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The School-Based Professional Development for Teachers' STEM Teaching: A Focus on Contextualized STEM Education in the Phuket Education Sandbox (Southern Regions of Thailand)

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Abstract

This research aims to develop a professional development model for science teachers using a school-based approach to enhance STEM literacy. The model leverages outdoor STEM education resources in southern Thailand. The study focuses on primary-level science and project-based teachers in Phuket Province, selected through purposive sampling from schools participating in an educational sandbox project with support from school administrators. The research employed a mixed-methods approach to design a professional development program emphasizing outdoor STEM activities and incorporating local Phuket contexts. Data collection involved STEM literacy assessments, lesson plan evaluations, classroom observations, and focus group interviews. Quantitative data were analyzed statistically, while qualitative data underwent content analysis over a one-year period. The project began in 2023 with a needs assessment, tool development, and a draft model, followed by implementation in 2024. Findings highlight that school-based coaching and ongoing lesson design workshops, core elements of the program, improved teachers' understanding of STEM integration. Teachers designed learning activities rooted in local contexts and engineering design principles, fostering interdisciplinary connections within a STEM framework. This approach enabled them to integrate STEM concepts into primary education while emphasizing continuous assessment of student outcomes and competencies. Despite the program's success, challenges remain, particularly in allocating time for curriculum implementation and securing stronger administrative support. Nevertheless, the program advanced STEM literacy by using local contexts as a platform, aligning with community-based education goals and enhancing primary-level STEM education practices.

Keywords: Contextualized STEM Education, Outdoor STEM, Professional Development, Community of Practice

1. Introduction

As science, technology, engineering, and mathematics (STEM) education gains increasing prominence in schools worldwide, STEM teacher development programs have been established to support educators in adopting this integrated approach. A central component of these programs is guiding teachers to create integrated STEM curricula. However, existing research often overlooks the processes by which teachers acquire the knowledge and skills necessary for effective curriculum design. As a result, there is a limited understanding in the literature of how to best support teachers in learning and developing integrated curriculum design, posing challenges for those tasked with designing STEM teacher development programs. In response, the government aims to shift Thailand's economy toward a value-based economy driven by innovation, technology, and creativity. The policy outlines four key dimensions: 1) Economic security, 2) Social well-being, 3) Human value enhancement, and 4) Environmental sustainability. The goal is to transform Thailand into a high-income nation, improve international economic competitiveness, and elevate Thailand to the status of a "First World Country" by 2032 (Office of Research Administration and Educational Quality Assurance, 2016). However, Thailand faces a shortage of skilled workers and experts in science, technology, and engineering to innovate and develop advanced technologies effectively. Addressing this challenge necessitates a critical role for the education sector in preparing and nurturing youth with lifelong learning capabilities and the potential to innovate (Puncreobutr, 2016). The development of human resources with knowledge and skills aligned with the needs of beneficiaries and the labor market is essential to enhance competitiveness and elevate Thailand to the ranks of economically advanced nations. Despite this necessity, Thailand still lacks sufficient skilled personnel with expertise matching market demands. Research outputs from universities are often underutilized, and many educational institutions have yet to achieve global recognition, particularly in science and technology, which are crucial for national development. Alarmingly, international assessments such as TIMSS (2015) and PISA (2018) indicate declining performance in mathematics and science among Thai students, alongside a waning interest in STEM fields. Furthermore, the scientific literacy of the Thai population remains low. According to the World Economic Forum (2014), Thailand ranked 67th out of 144 countries in innovation and 5th among ASEAN nations (Narong Sumthong, 2015). To address these challenges, it is vital to foster innovation and hands-on learning using modern tools that cultivate 21st-century skills and competencies, such as transversal competencies for life and work (Care & Luo, 2016). This aligns with Thailand's National Education Plan (2017–2036), which aims to develop learners with characteristics and skills necessary for the 21st century. Efforts must begin at the secondary education level, a critical period for fostering readiness and lifelong learning abilities, consistent with the educational objectives of Southern Thailand. Phuket Province, with its rich natural resources and multicultural heritage, is a model for educational innovation. As a "Phuket Education Sandbox," it exemplifies a collaborative approach involving government, private sectors, and the public to develop competent citizens who balance personal well-being with social and environmental harmony. The province's educational vision, "Phuket as an International Education Hub," highlights its role in nurturing well-rounded individuals ("Tongho" citizens) characterized by morality, health, and quality. These students are expected to excel in global citizenship, sustainability, critical thinking, and digital literacy while maintaining cultural integrity. Phuket's strategic development focuses on 10 pillars: 1) Gastronomy, 2) Education Hub, 3) Marina Hub, 4) Medical & Wellness Hub, 5) MICE City, 6) Sports Tourism, 7) Tourism, 8) Smart City, 9) Tuna Hub, and 10) Fusion Farming. Preparing students to meet these goals involves experiential learning and reflective practices.

STEM Education is pivotal to achieving the Thailand 4.0 agenda. It promotes collaborative, hands-on learning by integrating knowledge from Science, Technology, Engineering, and Mathematics (STEM) to solve real-world problems within constraints (Kelley & Knowles, 2016). STEM is not solely for STEM-related careers but is also essential for daily life and understanding technological advancements (Blackley & Howell, 2015). However, STEM education's success depends on teachers equipped with interdisciplinary knowledge and the ability to integrate STEM concepts with practical contexts. Preparing educators to deliver effective STEM education is critical (Atitaya Jituefu, 2020). Teacher preparation programs must prioritize producing educators who can meet evolving societal demands and deliver high-quality STEM education. Many in-service teachers lack confidence and understanding of STEM integration, highlighting the need for targeted professional development (Srikoom, Hanuscin, & Faikhamta, 2017). Systemic school reforms, including coaching, Professional Learning Communities (PLC), and lesson-learned practices, are necessary to support educators and administrators. These initiatives aim to cultivate a new generation of students who embody Phuket's vision for capable, innovative, and globally competitive citizens.

1.1 Objectives of the Research Project

1) To develop a program/model for the professional development of science teachers using a school-based approach to promote STEM literacy for teachers, utilizing outdoor STEM education resources in the southern region of Thailand.

2) To investigate the STEM literacy of teachers in the Phuket Education Sandbox area before and after participating in activities using a model designed to promote STEM literacy through the utilization of outdoor STEM education resources in Phuket, southern Thailand, within the context of the Phuket Education Sandbox.

3) To study the satisfaction levels of teachers in the Phuket Education Sandbox area with the model designed to promote STEM literacy for teachers using outdoor STEM education resources in the southern region of Thailand.

1.2 Definitions of Terms

1) A program/model for professional development of teachers promoting STEM literacy through outdoor STEM education resources refers to a structured framework for organizing professional development activities for teachers aimed at enhancing their STEM literacy. This includes using outdoor STEM education resources as a foundation, and integrating science, technology, engineering, and mathematics to design and conduct learning activities outside the classroom. The program/model is derived from synthesizing relevant documents on outdoor learning, STEM education, and research on STEM literacy, as well as evaluation tools for assessing the promotion of outdoor STEM literacy.

2) STEM Literacy of Teachers refers to teachers' ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex situations or problems. This includes the capacity to innovate solutions or create new approaches. STEM literacy encompasses the following competencies:

- Identification: The ability to recognize and articulate STEM concepts in real-world scenarios.
- Application: The capability to apply interdisciplinary STEM knowledge to address challenges.
- Integration: The skill to combine STEM domains for problem-solving and innovation.
- Creation: The ability to develop novel solutions or creative outputs that address issues effectively.

1.3 Research Framework

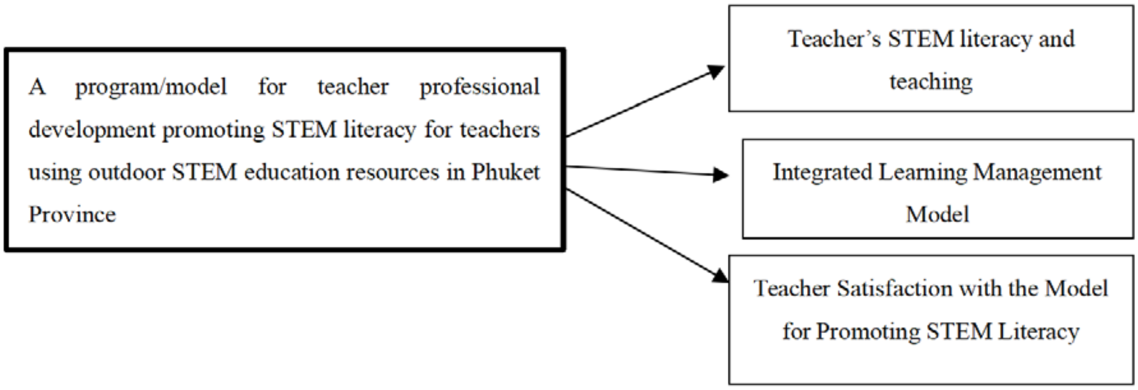

Figure 1. Research Framework

This research framework illustrates the relationship between a program/model for teacher professional development and three key outcomes related to STEM literacy. The framework centers on a program or model designed to enhance teacher professional development by promoting STEM literacy using contextualized STEM education in Phuket Province. The outcomes represent the direct impact of the program on improving teachers' understanding, skills, and application of STEM concepts. This study highlights the role of the program in developing or refining integrated approaches to learning management. This could involve combining outdoor education methods with STEM-based pedagogical practices. Through collaborative work, the professional development (PD) program focuses on evaluating how satisfied teachers are with the program/model. This measures the perceived effectiveness, usability, and relevance of the model in promoting STEM literacy and teaching. The arrows in the diagram depict a direct relationship between the program/model and each of the three outcomes. The program is expected to positively influence all three aspects:

- Enhance teachers' STEM literacy and teaching.
- Contribute to the development of an effective integrated learning management model.
- Increase teacher satisfaction with the professional development initiative.

1.4 Contextualizing STEM Education in Phuket Province

This framework is specifically designed to meet the unique needs of teachers in Phuket Province by utilizing outdoor STEM resources to develop practical, community-centered STEM education. Phuket's rich cultural heritage, biodiversity, and thriving tourism industry create an exceptional setting for STEM (Science, Technology, Engineering, and Mathematics) education. Successfully integrating STEM into education in this region requires aligning its principles with local environmental, social, and economic characteristics to ensure relevance and sustainability. Key contextualized aspects of STEM education in Phuket include addressing local challenges through STEM environmental degradation (coastal erosion, plastic pollution, and biodiversity loss, climate change adaptation), developing innovative engineering and environmental solutions to address rising sea levels and extreme weather conditions and engaging in community-relevant projects such as designing eco-friendly technologies, preserving architectural heritage, studying and conserving Sino-Portuguese architectural buildings, an integral part of Phuket's cultural identity, and promoting Renewable Energy: Developing and implementing sustainable energy solutions for local communities. The research framework highlights STEM education in Phuket as more than just the teaching of science, technology, engineering, and mathematics. It prioritizes cultivating a deeper understanding of the community's distinctive resources and addressing its unique challenges. By incorporating outdoor education, aligning with local needs, and equipping both students and teachers with practical, relevant skills, STEM education becomes a powerful tool for fostering meaningful engagement and sustainable development within the region.

2. Method

This research aims to develop a professional development model for science teachers using a school-based approach to promote STEM literacy through the utilization of outdoor STEM education resources in the southern region of Thailand. It also seeks to create an integrated learning model aligned with local contexts, driving educational innovation in the Phuket Education Sandbox area. The research follows a Mixed Methods Approach employing a Multistage Evaluation Design that integrates both Convergent Design and Explanatory Sequential Design (Creswell, 2015; Klangphahol, 2018; Creswell & Plano Clark, 2018). The study focuses on iterative program development and evaluation to ensure continuous improvement.

2.1 Research Phases and Steps

Phase 1: Need Assessment for Promoting STEM Literacy. This phase involves identifying the needs and developing a model to promote STEM literacy among teachers using outdoor STEM resources.

1) Identifying Teachers' Needs: Surveying and analyzing the essential requirements for promoting STEM literacy.

2) Analyzing Causes of Needs: Determining root causes and proposing strategies to address identified needs.

3) Developing a STEM Literacy Promotion Model: Designing the model based on need assessment results, incorporating insights from research and evaluation tools.

Phase 2: Development of the STEM Literacy Promotion Model. This phase focuses on developing, implementing, and refining the STEM literacy promotion program.

1) Instrument and Measures Development: Designing qualitative instruments for program evaluation.

2) STEM Development Program Implementation: Developing and implementing the STEM literacy promotion model using outdoor STEM education resources.

3) Follow-Up and Refinement: Assessing the program's impact through qualitative and quantitative evaluations and refining the model for greater effectiveness.

2.2 Research Participants

The research participants consist of teachers who teach in Science or Project based subjects at the basic education level in Phuket, selected through purposive sampling based on the following criteria:

1) Schools located in Phuket's education area.

2) Schools with at least two science teachers willing to participate in the professional development program.

3) School administrators who voluntarily support the initiative.

4) Schools hosting student teachers majoring in General Science.

The study involves 30 teachers who teach Science or Project-Based subjects at elementary schools within the Phuket Education Sandbox. These teachers collaborate with pre-service teachers, who take on the role of mentors, providing guidance and support throughout the study.

2.3 Research Implementation Process

The research is divided into two main phases:

Phase 1: Need Assessment and Model Development

- Assessing teachers' needs for STEM literacy promotion.
- Designing a STEM literacy promotion model using outdoor STEM resources.

Phase 2: Model Development and Evaluation

- Developing the STEM literacy promotion model.
- Implementing, evaluating, and refining the model to ensure its alignment with teachers' and schools' contexts.

The research process follows a structured flowchart, detailing steps for need assessment, model creation, implementation, and evaluation in both qualitative and quantitative dimensions (Refer to Flowchart 2 for detailed steps).

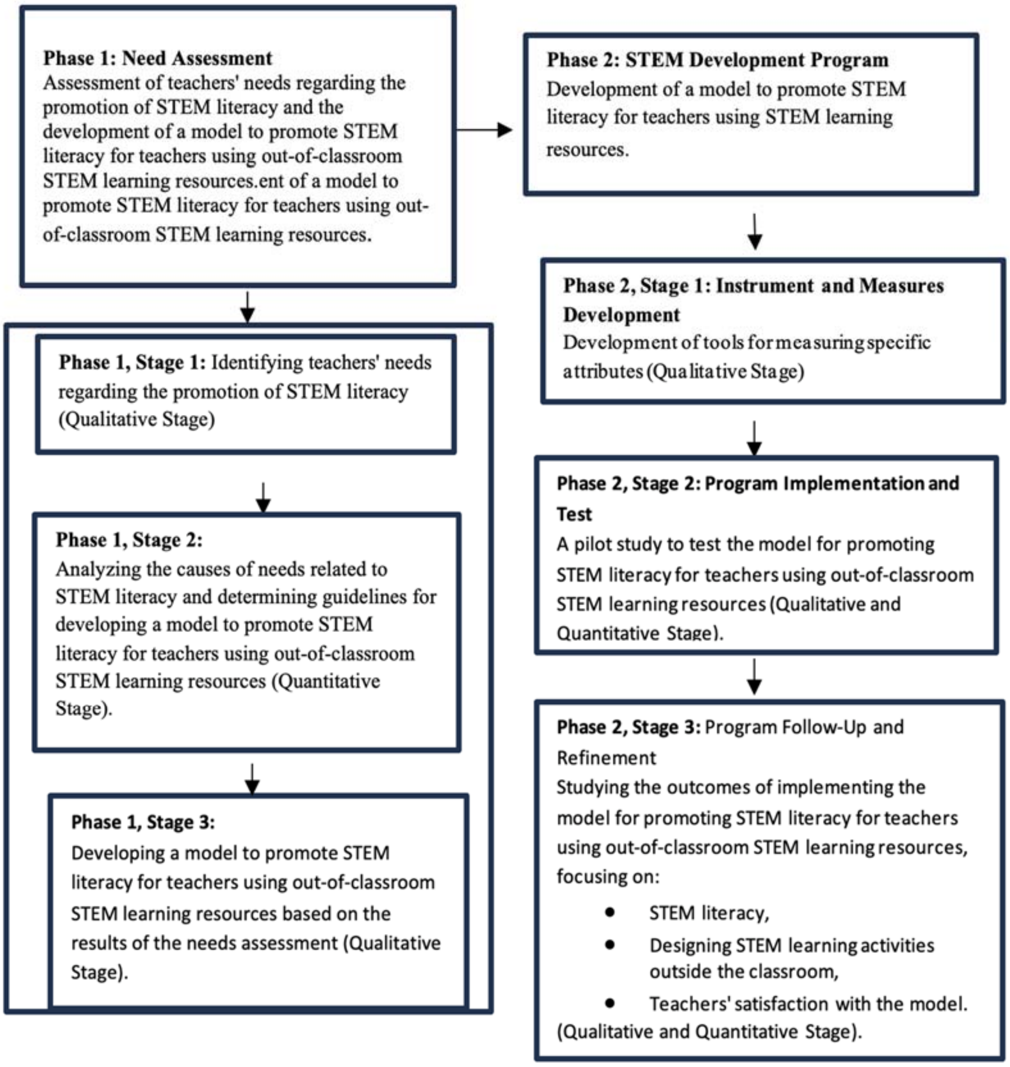

Figure 2. Steps in the Research Process

This systematic approach ensures the model's relevance and effectiveness in enhancing STEM literacy among teachers in the Phuket Education Sandbox, contributing to educational innovation and professional development.

2.4 Research Tools in This Phase Include

1) A model for promoting STEM literacy for teachers using out-of-classroom STEM learning resources.

2) A STEM literacy assessment for teachers utilizing out-of-classroom STEM learning resources.

3) A satisfaction evaluation form for participants in activities promoting STEM literacy for teachers through out-of-classroom STEM learning resources.

4) A focus group discussion guide for participants in activities promoting STEM literacy for teachers through out-of-classroom STEM learning resources.

5) A checklist to evaluate teachers' ability to design STEM-based learning management using outdoor classroom STEM learning resources to promote STEM literacy for students.

2.5 Quality Assurance of Research Tools

Five experts validated the tools for accuracy, question appropriateness, and provided suggestions. The panel included two science education specialists, two teachers experienced in STEM-based learning management, and one assessment and evaluation expert. The Index of Item Objective Congruence (IOC) was calculated at 1.0. Suggestions included rephrasing questions for clarity, such as changing "Besides the four disciplines mentioned, which other disciplines do you think are relevant?" to "Apart from science, technology, engineering, and mathematics, which other disciplines do you think are relevant?" For Development of Focus Group Discussion Guide, a discussion guide was created based on Stufflebeam's CIPP Model, encompassing Context Evaluation (C); Input Evaluation (I); Process Evaluation (P); and Product Evaluation (P) (Stufflebeam, 1971).

2.6 Data Collection

1) Recruitment of Participants

The researcher recruited at least 20 basic education teachers. Participants were briefed about the study, adhering to ethical principles: respect for persons, risk-benefit assessment, privacy and confidentiality, justice, and addressing challenges and risks.

2) Assessment of STEM Literacy

Teachers' STEM literacy was assessed before, during, and after their participation in the professional development program. The data were used to study changes in the participants, combined with evaluations of lesson plans and focus group discussions.

2.7 Data Analysis

1) Response Analysis: Researchers analyzed teachers' responses question-by-question, categorizing answers and counting occurrences within each category.

2) STEM Literacy Analysis: Responses were grouped according to criteria and analyzed using a dependent t-test to compare pre- and post-intervention scores. STEM literacy quality levels were determined based on average scores.

3) Analysis of Learning Management Design Ability: Lesson plans were evaluated based on predetermined criteria, scored, and averaged. Comparisons were made against benchmarks to determine quality levels. Content analysis was also employed to identify teaching methods, categorize them, and calculate percentages.

3. Results

3.1 Research Group Background

The research group consisted mostly of female teachers (90%), aged 30–39 years (53.33%), primarily teaching elementary levels (86.67%) in science and technology (63.33%). Most had 6–10 years of teaching experience (66.67%), and only 13.33% had prior STEM experience.

3.2 Professional Development Model

A professional development model for science teachers, rooted in school-based approaches, was developed. This model linked teaching with real-world contexts and emphasized experiential learning and collaboration within professional learning communities. The findings underscore the importance of teacher professional development models that integrate community and natural contexts into education. This approach fosters STEM literacy and prepares students for 21st-century challenges. A summary of the TPACK-MEA Professional Development Program activities is presented in Table 1.

Table 1. Summary of steps in the development of the STEM Literacy Promotion Model for teachers using STEM learning resources outside the classroom

Phase	Research Process	Research Findings	Development Process	Outcomes/Innovations
Phase 1 Need Assessment	Assessing Teachers' Needs Regarding STEM Literacy	Guidelines for Developing a Model to Promote STEM Literacy for Teachers Using Out-of-Classroom STEM Learning Resources	Developing a Model to Promote STEM Literacy for Teachers Using Out-of-Classroom STEM Learning Resources Based on the Findings of Needs Assessment Research	A Model for Promoting STEM Literacy for Teachers Using Out-of-Classroom STEM Learning Resources for Pilot Study Implementation
Phase 2 **Program Implementation and Test**	The pilot study for testing the model to promote STEM literacy for teachers using out-of-classroom STEM learning resources is quantitative research utilizing a one-group pretest-posttest design.	Strengths, areas for improvement, issues, and challenges of the model to promote STEM literacy for teachers using out-of-classroom STEM learning resources, aimed at refining the model for practical implementation in future trials.	Refinement of the model to promote STEM literacy for teachers using out-of-classroom STEM learning resources based on the results of the pilot study research.	A model for promoting STEM literacy for teachers using out-of-classroom STEM learning resources for practical implementation trials.
Phase 3 **Program Follow-Up and Refinement**	The implementation of the STEM literacy promotion model for teachers using out-of-classroom STEM learning resources was conducted through a mixed-method research approach. The quantitative research employed the one-group pretest-posttest design to examine the effects of the STEM literacy promotion model. This was followed by qualitative research using an interpretivist approach to explore contextualized understanding of phenomena within specific contexts, such as the social, cultural, or situational aspects of different research groups. The study involved teachers applying the model in schools with varying contexts, focusing on their teaching practices. The findings were presented as a series of case studies.	The outcomes of using the STEM literacy promotion model for teachers with out-of-classroom STEM learning resources include STEM literacy, satisfaction, and the ability to design and manage learning activities.	The improvement of the model and obtaining expert critique.	The comprehensive model for promoting STEM literacy for teachers using out-of-classroom STEM learning resources.

Top of FormThrough participation in the TPACK-MEAs Professional Development Program, research teachers had the opportunity to engage in hands-on activities with example STEM projects and collaboratively design STEM-based learning activities utilizing outdoor classroom contexts. During the Lesson Study process.

3.3 STEM Literacy of Teachers in the Educational Innovation Area, Phuket Province

Before and after implementing activities under the model for promoting STEM literacy for teachers using outdoor classroom STEM learning resources in Southern Thailand, specifically in the educational innovation area of Phuket Province, the results were analyzed as follows:

Analysis of STEM Literacy Scores: The study involved research participants of 30 teachers. A STEM literacy assessment comprising six items was used to measure different dimensions of STEM literacy:

1) Knowledge and Integration: Understanding content and applying scientific, mathematical, technological, and engineering processes to solve problems.

2) Interdisciplinary Connections: Linking STEM education with scientific, mathematical, technological, and engineering concepts alongside other learned disciplines.

3) Rational Decision-Making: Demonstrating clear reasoning by applying STEM principles and tools to design solutions or create innovative outputs.

4) Social and Cultural Application: Engaging in the application of STEM fields in relation to society, culture, and responsible citizenship.

5) Evaluation and Reflection: Assessing and reflecting on problem-solving outcomes through STEM disciplines.

6) STEM Awareness: Recognizing the role of STEM in daily life for problem-solving, innovation, and career progression. Key Results: Teachers in the research group who participated in continuous professional development activities (30 individuals) showed significant improvement in their STEM literacy. Average Pre-Training Score: 9.43 Average Post-Training Score: 17.83 Score Increase: 8.40

An individual analysis revealed that STEM literacy improved for all 30 participants, representing 100% of the sample, as detailed in Table 2.

Table 2. Statistical test results of pre- and post-training average score differences for the research group teachers

Scores	M	SD	$\bar{D}$	$SD_{\bar{D}}$	t	df	p
Before Training	9.43	2.47	8.40	2.82	16.30	29	.001
After Training	17.83	2.51					

From Table 2, it was found that the 30 teachers in the research group had an average post-training score of 17.83, which was significantly higher than the pre-training average score of 9.43 at the .001 level of statistical significance. When analyzing the teachers' responses in the STEM literacy assessment, the researcher found that the teachers demonstrated increased STEM literacy across all aspects. Specifically, in terms of knowledge and understanding of the content and the use of scientific, mathematical, technological, and engineering processes, teachers were able to integrate and apply these skills to solve various problems. They could explain how they solved problems using STEM and how each discipline was interconnected. For example, T21 (a pseudonym) provided responses illustrated in Figure 3.

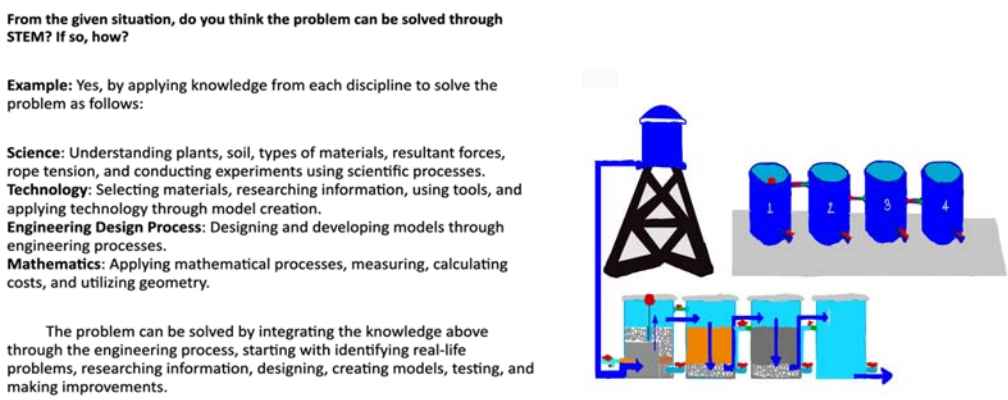

Figure 3. Examples of teachers' responses demonstrating knowledge and understanding of content and the use of scientific, mathematical, technological, and engineering processes

The research findings illustrate the development of STEM literacy among teachers in the educational innovation area of Phuket Province, both before and after participating in activities using the model for promoting STEM literacy through out-of-classroom STEM learning resources. This approach, applied in the southern region of Thailand, has led to a transformation in teaching practices among the participating teachers. These teachers were able to connect classroom learning within schools to community-based and natural learning environments. Through interviews, post-lesson reflections, and small group discussions, the research results were presented on an individual basis, with each of the 30 participating teachers assigned identifiers T1–T30. The outcomes are summarized in Table 3, which shows the development of teaching practices through STEM education over the duration of their participation in the TPACK-MEAs Professional Development Program.

Table 3. Demonstrates the progression in teaching practices through STEM education during the teachers' involvement in the program

STEM Learning Management Topics	Grouped Responses from Focus Group Discussions and Post-Lesson Reflections	Before Joining the Program	After Joining the Program
The goal of integrated STEM learning management	**Group 1**: utilizes project-based learning aimed at creating innovations that address local issues.		T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T21, T22, T23, T24, T25, T26, T27, T28, T30
	Group 2: applies this teaching approach in schools that focus on science, mathematics, and technology.	T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30	T29
Designing learning management activities	**Group 1:** Using differentiated learning activities based on students' abilities, with an emphasis on ensuring active participation in each activity. Teachers act as facilitators of students' learning, allowing students to engage in hands-on activities. Students learn in real-world settings and identify issues that contribute to development or problem-solving.	T2, T3 T5, T6, T7, T9, T10, T11, T12, T14, T15, T16, T17, T18,	T1,T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30
	Group 2: Designing activities focused on hands-on learning, where students explore the community during the learning process. Teaching integrates approaches like the spider web model and bead-threading model.	T1	T1, T13, T14, T15, T16, T17, T18, T19, T20, T21
	Group 3: Designing activities that allow students to create projects and present their work in class or exhibitions.	T2, T3, T4, T8, T13, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30	T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30
Classroom Management	**Group 1**: Facilitating group-based learning where students work collaboratively, with an emphasis on preparation in the classroom. Experts are invited to assist in brainstorming STEM project topics.	T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15, T16, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30	T12, T18, T23, T25, T27
	Group 2: Organizing activities that involve students interacting with external learning sources and the community. Students explore and identify topics of interest. STEM classrooms extend beyond traditional settings to incorporate outdoor learning opportunities.		T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14 T15, T16, T17, T18, T19, T20, T21, T22, T24, , T26, T27, T28, T29, T30
Student Grouping in the Learning Process	**Group 1**: Grouping students based on abilities and interests in the subject or project being studied, mixing skill levels for collaboration.	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30	T1, T3, T4, T5, T6, T7, T8, T10, T11, T12, T13, T15, T30

STEM Learning Management Topics	Grouped Responses from Focus Group Discussions and Post-Lesson Reflections	Before Joining the Program	After Joining the Program
	Group 2: Grouping students based on interests identified during exploratory learning. Activities focus on STEM processes, connecting science, technology, engineering, and mathematics, with an emphasis on problem-based learning (PBL) or project-based learning (PjBL).	T16, T17	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30
Teacher Assignment in the Classroom	**Group 1**: Utilizing classroom teachers trained in STEM teaching. At times, specialized teachers in relevant subjects are brought in to assist.	T1, T2, T3, T4, T5, T7, T8, T9, T10, T11, T12, T13, T14, T15, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30	
	Group 2: Forming teacher teams for specific subjects. Teachers hold planning meetings to align activities with core curriculum standards and indicators.	T6, T16, T17	
Integration of Subject Disciplines	**Group1**: STEM learning is implemented within the existing eight core subjects scheduled in the curriculum, with time allocated for core subjects, integrated classes, or Enrichment Programs.	T1, T2, T3, T4, T5, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T22, T24, T25, T26, T27, T28, T29, T30	
	Group2: STEM learning is implemented as part of project-based subjects.	T6, T21	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30
Design of Learning Assessment Tools	**Group 1**: Learning assessment is tailored to students' ability levels, incorporating the creation and presentation of student projects as part of the learning process to evaluate their progress.	T1, T6	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T15, T18, T19, T20, T21, T22, T24, T26, T27, T28, T29, T30
Connection with the Community	**Group 1**: Community resources are utilized, allowing students to gain hands-on learning experiences in real-world contexts. This approach serves as a starting point for connecting academic content with daily life. Teachers may include community members who contribute their expertise, co-teach with school teachers, and use social science tools to train students in data collection, analysis, and summarizing topics of interest.	T1, T17	
Lesson Development through Professional Learning Communities and Lesson Study	**Group 1**: A Professional Learning Community (PLC) is employed to design STEM-based teaching. Teachers collaborate to reflect on their practices, support each other, and provide individualized attention to students.		T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15, T18, T19, T20, T21, T22, T24, T25, T26, T27, T28, T29, T30

From Table 3, it was found that 30 research teachers provided information about their STEM teaching practices. Among the research group, 96.67% aimed to design integrated STEM learning to promote innovation that addresses local issues. Additionally, 96.67% developed STEM learning activities during their participation in the TPACK-MEA professional development program, using differentiated learning activities based on students' abilities. These activities emphasized student participation, with teachers facilitating the learning process. Students engaged in hands-on experiences, explored real-world contexts, identified issues impacting development or problem-solving, and created tangible outputs to present in classrooms or exhibitions. Furthermore, 93.33% of the research group started lessons by fostering interactions between students and the community. Students interacted with external learning sources and the community, exploring topics of interest and connecting classroom learning with real-world applications. Teachers grouped students based on interests identified through exploratory learning outside the classroom, employing activities focused on STEM processes that integrated science, technology, engineering, and mathematics (STEM) with a problem-based learning (PBL) or project-based learning (PjBL) approach. Regarding curriculum design, 96.67% of the research group initially combined teaching across subjects in the standard curriculum. By the end of the 2023 academic year, 100% had developed STEM project-based courses linked to community contexts. Learning assessments were tailored to different student ability groups and included evaluations of students' creative works and presentations to assess learning progress. Teachers increasingly designed activities using community-based learning resources, allowing students to gain hands-on experience. This approach marked the beginning of connecting academic topics to daily life. Community members were sometimes involved as co-teachers, enriching students' experiences and supporting teachers in their instruction. Social science tools were integrated to train students in data collection, analysis, and summarizing topics of interest. All research teachers (100%) indicated that utilizing PLCs (Professional Learning Communities) significantly contributed to designing STEM-based instruction. Reflective collaboration with school-based teaching teams and individualized student support were emphasized. This systematic and routine collaboration involved 30 teachers and STEM education specialists. The collaborative reflection of this program/model, as part of the TPACK-MEA professional development program, demonstrated that effective professional development for teachers to deliver STEM learning outside the classroom requires:

1) Training teachers on integrated approaches that link scientific methods and engineering design processes, supported by practical examples and activities.

2) Utilizing exemplary projects that integrate science and engineering processes, such as exploring material resistance (science) and designing bridge models (engineering).

3) Establishing PLC networks for STEM teachers at the school or district level to exchange best practices and collaborate on developing integrated teaching activities.

Support from schools and administrators is essential, including resources for teaching, tools, instructional materials, and information supporting STEM education. Schools should aim to develop PjBL activities that allow teachers to design project-based learning integrating scientific and engineering methods, such as addressing natural disasters in the community through research and prototype development. Practical training sessions for teachers should include scenarios combining scientific experiments and engineering design. The framework for the program/model of professional development to promote STEM literacy for teachers using external STEM learning resources includes: 1) Defining the principles and foundational concepts of the model; 2) Setting objectives for the model; 3) Establishing activity implementation steps; 4) Identifying key strategies critical to the model's success; and 5) Determining assessment and evaluation methods for the model. The implementation of the professional development program/model was revised after its application with the research group. Strategies contributing to the model's success and the implementation of learning activities through professional learning communities were presented, as illustrated in Figure 4.

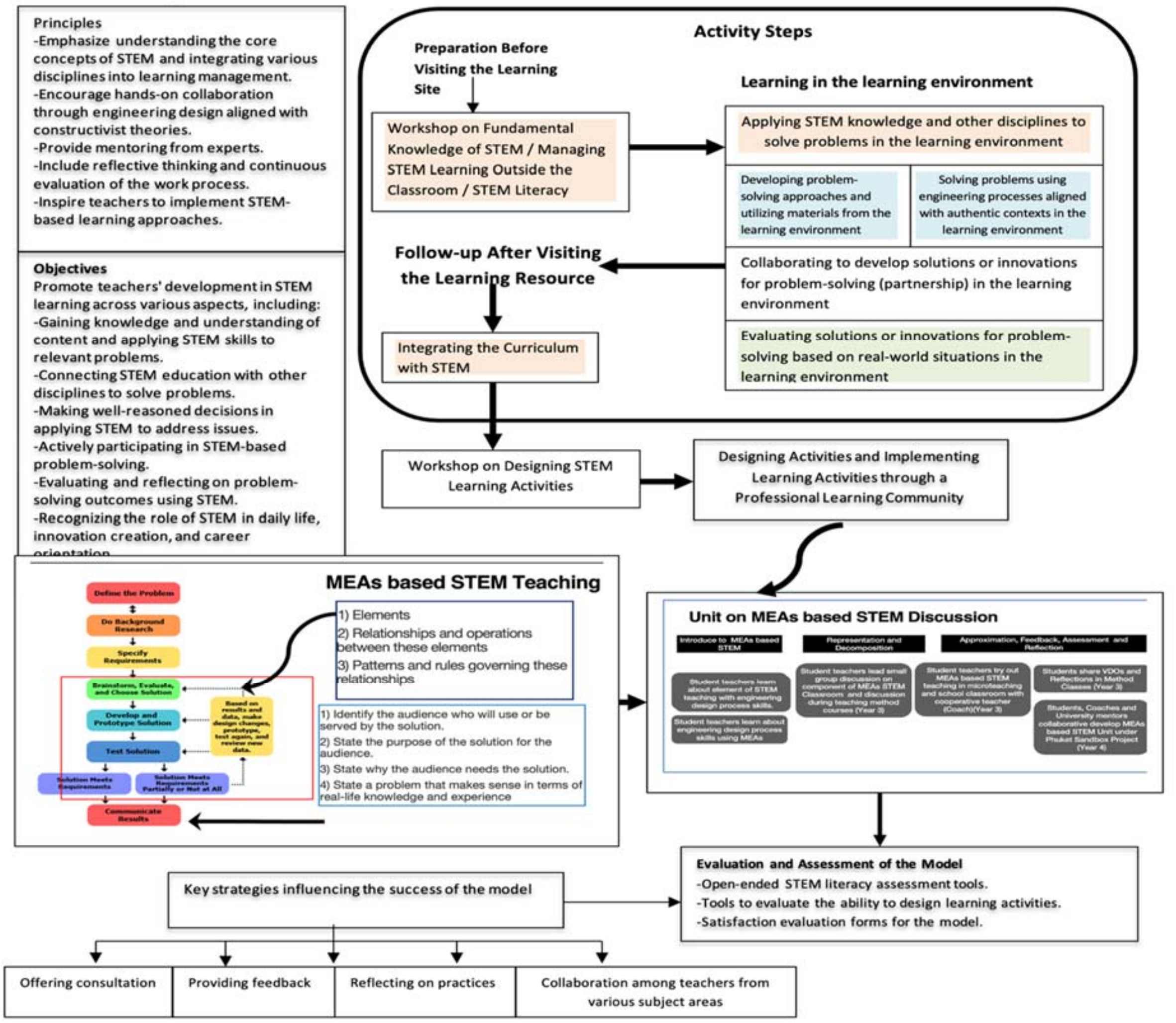

Figure 4. A program/model for teacher professional development to promote STEM literacy using external STEM learning resources

4. Discussion

Research findings suggest that educators require substantial support to effectively integrate STEM education with science, mathematics, technology, and engineering design while integrating these disciplines with other subject areas. Challenges in STEM education often stem from educators' limited understanding and apprehensions regarding the implementation of inquiry-based approaches (Asghar et al., 2012). Such apprehensions can impede the successful integration of these methodologies into classroom practices (Johnson & Czerniak, 2023). One contributing factor is that teachers have not been adequately encouraged to learn about STEM education in an integrated manner. For instance, global outdoor STEM programs, such as those in the United States, Finland, and Australia, successfully utilize local environments, such as forests and wetlands, to teach STEM concepts. The United States National Park Service, for example, integrates STEM education with environmental conservation. Similarly, the Phuket model leverages the region's unique natural resources, including marine ecosystems, mangroves, and Sino-Portuguese architecture, to create a curriculum tailored to its local context. This model addresses regional challenges such as coastal erosion, plastic pollution, and sustainable tourism, offering students a community-relevant and practical learning experience. The contextualized STEM education approach in Phuket not only promotes problem-solving but also emphasizes community engagement as a vital component of STEM teaching. Programs like "Citizen Science" in Europe engage students in real-world challenges such as biodiversity monitoring and water quality testing. Similarly, the Phuket model focuses on specific regional issues, such as climate change adaptation and renewable energy solutions, fostering local sustainability and helping students develop a deeper connection to their community. Incorporating cutting-edge technologies, such as augmented reality (AR) and virtual reality (VR), is a hallmark of outdoor STEM education in countries like Singapore and

South Korea. The Phuket model also has the potential to integrate these tools; however, it distinguishes itself by combining technology with hands-on outdoor activities rooted in Phuket's cultural and environmental heritage. This ensures both technological advancement and the preservation of local traditions. Research shows that many teachers struggle to independently integrate curriculum content and learning standards across various subjects into STEM-oriented instructional designs. For instance, Holincheck et al. (2024) found that while teachers were enthusiastic about introducing quantum concepts into K-12 education, they faced barriers in connecting these ideas across disciplines. Similarly, Stevenson et al. (2023) observed that teachers often struggle with integrating STEM curricula into existing educational structures due to a lack of interdisciplinary collaboration and difficulties in merging subject areas. These findings emphasize the need for targeted professional development programs to equip teachers with the skills and resources required for interdisciplinary STEM education. Furthermore, a lack of national-level support for integrated STEM learning and insufficient emphasis by schools and authorities exacerbate the challenges teachers face. Teachers need opportunities to develop their content knowledge and apply scientific, mathematical, technological, and engineering processes to solve real-world problems. Effective STEM teaching requires a comprehensive understanding of all four disciplines, as noted by Kedzior and Fifeld (2004), who highlighted the strong correlation between teachers' professional development experiences and their knowledge and skills. Continuous, practice-oriented knowledge development and collaboration among educators are crucial. Research emphasizes the significance of context-based approaches in fostering student engagement (Bennett et al., 2007). These approaches can enhance interest and participation in STEM opportunities. Participating in teacher professional development programs that incorporate out-of-classroom STEM learning resources enables educators to acquire foundational STEM training, implement STEM-based instructional strategies, and improve STEM literacy. This training provides practical experience in problem-solving and innovative project development, thereby enhancing STEM competencies.

Informal STEM learning environments further support teacher development by promoting collaboration, direct engagement, and hands-on learning in a relaxed setting. This aligns with the findings of Avery and Reeve (2013), who suggest that STEM-focused professional development should not only enhance student outcomes but also facilitate the application of teachers' learning. Similarly, Jackson et al. (2020) demonstrated that informal STEM experiences enhance teachers' ability to design integrated learning activities. Reflecting on these experiences and collaborating with peers strengthens their classroom implementation skills. The Phuket outdoor STEM education model aligns with global best practices in experiential learning, real-world problem-solving, and technology integration. However, its emphasis on leveraging local resources, addressing specific regional challenges, and preserving cultural heritage distinguishes it as a uniquely original framework. This approach ensures relevance for Phuket's educators and students while serving as a potential blueprint for adapting STEM education to other regions with distinct cultural and environmental contexts. Teacher training and professional development programs, such as "Outdoor Classroom Day" in the UK, provide structured frameworks for educators to effectively utilize outdoor resources for STEM education. In contrast, the Phuket model adopts a collaborative approach specifically tailored to address the local needs of the community. This approach ensures that teachers are well-equipped with both pedagogical and contextual knowledge, thereby enhancing the outdoor STEM learning experience.

4.1 Recommendations for Applying Research Findings

1) Since the research shows that teachers from STEM and non-STEM disciplines can enhance their STEM literacy through hands-on, problem-solving activities and direct experience, stakeholders in teacher professional development should incorporate such activities into programs. These activities should encourage exploration, problem-solving, and collaboration to increase teachers' STEM literacy.

2) The research also highlights that teachers can design STEM learning activities aligned with STEM instructional strategies and connect them to out-of-classroom contexts. Professional development programs should facilitate cross-disciplinary collaboration and knowledge-sharing among teachers from diverse subject areas and schools.

4.2 Recommendations for Future Research

1) Although teachers showed improvements in all aspects of STEM literacy, their awareness of STEM's role in daily life, innovation, and career development remained lower than other aspects. Future research should explore strategies to enhance this awareness and its application in problem-solving and innovation.

2) Continuous evaluation and follow-up of out-of-classroom learning activities are crucial for measuring the impact on teachers' and students' STEM literacy. Future studies should also analyze factors promoting or hindering the effective use of learning resources. Researchers should consider developing teacher competencies in assessment alongside supporting tools and technologies, such as AR/VR simulations and data-collection

applications, to improve the effectiveness and engagement of STEM learning outside the classroom.

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1) Informed Consent: Participants were fully informed about the research objectives, procedures, potential risks, and their right to withdraw at any time without negative consequences. Written consent was obtained before participation.

2) Confidentiality and Anonymity: Personal information was kept confidential and used solely for research purposes. Data was anonymized to prevent any identifiable links to individual participants.

3) Voluntary Participation: Participation was entirely voluntary. Participants had the right to refuse or withdraw from the study at any stage without penalty.

4) Non-Maleficence: Every effort was made to minimize potential risks or discomforts. No harmful procedures or interventions were involved in the study.

5) Data Security: Collected data were securely stored and accessed only by authorized researchers. Data management followed relevant privacy and data protection regulations.

6) Transparency and Integrity: The research process and findings were reported transparently and honestly, ensuring accuracy and reliability in data presentation and interpretation.

These measures ensured that participants’ rights, safety, and well-being were protected throughout the study.

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Authors’ contributions

Assistant Professor Dr. Siriwan Chatmaneerungcharoen, in collaboration with the school supervisors, conceptualized the study and developed a professional development model that integrates outdoor STEM education resources to enhance STEM literacy in southern Thailand. Dr. Chatmaneerungcharoen coordinated the data collection process—including administering STEM literacy assessments, lesson plan evaluations, classroom observations, and focus group interviews—led the quantitative analysis, and drafted the initial manuscript. The author contributed to its revision and approved the final version.

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Competing interests

The authors confirm that they have no financial interests or personal relationships that could be perceived as influencing the work presented in this paper.

Informed consent

Obtained.

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The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal’s policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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