between local actions and global challenges. This finding aligns with previous studies showing nascent SDG integration in Thai educational practices.

Nevertheless, the creative integration of Thai cultural frameworks, particularly the Sufficiency Economy Philosophy, reflects a culturally responsive approach to sustainability education. This localization of sustainability concepts represents a strength that could be further developed and shared as Thailand’s contribution to global sustainability education discourse.

Impact on Student Outcomes: Building Sustainability Competencies

The positive effects on critical thinking, creativity, collaboration, and systems thinking indicate that STEAM education, when effectively implemented, develops core competencies for addressing sustainability challenges. These results align with international research demonstrating STEAM's effectiveness in developing 21st-century skills (Liao, 2019; Perignat & Katz-Buonincontro, 2020).

The stronger impact reported for STEAM initiatives with explicit sustainability connections highlights the importance of intentional linkages between educational approaches and sustainability objectives. This supports findings by Colucci-Gray et al. (2019), emphasizing the need for explicit sustainability framings in science education.

Facilitators and Barriers: Building Supportive Ecosystems

The facilitating factors identified by respondents (administrative support, adequate resources, teacher collaboration, and professional development) represent systemic conditions necessary for effective STEAM implementation. This aligns with research on educational innovation adoption (Segarra-Morales & Rodríguez-Miranda, 2026) and emphasizes the importance of whole-school approaches rather than isolated classroom initiatives.

The reported barriers, particularly time constraints and assessment challenges, reflect tensions between traditional educational structures and innovative pedagogical approaches. These findings resonate with international research on STEAM implementation challenges (Land, 2013) but are particularly relevant to Thailand's examination-driven educational context (Office of the Education Council, 2017).

The cultural considerations emerging from qualitative data highlight the importance of contextualizing STEAM education within Thai cultural values and practices (Pimthong & Williams, 2020). Rather than uncritically adopting international models, effective implementation requires negotiating between innovative pedagogical principles and cultural contexts, an approach supported by research on culturally responsive STEAM education (Techakosit & Wannapiroon, 2015).

Theoretical and Practical Contributions

This study contributes to scholarly understanding of STEAM education in a Southeast Asian context, particularly its integration with sustainable development frameworks. The findings demonstrate that effective STEAM education can develop critical competencies for addressing sustainability challenges while highlighting the importance of contextual factors in implementation success.

Theoretically, this study supports conceptualizing STEAM education as a transformative pedagogy rather than mere content integration. The documented connections between STEAM education and sustainability competencies strengthen the theoretical foundation for positioning STEAM as an effective approach to education for sustainable development.

Practically, the research identifies specific strategies, facilitators, and barriers that can inform policy development and educational practice. The documented implementation approaches provide models adaptable to diverse educational contexts while considering resource constraints and cultural considerations.

Recommendations

Based on the findings, the following recommendations are proposed to enhance STEAM education's contribution to sustainable development in Thailand.

Policy Recommendations

Develop a Comprehensive Policy Framework: Create explicit policy connections between STEAM education and Thailand's sustainable development priorities and UN SDGs, providing conceptual clarity and implementation guidance for educators and administrators.

Address Implementation Disparities: Implement targeted resource allocation and capacity-building initiatives for rural and under-resourced institutions to ensure equitable access to quality STEAM education across all regions and institutional types.

Reform Assessment Systems: Modify assessment frameworks to reduce tensions between innovative pedagogical approaches and accountability requirements, ensuring alignment with STEAM education's interdisciplinary, competency-based nature.

Establish Collaborative Networks: Build systematic partnerships connecting educational institutions with industry, community organizations, and government agencies to create supportive ecosystems for STEAM education implementation.

Practical Recommendations

Strengthen Sustainability Connections: Develop explicit links between STEAM activities and sustainability dimensions to help students understand how their learning connects to broader sustainability challenges and opportunities.

Integrate Thai Cultural Frameworks: Incorporate the Sufficiency Economy Philosophy and other Thai cultural frameworks to develop culturally responsive approaches to STEAM education with a sustainability focus (Bean, 2023).

Prioritize Teacher Collaboration: Implement structured professional learning communities and collaborative planning time to address subject-specific knowledge boundaries and enhance interdisciplinary teaching capacity.

Develop Appropriate Assessment Methods: Create assessment approaches that capture the full range of competencies developed through STEAM education, including both subject-specific knowledge and transversal skills.

Engage Community Partners: Involve community members and organizations as partners in STEAM initiatives, connecting learning experiences with authentic, local sustainability challenges and opportunities.

Limitations and Future Research Directions

This study had several limitations that point to meaningful directions for future research. The cross-sectional design offers only a single-time snapshot, which restricts understanding of long-term development and sustained impacts. Longitudinal studies are therefore needed to track STEAM implementation and student outcomes over extended periods. Although a mixed methods approach provides both breadth and depth, the focus on educator perspectives may not have fully reflected student experiences. Future studies should include direct assessments of student competencies, as well as student perspectives to strengthen evidence of STEAM's effectiveness.

Additionally, the study concentrated on formal educational institutions, leaving non-formal and informal settings underexplored. Expanding research to these environments would contribute to a more comprehensive picture of Thailand's STEAM education landscape. Future investigations should examine the effectiveness of various STEAM implementation models in developing sustainability competencies, explore culturally responsive pedagogies that integrate Thai cultural contexts with global sustainability goals, and analyze how STEAM education can address specific sustainability challenges in Thailand. Research on the long-term influences of STEAM learning on student career pathways and sustainability-related behaviors would also provide valuable insights.

Conclusion

STEAM education in Thailand stands at a promising intersection of educational innovation and sustainable development. This study highlighted both significant progress and ongoing challenges in realizing STEAM education's potential to develop the capabilities needed to address complex sustainability challenges.

Thailand can build upon existing strengths—particularly creative implementation approaches, cultural integration, and growing policy support—to develop a distinctive approach to STEAM

education that significantly contributes to the country's sustainable development priorities while providing valuable insights to the global educational community. By systematically addressing identified barriers related to resources, training, and assessment while strengthening facilitating factors, Thailand can position STEAM education as a cornerstone of its educational transformation toward sustainability.

The integration of Thai cultural values with global sustainability frameworks represents a unique contribution to international STEAM education discourse, demonstrating how local contexts can enrich and strengthen global educational approaches. This culturally grounded yet globally connected approach offers a model for other nations seeking to implement STEAM education in ways that honor local values while addressing global challenges.

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Author Contributions

Atchara Limwongthong: Data curation, investigation, validation, resources, writing–review and editing; **Nachon Prayoonvong:** Conceptualization, methodology, formal analysis, investigation, writing–original draft, writing–review and editing, visualization.

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