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Empowering Phuket's Community Identity with Place-Based STEM: Enhancing Grade 5 Students' Scientific Explanation and Literacy

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ABSTRACT

This classroom action research examined how Grade 5 students develop their scientific explanation skills through outdoor STEM learning centered on the local context in Phuket, Thailand. The study involved 36 students selected through purposive sampling. Throughout multiple PAOR (Plan–Act–Observe–Reflect) cycles, students participated in tasks related to their community, such as Oh-Aew dessert, local fruits, and Apong, aimed at promoting modeling and Claim–Evidence–Reasoning (CER). Data collected included pre- and post-assessments of scientific modeling, STEM worksheets, observations, and semi-structured interviews. Descriptive statistics summarized students' performance changes, while content analysis was used to interpret qualitative data. Results showed significant progress in students' ability to create modeling-based scientific explanations, with fully accurate models increasing from 5.15% before instruction to 84.72% afterward (n=36). The findings demonstrate that place-based tasks combined with clear modeling scaffolds can enhance scientific reasoning and strengthen connections to the community and cultural identity. The study discusses implications for curriculum design, teacher development, and local community partnerships.

Keywords: evidence-based practice, STEM teaching, education research, teacher development, teacher perceptions

INTRODUCTION

Building learners' capacity to explain phenomena with evidence and reasoning is central to contemporary science education and scientific literacy, the ability to make sense of real-world phenomena and reason with evidence in personal and civic life (AAAS, 1990; IPST, 2008; NRC, 2012; UNESCO, 2017). In this study, scientific explanation is defined as a defensible claim about a phenomenon supported by relevant evidence and a chain of reasoning grounded in disciplinary ideas (AAAS, 1990; McNeill & Krajcik, 2012; NRC, 2012). Scientific modeling is defined as constructing, using, evaluating, and revising representations, diagrams, physical prototypes, mathematical or conceptual forms, to explain mechanisms and generate predictions (NRC, 2012; Schwarz et al., 2009). Together, modeling and explanation operate as complementary 'thinking tools' that align data with theory and keep mechanistic accounts open to critique and revision (Thibaut et al., 2018). The Claim–Evidence–Reasoning (CER) routine provides a practical structure for organizing students' explanatory talk and writing (Cohen & Waite-Stupiansky, 2020; McNeill & Krajcik, 2012), while modeling supports abstraction, prediction, and conceptual coherence (Schwarz et al., 2009). Recent reforms, therefore, emphasize learning through core practices, asking questions, analyzing data, modeling, and constructing explanations, rather than only learning about decontextualized content (AAAS, 1990; NRC, 2012).

A persistent critique of many STEM initiatives, however, is their limited relevance to learners' lived worlds. Place-based STEM addresses this gap by anchoring modeling and explanation in local ecologies, practices, and issues, which provide accessible phenomena and usable variability for sense-making. Global policy frames similarly call for inquiry experiences that connect school science with local sustainability challenges (UNESCO, 2017, 2020). In Phuket, coastal and island systems, mangrove creeks, tidal mixing zones, shoreline change, and freshwater–seawater gradients offer rich contexts in which Grade 5 learners can collect data, iteratively build and revise models, and produce CER explanations that connect measurements to disciplinary ideas. In this work, community identity functions as a contextual frame guiding the selection of locally meaningful phenomena and activities rather than as a measured outcome. Evidence from outdoor/place-based studies indicates benefits for observation quality, sense-making, and motivation when investigations occur where phenomena naturally unfold (Pulido et al., 2023) At the elementary level, growing evidence shows measurable gains in model sophistication and explanation quality when instruction cycles through constructing, testing, and revising models in tandem with CER writing. Quasi-experimental and design studies report improvements in students' mechanistic accounts of Earth-system phenomena under model-centered curricula, and instructional moves that surface epistemic criteria (what counts as a good model or explanation) and organize public comparison of models appear especially consequential (Baumfalk et al., 2019; Schwarz et al., 2023; Zangori et al., 2017). Complementary findings from broader NGSS-aligned interventions and elementary CER implementations further indicate positive effects on three-dimensional performance and scientific reasoning (Birzina & Pigozne, 2020; Talib et al., 2024), while advances in automated assessment show how causal-mechanistic explanations can be supported and monitored at scale (Triplett, 2023).

In Thailand, the Basic Education Core Curriculum (2008) emphasizes competencies aligned with scientific literacy and practice-based learning, providing a policy rationale for focusing on modeling-based explanation at the primary level (Ministry of Education, 2008; IPST, 2008). Yet empirical evidence at the Thai primary level remains limited regarding (a) the extent to which structured outdoor, place-based tasks improve the quality of students' scientific explanations and the sophistication of their models, and (b) which instructional practices most effectively support such gains. Addressing this gap, the present study implements a short sequence of structured, place-based outdoor tasks in Phuket and evaluates student learning using research-aligned rubrics for CER explanations and scientific modeling. This study addresses a persistent gap in Thai primary science education: students often experience science as decontextualized, while teachers have limited models for integrating local knowledge with core scientific practices. By grounding instruction in Phuket's community contexts and explicitly emphasizing scientific explanation (via Claim–Evidence–Reasoning) alongside modeling, the study aims to make science relevant, culturally sustainable, and empowering for Grade 5 learners. The work contributes practice-based evidence on how place-based STEM can strengthen explanatory competence and how teachers can implement it within ordinary classrooms.

LITERATURE REVIEW

Scientific Explanation and Modeling

Scientific explanation and modeling are essential complementary practices in science education (NGSS Lead States, 2013; NRC, 2012). Explanation is typically defined as a claim about a phenomenon supported by evidence and reasoning, often operationalized through the Claim–Evidence–Reasoning (CER) framework McNeill et al., 2006; McNeill & Krajcik, 2011). Modeling involves creating, using, evaluating, and revising representations—conceptual, physical, mathematical, or computational—to explain mechanisms, predict outcomes, and align theory with evidence (Gilbert & Justi, 2016; Schwarz et al., 2009). Both practices are iterative, requiring cycles of construction, critique, and refinement (Clement, 2000; Windschitl & Thompson, 2006).

Though explanations describe phenomena and arguments defend claims, classroom practice intertwines them: students use models and data to justify explanations, compare alternatives, and refine reasoning (Berland & Reiser, 2009; Osborne, 2010). NGSS positions explanation and modeling as distinct yet interconnected practices (NGSS Lead States, 2013). Learning progressions show that students advance from descriptive representations to mechanistic models and from fact lists to principled explanations with explicit evidence–reasoning links (McNeill & Krajcik, 2011; Schwarz & White, 2005). Persistent challenges include treating evidence as description, circular reasoning, and leaving mechanisms implicit (McNeill & Krajcik, 2011; NRC, 2012).

Framed within academic literacy, argumentation serves as a social process for constructing and validating knowledge (Faize et al., 2017; Nugroho et al., 2023; Omoniyi, 2025; Sultan et al., 2025). CER has become a widely adopted routine that clarifies explanatory structure and supports critical thinking (McNeill et al., 2006; McNeill & Krajcik, 2011; Yang et al., 2021). Studies confirm CER improves writing, discussion, and argumentation across topics and levels (Antonio & Prudente, 2021; Dare et al., 2018; Llewellyn & Ullock, 2017; Izquierdo Acebes, 2020; Pierson & Clark, 2019). At all levels, scaffolding enables authentic participation, helping learners revise explanations with data and develop metamodeling knowledge (Lehrer & Schauble, 2002; Schwarz & White, 2005).

Design principles emphasize: (1) anchoring learning in observable phenomena with repeated modeling cycles (Schwarz et al., 2009; Windschitl et al., 2008); (2) providing representational scaffolds to move toward causal–mechanistic accounts (Gilbert & Justi, 2016; Schwarz et al., 2009); (3) making quality criteria for models and explanations explicit (McNeill & Krajcik, 2011; Schwarz & White, 2005); (4) orchestrating argumentation routines to connect evidence with mechanism (Berland & Reiser, 2009; Osborne, 2010); and (5) integrating measurement and visualization to strengthen reasoning (Lehrer and Schauble, 2002). Effective implementation requires explicit instruction and fading supports (Dare et al., 2018; Higgins & Spitulnik, 2008; Pierson & Clark, 2019).

Overall, explanation, modeling, and argumentation via CER form an integrated sense-making process. When instruction clarifies purposes, cycles engage real evidence, and scaffolds fade, students develop increasing mechanistic models and principled explanations, key components of scientific literacy (Clement, 2000; Lehrer & Schauble, 2002; McNeill & Krajcik, 2011; Schwarz et al., 2009; Villegas, 2025). In this study, explanation is defined as a justified claim with sufficient evidence and reasoning (CER), and modeling as the creation, use, and revision of representations to explain and predict. Argumentation makes justifications public for critique and refinement. Within place-based STEM in Phuket, these practices are anchored in local phenomena to support the development of evidence-based modeling and CER explanations, guiding instrument design and analysis while emphasizing authentic learning rather than rote recall.

Place-Based STEM and Community Connection

Place-based STEM integrates local environments and cultural practices into STEM tasks, using familiar contexts to boost engagement, identity, and relevance (Sobel, 2004; Semken and Freeman, 2008; Grewe, 2025). Students explore authentic places and issues through hands-on inquiry, connecting personal interests to disciplinary ideas and community improvement (Anderson, 2002; Ballantyne & Packer, 2009). Policy frameworks support this approach: NGSS emphasizes real-world inquiry and crosscutting concepts, such as systems, scale, and proportion, that are naturally grounded locally (Achieve, 2013). Examples demonstrate these benefits. 'Oceans of Inspiration' connected students to coastal ecosystems to build STEM identity and community ties (Cincera et al., 2019; Smith, 2013). 'Seeds of STEM' co-designed problem-based curricula with educators to reflect early childhood contexts and community needs (Dogan et al., 2016). Interdisciplinary STEAM projects like 'Delta Studies' show how arts integration boosts creativity, cultural relevance, and community bonds (Alves et al., 2019). Inclusive STEM high schools that partner locally and adopt inclusive strategies reduce race and gender gaps while fostering STEM identity (LaForce et al., 2016). Research confirms that integrated, place-connected curricula produce achievement levels equal to or better than traditional instruction and consistently increase motivation (Barnhardt & Kawagley, 2005; Czerniak et al., 1999; Drake & Reid, 2018; Hinde, 2005; Vars, 1991, 2001). Place-based learning also helps counter student beliefs that math and science are irrelevant (Aikenhead, 2007; Sampson & Blanchard, 2012) and aligns with longstanding calls for inquiry-focused, critical thinking–oriented teaching across disciplines (Alberts, 2000; Buxton & Provenzo, 2012; Jarrett, 1997; National Academy of Engineering & National Research Council, 2009; National Council for the Social Studies [NCSS], 2010; National Council of Teachers of Mathematics [NCTM], 1991, 2000; National Research Council [NRC], 2000). However, systemic adoption remains uneven: only one-fifth of K–4 teachers regularly integrate science with other subjects (Weiss et al., 2001), and teacher-preparation programs often lack authentic, integrated coursework (Furner & Kumar, 2007; Roebuck & Warden, 1998; Türkoğuz & Kayalar, 2021). While well established in environmental education (Buxton, 2010; Meichtry & Smith, 2007; Semken, 2005; Sobel, 2004), place-based pedagogies are still underemphasized in teacher training. Effective designs connect investigations to local systems, incorporate measurement across sites and times, and involve community partnerships to frame authentic problems and audiences with long-term intervention (De Loof et al., 2022). These approaches link data to disciplinary ideas, strengthen STEM identities, and support persistence, especially for marginalized learners (Achieve, 2013; Boyd, 2019; Cincera et al., 2019; John et al., 2018; LaForce et al., 2016; Smith, 2013). In this study, place-based STEM is defined as integrated investigations rooted in Phuket's environments and cultural practices. Students participate in iterative, data-rich inquiry, collecting measurements, building and refining models, and producing CER explanations that connect local observations to disciplinary concepts. Community features serve as a contextual frame for selecting phenomena and audiences, not as measured outcomes.

Research Questions

Based on the introduction above, the author explores the following research questions:

1. To what extent, and in what ways, does a short sequence of place-based STEM lessons grounded in Phuket's local contexts improve Grade 5 students' scientific explanation skills, measured as (a) CER quality and (b) modeling-based explanation, across iterative PAOR cycles?
2. Which task features and instructional practices most strongly correlate with improvements in students' explanatory quality?
3. What challenges and supportive conditions do teachers encounter when implementing place-based STEM to enhance scientific explanation in primary science, and how can these insights inform scalable practices?

CONCEPTUAL FRAMEWORK

The framework combines (a) IPST STEM design principles and (b) modeling-based scientific explanations. Students move through iterative phases: model creation, application, comparison/evaluation, and refinement. Instruction follows an engineering, design-inspired sequence, starting with identifying a local problem, gathering information, designing and implementing solutions, evaluating, and communicating. This study aims to improve scientific explanation skills by using *scientific modeling* as a representation of students' scientific understanding. The conceptual framework draws on STEM education design principles by the Institute for the Promotion of Teaching Science and Technology (IPST, 2014), Abdul-Yamin Hayee Khader (2017), and the scientific explanation competency outlined in the PISA assessment framework by the OECD (2017). The researcher's conceptual framework is shown in **Figure 1.**

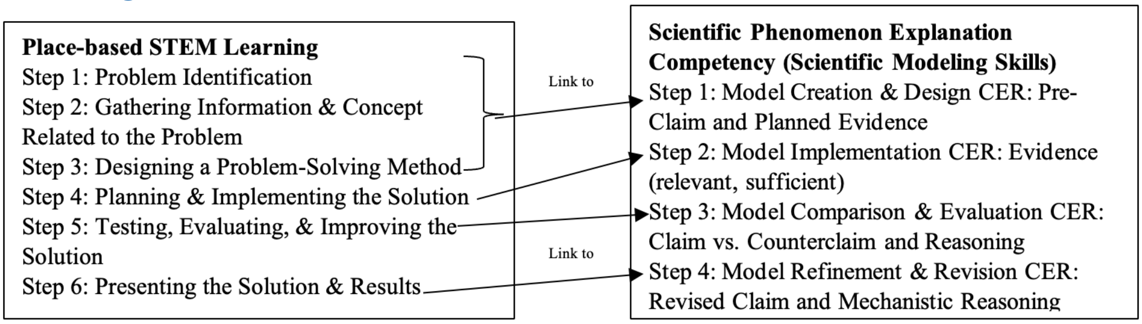


Figure 1. Research framework

The framework links a six-step place-based STEM workflow (left) to a four-step scientific modeling cycle (right) that uses students' scientific explanations (CER). Steps 1–3 (problem identification focused on gathering information, concepts, and designing a method) correspond to Modeling Step 1: Model Creation and Design, where students state a pre-claim, plan measures or variables, and sketch Model v1. Step 4 (planning and implementing the solution) aligns with Modeling Step 2: Model Implementation, emphasizing CER–Evidence (relevant, sufficient, traceable). Step 5 (testing, evaluating, improving) maps to Modeling Step 3: Comparison and Evaluation, where students compare claim versus counterclaim and explicitly use CER–Reasoning based on agreed criteria (fit, prediction, mechanism). Step 6 (presenting solution and results) corresponds to Modeling Step 4: Refinement and Revision, resulting in a revised claim and a stronger mechanistic model (Model v2). The cycle is carried out across iterative PAOR (Plan, Act, Observe, Reflect) rounds; student artifacts (models, data tables/graphs, and CER writing) provide evidence of growth in modeling sophistication and explanation quality.

METHODOLOGY

Research Design

We used Classroom Action Research (CAR) with iterative PAOR cycles of Plan, Act, Observe, and Reflect, during which the teacher served as both instructor and researcher (Kemmis & McTaggart, 1988). Each cycle resulted in specific adjustments to tasks, scaffolds, and assessments, which were then applied in the following cycle, as shown in Figure 2. which illustrates the cyclical process of classroom action research, consisting of four core stages:

1. Plan – Identifying problems and designing instructional strategies.
2. Act – Implementing the planned actions in the classroom.
3. Observe – Collecting data and monitoring the outcomes of the actions.
4. Reflect – Analyzing results to refine teaching practices and inform the next cycle.

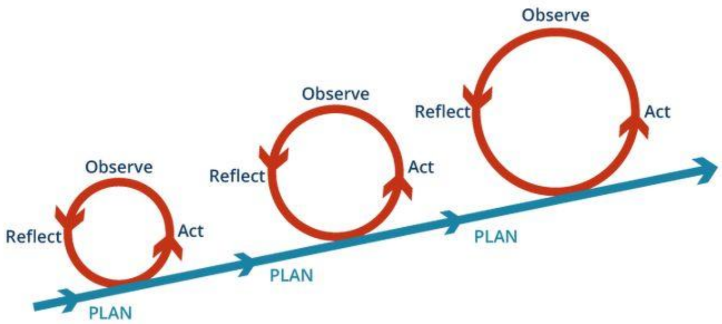


Figure 2. Stages of classroom action research (Kemmis & McTaggart, 1988)

These stages are repeated in iterative cycles, allowing continuous improvement of teaching methods through real-time feedback and classroom evidence. The classroom teacher functions as a teacher-researcher, with a university colleague acting as an external observer and coder. Instructional Sequence (Local, Place-Based Tasks) involves a short unit made up of three iterative cycles, each with 2–3 lessons lasting 40–60 minutes, that focus on locally meaningful phenomena: Cycle 1 investigates Delicious Oh-Aew dessert (jelly setting under different salt and temperature conditions), Cycle 2 looks at Eco Print and Southern Botany (leaf-based dye imprint using local plants), and Cycle 3 explores Apong Coconut with Natural Color (fermented batter influenced by temperature and time). Each task clearly incorporates modeling with CER routines.

Participants and Context

Participants were 36 Grade 5 students enrolled in Semester 2 of the 2024 academic year at a large public primary school (Grades 1–6) near Phuket Town (Mueang Phuket District), Thailand. Purposive sampling was used based on three criteria: students were enrolled in Grade 5 science during Semester 2/2024; students and their parents or guardians volunteered and provided informed consent (students provided assent); and the class was taught by the teacher-researcher, who served as both instructor and investigator. The school's proximity to community sites enabled short, supervised field trips to markets, school grounds, and accessible shoreline/mangrove areas. The broader Phuket context, including coral reefs, mangrove forests, tropical shorelines, and a Thai, Chinese, Malay cultural heritage visible in Sino-Portuguese Old Town architecture, local foods (e.g., Oh-Aew, Apong), festivals, and eco-printing crafts, provided authentic phenomena for place-based STEM learning. The school convened the principal, teachers, and parents to affirm a shared vision emphasizing students' cultural identity and civic responsibility. Parents committed to support learning activities and data collection consistent with ethical practices; participation was voluntary, with the right to withdraw, and identifying information was protected. Instruction was grounded in place-based STEM, situating investigation within students' own environments and traditions to make scientific ideas actionable and relevant. A central focus was scientific explanation, constructing claims supported by evidence and principled reasoning (CER). The design aimed to cultivate active student agency, integrating data, models, and cultural understanding to interpret local phenomena and imagine community-focused improvements.

Place-based STEM Learning Program

The unit 'Changes in Matter' consisted of three lesson clusters (a total of 15 hours) anchored in local contexts: Oh-Aew (gelation and material properties), Eco Print and Southern Botany (classification and environmental factors), and Apong (heat transfer and ingredients). Tasks explicitly involved modeling and CER. Students collected observations and measurements, represented processes with diagrams and flowcharts, and revised models based on peer and teacher feedback. Place-based STEM learning offers a powerful way to connect scientific concepts with real-world experiences, primarily when rooted in students' local community. In Phuket province, rich in natural resources and cultural heritage, place-based STEM education becomes more than just a method; it becomes a pathway for meaningful learning, identity development, and fostering scientific reasoning.

Cycle 1, Oh-Aew lesson plan focused on establishing baselines and routines. Starting with the local dessert Oh-Aew, the class conducted an initial inquiry: revisiting prior ideas about why the jelly sets differently, then collaboratively designing simple measures such as salinity, mixture temperature (°C), and setting time (min). Students were provided only with a basic CER framework and an open prompt to sketch Model v1. We then engaged in short, mixed classroom and field sessions where teams measured, timed, and recorded results in hand-drawn tables. During observation, many models appeared as labeled pictures; units and replicates lacked consistency, and CER writing rarely linked specific data to the claim. In reflection, we chose to strengthen the structure by introducing a modeling template (Components–Interactions–Mechanism–Prediction), CER sentence frames, a clear measurement protocol (tools, units, 3 trials), and an anchor chart titled "What counts as a good model/explanation?" Additionally, we scheduled a brief gallery walk to share and discuss the criteria.

Cycle 2: Eco Print and Southern Botany lesson plan focused on strengthening evidence-use and comparison skills. Building on Cycle 1, our plan introduced team roles (data manager, modeler, skeptic), designed contrasts across conditions and sites, and created a comparison matrix (Model A vs. Model B vs. Data). We conducted controlled investigations in familiar food contexts, generated graphs, and organized a gallery walk. During the observation, the quality of the evidence and the graphs improved significantly, but students still struggled to weigh competing models and explain anomalies. Our reflection included explicit evaluation criteria (fit to data, predictive power, mechanism clarity), an anomaly protocol (find, define, decide), and checkpoints for prediction, testing, and explanation. To make the lessons more accessible, we added support for English Language Learners (bilingual key terms, visual word bank) and improved formative feedback with mid-task modeling and CER rubrics.

Cycle 3, Apong' lesson plan focused on revision and communication. For the fermented batter Apong, the plan aimed to improve revision quality and enhance public communication: students were to produce Model v2 and a final CER explanation aimed at a community audience. We responded by collecting time-series data (rise height versus temperature/time), then comparing models against the new evidence while creating final posters. During observation, students refined system boundaries, clearly explained mechanisms (e.g., gas production and viscosity change), and applied principles more consistently; remaining challenges involved adjusting pacing and writing explicit rationales. Our reflective finale included a revision rationale (what changed and why, with specific data), archived artifacts for analysis, and recorded implications for the next cohort.

Across the three PAOR (Plan, Act, Observe, Reflect) cycles, the classroom moved from descriptive representations and weak evidence–claim links to data-coordinated, mechanistic models and principled CER explanations, with scaffolds gradually shifting from structure-providing to critique-and-revision supports, as shown in **Figure 3.**

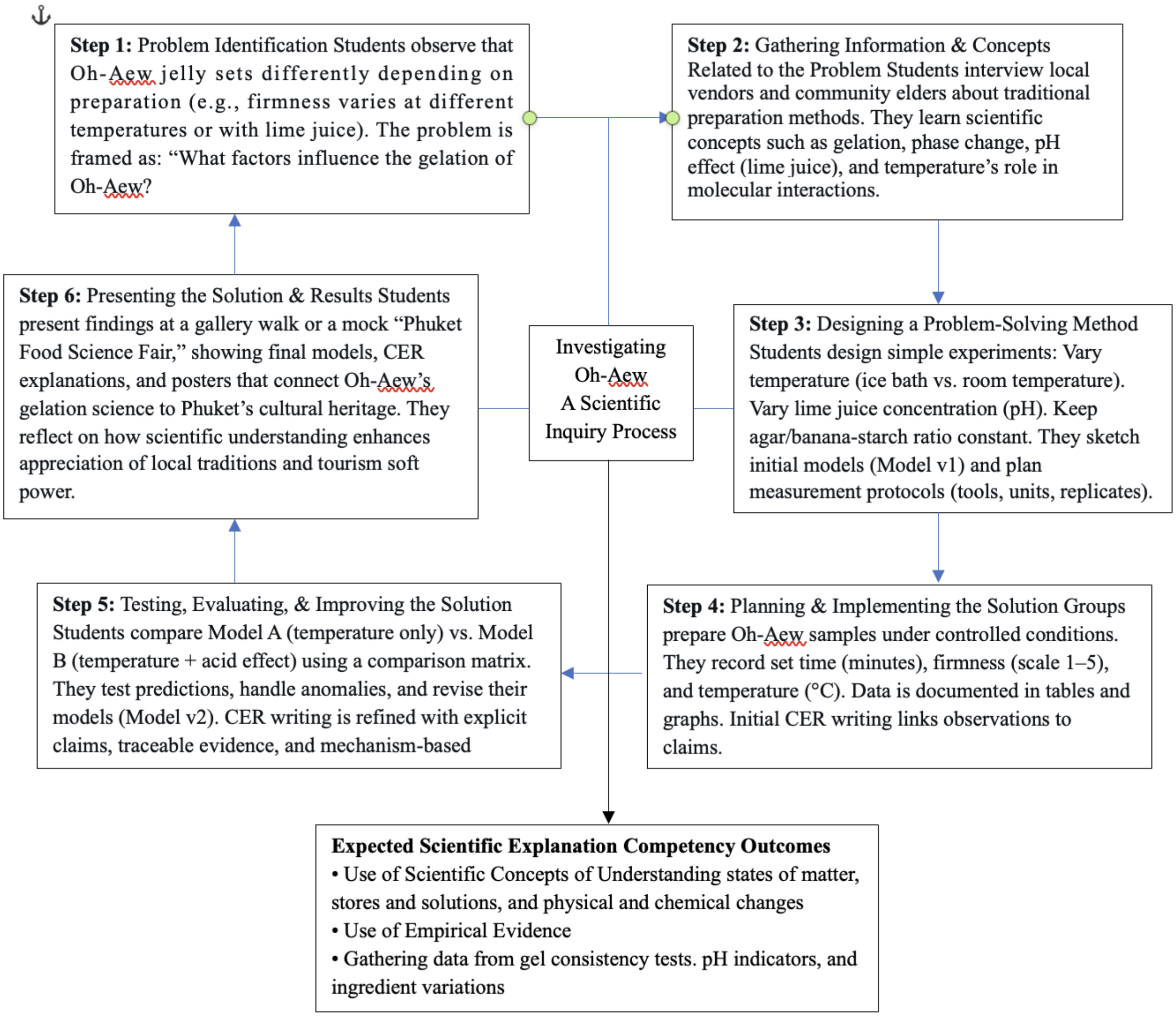


Figure 3. Place-based STEM learning process

This lesson includes multiple assessment tools to ensure students' learning is comprehensive and reflective. Teachers employ observation checklists to track participation, inquiry behavior, and collaborative skills during the activity. Students maintain science journals in which they document their hypotheses, procedures, and conclusions using the Claim–Evidence–Reasoning (CER) framework.

Research Instruments

The instructional framework was grounded in real-life applications and aimed to foster students' understanding of scientific concepts through hands-on learning and model-based reasoning.

1. ***Place-based STEM Lesson Plans***
   The 15-hour unit Changes in Matter included three lessons rooted in Phuket's culture and environment: Delicious Oh-Aew (physical/chemical changes in a dessert), Eco Print and Southern Botany (plant pigments and sustainable practices), and Apong Coconut with Natural Color (natural materials and heat transfer). Designed as place-based, model-centered STEM, the unit followed iterative cycles of model construction, use, evaluation, and revision with explicit CER writing (McNeill & Krajcik, 2011; Semken & Freeman, 2008; Sobel, 2004; Windschitl et al., 2008).
2. ***Scientific Modeling Assessment***
   A rubric-based pre/post measure tracked growth in five dimensions: components/relations, mechanism, prediction/generativity, evidence coordination, and revision quality (Schwarz & White, 2005; Schwarz et al., 2009; Windschitl et al., 2008).
3. ***STEM Worksheets***
   Worksheets included CER prompts (Claim, Evidence with data/units/replicates, Reasoning with principle/mechanism) and space for successive model versions (McNeill & Krajcik, 2011; Mercier et al., 2020; **Rehman** et al., 2025).
4. ***Observation Protocols***
   Structured notes recorded discourse, measurement practices, and scaffold use, reflecting prior work linking public representation and critique to stronger explanations (Berland & Reiser, 2009; Osborne, 2010).
5. ***Semi-structured Interviews***
   Short group probes examined how students used data to revise models, justify mechanisms, and compare alternatives (Passmore et al., 2009).
6. ***Artifacts***
   Photographs, student data (tables/graphs), anchor charts, and a teacher's reflective journal provided an audit trail and triangulation (Lincoln & Guba, 1985).

A questionnaire adapted from established instruments (Cohen et al., 2018; Saah et al., 2023; Appianing and Van Eck, 2018; Iddrisu et al., 2023; Tapia and Marsh, 2004; Chen et al., 2024) was used for the quantitative portion of this study, achieving a reliability coefficient of 0.7. The questionnaire was structured using a Likert scale format (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree) to measure the degree of agreement or disagreement with various statements/items related to the subconstruct. The Likert-scale questionnaire collected data on factors affecting girls' STEM career choices in the three prominent universities in Ghana, including parental educational attainment, parental involvement, role models, and career counselling. Structured into five sections, the first section focused on the demographic information, and the remaining four sections aligned with the research questions. It covered parental educational impact (20 items), parental involvement (19 items), career counselling (30 items), and role models (20 items).

A pilot test with 72 students, following Van Teijlingen et al.'s (2001) guidance, was conducted to refine the questionnaire for cultural relevance and measurement accuracy. Feedback led to enhancements that improved reliability and validity in the main study. Expert reviews supported content validity, factor analysis assessed construct validity, and comparison with established benchmarks ensured criterion-related validity. Random sampling strengthened external validity, while precise variable definitions reduced ambiguity.

A semi-structured interview guide, informed by a literature review and quantitative survey findings (Creswell and Creswell, 2018), was developed to gain further insights and answer the fifth research question. Guba and Lincoln's (1985) trustworthiness criteria guided qualitative reliability: credibility was reinforced through participant response reviews, transferability through contextual descriptions, dependability via research process documentation, and confirmability by bias reflection. Data collection spanned May 2024, with questionnaires taking 30–40 minutes and interviews lasting 20 minutes. Linear regression analysed continuous influences like parental support, career counselling, and role models against the constant outcome of girls' STEM career intentions. Interview transcripts were analysed using Braun and Clarke's (2006) thematic coding approach, ensuring accurate reflection of participants' perspectives.

Data Collection

Data were collected across three phases to capture both student learning outcomes and processes. Pre-learning, all 36 students completed a rubric-based Scientific Modeling Assessment to establish baseline skills. During learning, evidence was gathered through STEM worksheets with CER prompts and model drafts (Model v1 → v2), structured classroom observations, video recordings, and artifacts such as photos, data tables, anchor charts, and reflective teacher notes. Semi-structured interviews and brief small-group discussions further explored how students used data to revise models and justify claims. Post-learning, the same Scientific Modeling Assessment was administered to measure growth, complemented by analysis of final worksheets, models, and interview reflections. This multi-source approach provided both quantitative data on changes in modeling and CER performance and qualitative data on how students engaged with inquiry tasks rooted in Phuket's local context.

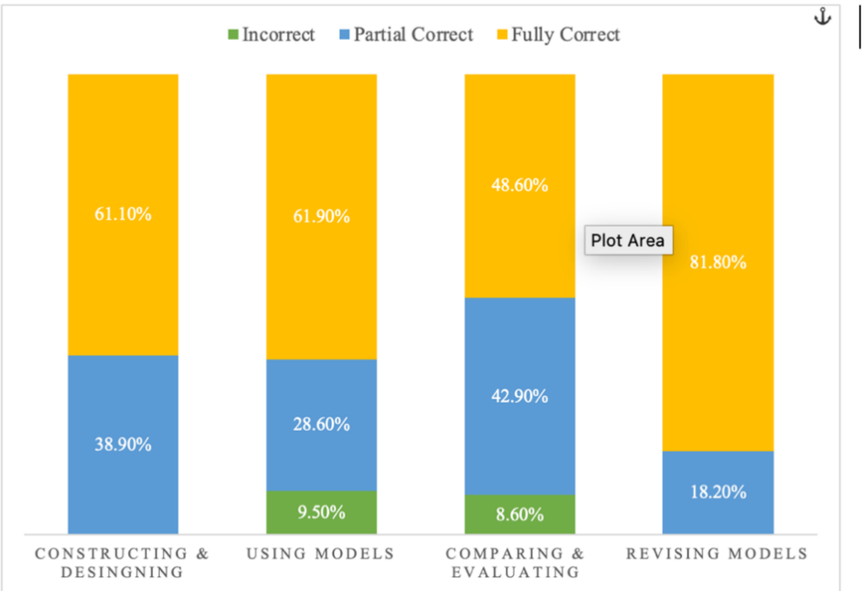
Data Analysis and Trustworthiness

Data from pre-/post-assessments, worksheets, observations, interviews, and artifacts were analyzed using a mixed-methods approach. Quantitatively, pre-/and distributions, percentages, and means of modeling and CER dimensions (n = 36) were compared to estimate student growth. Qualitatively, worksheets, interviews, and observation notes were coded using an a priori scheme (model components, mechanisms, prediction/generativity, revision, CER elements), with constant comparison to refine categories and identify emerging patterns.
Trustworthiness was ensured through triangulation of data types and methods, independent coding of 25% of the sample (88% agreement, $\varkappa = 0.72$), and peer debriefing with an external science educator. Reliability and validity check confirmed instrument quality: internal consistency was strong ($\alpha = 0.83$ for Modeling; $\alpha = 0.80$ for CER), and content validity was high (S-CVI/Ave = 0.92). An audit trail (plans, rubrics, memos, artifacts) and reflexive journaling further strengthened credibility. Together, the reliability checks, expert review, and converging evidence indicate that PAOR cycles with explicit modeling and CER scaffolds can produce substantial, observable improvements in Grade 5 students' scientific explanations.

RESEARCH RESULTS

Baseline Modeling Skills

Before introducing place-based STEM learning, it was important to understand students' starting points in scientific modeling. From qualitative and quantitative analyses of data collected before, during, and after instruction, the following findings emerged. Before implementing the STEM-based learning activities, it was essential to assess students' existing competencies in scientific modeling to establish a baseline for comparison. The assessment measured four key indicators of scientific modeling competency, as shown in **Figure 4.**



Modeling Skill Indicators

Figure 4. Students' initial scientific modeling skills prior to participating in STEM-based learning activities.

Figure 4, the stacked percentage bar chart, shows the baseline scientific modeling skills of Grade 5 students across four indicators: constructing and designing models, using models, comparing and evaluating models, and revising models. The results indicate that most students were unable to demonstrate accurate modeling skills before instruction. In constructing and designing models, no student achieved full accuracy, while 38.9% were partially correct, and 61.1% gave incorrect responses. Similarly, in revising models, no student reached complete accuracy, with only 18.2% being partially correct and 81.8% incorrect. These two indicators highlight the biggest challenges for students initially. For using models, a small percentage of students (9.5%) were entirely correct, while 28.6% showed partial accuracy and 61.9% were incorrect. A slight improvement was observed in model comparison and evaluation, with 8.6% achieving complete accuracy and 42.9% partially correct; however, nearly half of the students (48.6%) remained incorrect. Overall, the chart reveals that before the place-based STEM intervention, students' modeling skills were incomplete or incorrect, with very few able to build entirely accurate models. This baseline distribution underscores the importance of explicit instructional scaffolding and repeated practice in developing scientific modeling skills.6.2 Post-Instruction Outcomes

To assess the effectiveness of the place-based STEM intervention, students' modeling performance was analyzed across three stages of the unit, each aligned with iterative PAOR (Plan, Act, Observe, Reflect) cycles. These cycles were based on locally meaningful tasks, such as gelation in the Oh-Aew dessert, plant-based dyes in the Eco Print activity, and fermentation in the Apong coconut snack, which provided accessible contexts for developing and improving scientific models. In each cycle, students moved from creating initial models to applying, comparing, and refining them, supported by explicit Claim–Evidence–Reasoning (CER) scaffolds. Monitoring the distribution of fully correct, partially correct, and incorrect models across stages highlights how repeated engagement with culturally relevant phenomena and structured modeling routines gradually enhanced students' mechanistic reasoning and explanatory skills. The progression of Grade 5 students' modeling abilities across the three stages of the place-based STEM unit shows clear and significant improvement. In Stage 1, nearly half of the students (47.9%) produced fully correct models, while 36.8% showed partial accuracy. A smaller percentage, 15.3%, provided incorrect responses. By Stage 2, the share of fully correct responses increased notably to 68.1%, with 25.7% partially correct and only 6.2% incorrect. Finally, in Stage 3, most students (85.4%) generated fully correct models, with the remaining 14.6% achieving partial accuracy. Importantly, no students produced incorrect responses at this stage, as shown in Figure 5.

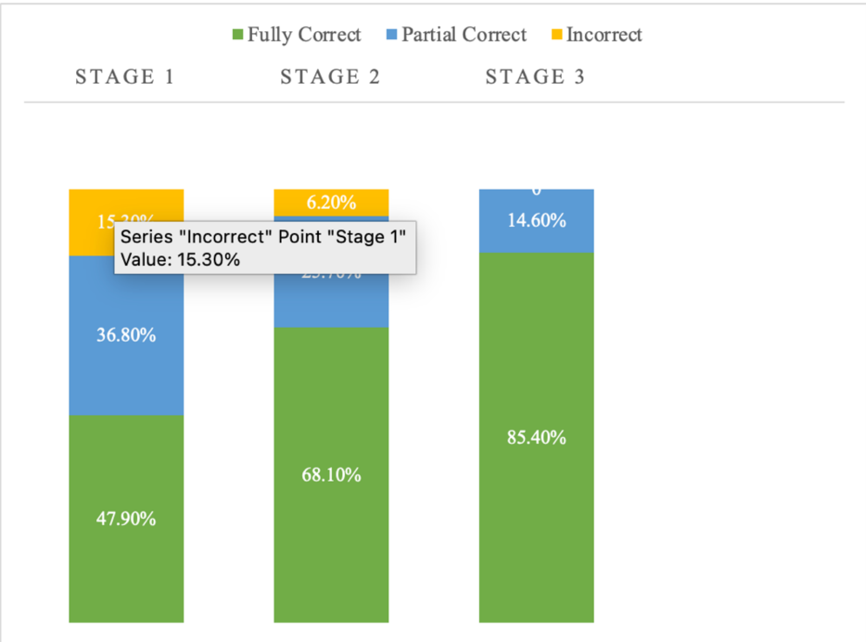


Figure 5. Students' post-instruction scientific modeling skills during STEM-based learning activities.

Figure 5 shows a stacked percentage bar chart illustrating the distribution of Grade 5 students' modeling skills across three stages of learning after the implementation of place-based STEM instruction. The overall trend shows a clear improvement in students' modeling skills across the three instructional stages. The percentage of entirely correct models increased steadily, partial responses decreased, and the final stage effectively eliminated incorrect responses. This pattern indicates that repeated cycles of inquiry and scaffolded instruction helped students develop more accurate, mechanistic, and evidence-based models over time. This trend is further confirmed by the pre–post comparison summarized in **Table 1.** Before the intervention, only 5.15% of students could build entirely correct models, while 27.21% showed partial accuracy and 67.65% had no modeling ability. After participating in the place-based STEM lessons, the distribution changed dramatically: 84.72% of students achieved entirely correct modeling, 15.28% showed partial accuracy, and no students were without modeling skills. These results demonstrate that the iterative PAOR cycles, anchored in local contexts such as Oh-Aew, Eco Print, and Apong, offered an effective way to help all students develop competence in mechanistic, evidence-based modeling.

Table 1. Results of the Development of Modeling Skills of Grade 5 Students Who Received Place-based STEM. According to the Context of Phuket Province, Comparing Post-Learning and Pre-Learning Results

Modeling skills	% of Number of Students with Indicative behaviors		
	Students with fully correct modeling skills	**Students with partially correct modeling skills**	**Students without modeling skills**
Before participating in Place-based STEM learning according to the context of Phuket Province	5.15	27.21	67.65
After participating in Place-based STEM learning according to the context of Phuket Province	84.72	15.28	-

In summary, the results demonstrate that place-based STEM learning, structured through iterative PAOR cycles and anchored in culturally relevant contexts, significantly enhanced Grade 5 students' modeling skills. Students progressed from having little or no modeling ability to producing accurate, mechanistic, and evidence-based models, as reflected in both the stage-by-stage progression and the pre–post comparison. These findings confirm the effectiveness of scaffolded instruction and repeated inquiry in fostering scientific reasoning. To gain a deeper understanding of how this development unfolded in practice, the following section presents illustrative student work. These artifacts reveal not only the accuracy of students' final models but also the processes by which they refined their ideas, integrated data, and applied Claim–Evidence–Reasoning (CER) to explain local phenomena.

Illustrative Student Work

The progression of students' modeling skills was clearly noticeable across three place-based STEM activities, each embedded in a PAOR cycle and rooted in Phuket's cultural context. The first activity, Oh-Aew, introduced students to scientific modeling by having them prepare a traditional jelly-based dessert made from banana seeds and Chinese herbs, often enjoyed with shaved ice, red beans, or syrup in Phuket's hot southern climate. This familiar cultural practice offered students an accessible way to begin translating their conceptual understanding into visual or representational forms. Initially, one student drew a simple sketch of the dessert with arrows pointing to "ice" and "agar," but did not indicate causal relationships. After engaging in structured measurement—recording set time in minutes and firmness on a 1–5 scale, and peer critique, the same student created a revised model (Model v2). This version included labeled components such as temperature (°C), lime juice (pH), and set time (min), along with interaction arrows showing how cooling promoted polymer linkages while acid weakened the gel network. The student's Claim–Evidence–Reasoning (CER) explanation reflected these refinements in their modeling, as summarized in **Table 2.**

Table 2 presents a clear modeling scaffold combined with CER frames, organized around the four steps of Components, Interactions, Mechanism, and Prediction. The student responses show how the scaffold helped shift from a descriptive drawing to a mechanistic explanation: identifying relevant components, clarifying interactions, explaining a causal mechanism, and predicting outcomes. This demonstrates how place-based STEM instruction allowed students to develop evidence-based explanations rooted in measurement and local cultural practices. The move from a descriptive sketch to a mechanistic diagram with traceable evidence illustrates how students improved their modeling skills through place-based STEM activities, as shown in **Figure 6.**

Building on the structures and CER explanations summarized in **Table 2**, students' revised models also demonstrated their growing ability to visually represent causal mechanisms. Figure 6 illustrates examples of student-constructed models developed during the place-based STEM learning activities. These models capture scientific concepts such as gel formation, material properties, and the effects of pH and temperature on texture, and show how learners apply scientific reasoning within a familiar cultural context. Beyond representing processes, the models served as tools for generating new lines of inquiry. As part of a community survey, students explored their surroundings and constructed conceptual models to guide investigation. They began by posing authentic questions about the *Oh-Aew* dessert, linking their scientific inquiry to cultural traditions. The developmental trajectory across the *Oh-Aew*, *Fruits*, and *Apong* activities illustrates how students progressed from descriptive to mechanistic modeling, supported by CER scaffolds and repeated PAOR cycles. This progression is further substantiated by the detailed breakdown in **Table 3,** which presents the development of students' modeling skills across four key stages: model creation and design, model usage, model comparison and evaluation, and model improvement

From **Table 3**, before the intervention, most students had little or no skills across all stages, for example, 61.11% showed no ability in model creation, 72.22% lacked skills in model usage, and 75.00% were unable to revise or improve their models. After participating in the place-based STEM learning program, however, the distribution changed significantly. By the end of the intervention, 77.78% of students achieved full accuracy in model creation, 86.11% in model usage, 83.33% in model comparison and evaluation, and an impressive 91.67% in model improvement. These results support the patterns observed in the student work: place-based, scaffolded STEM activities helped students not only build initial models but also to apply, evaluate, and refine them through repeated cycles of inquiry. Table 3, therefore, reinforces the evidence that the instructional design effectively supported all four aspects of scientific modeling competence in Grade 5 learners. Taken together, the quantitative outcomes presented in Table 3 and the qualitative evidence from illustrative student work converge to show a consistent developmental trajectory. Students moved from limited or absent modeling ability to demonstrating competence across all four stages of modeling: creation, usage, comparison, and improvement. These gains highlight not only the effectiveness of place-based STEM activities but also the central role of iterative PAOR cycles and CER scaffolds in promoting mechanistic, evidence-based reasoning. Building on these findings, the next section draws the results together in a broader conclusion, reflecting on the instructional implications, contributions to primary STEM education, and the potential for scaling place-based approaches in other contexts

Table 2. Example of a Modeling Scaffold and Corresponding Student Responses Using the Claim–Evidence–Reasoning (CER) Framework in the Oh-Aew Activity

Modeling Scaffold	Student Responses	CER	Student Responses
Components	water, agar/banana-starch mix (1.5% w/w), lime juice (pH), salt, temperature (°C).	Claim	I claim the ice-bath sample sets faster and firmer than room temperature for 1.5% agar.
Interactions	heat dissolves polymers and cooling forms a network; acid weakens the network; temperature controls set time.	Evidence	My evidence shows set time = 12, 13, 11 min (mean 12.0 min) in ice vs 27, 25, 29 min (mean 27.0 min) at room temp; firmness 4/5 vs 2/5 (3 trials each)
Mechanism	When the mixture cools, agar chains link to form a gel; more acid interrupts links, so the gel is softer	Reasoning	This supports my claim because lower temperature reduces molecular motion so polymer links form sooner; acid (5 mL/100 mL) is constant, so temperature explains the time difference.
Prediction	If we cool in ice (≈5 °C), set time will be shorter and firmness higher than room temp (≈30 °C)		

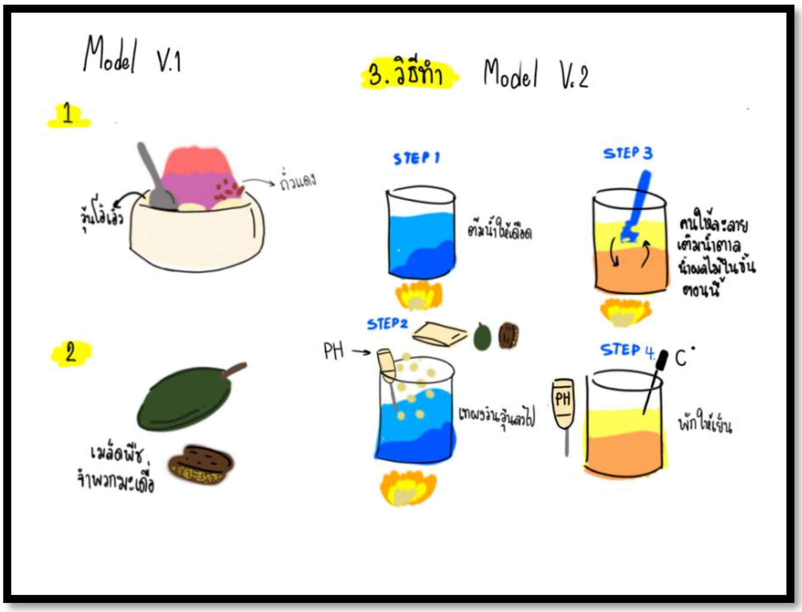


Figure 6. Students' Model Construction for Scientific Explanation

Table 3. Development of Grade 5 Students' Modeling Skills Across 3 Stages Before and After Participation in Place-Based STEM Learning in Phuket Province

Modeling skills	Students' Modeling Skills Across 3 Stage	
	Before participating in Place-based STEM Learning	After participating in Place-based STEM Learning
1. Model Creation and Design Stage		
The student has all the correct modeling skills (2)	-	77.78
The student has some of the correct modeling skills (1)	38.89	22.22
The student has no modeling skills (0)	61.11	-
2. Model Usage Stage		
The student has all the correct modeling skills (2)	-	86.11
The student has some of the correct modeling skills (1)	27.78	13.89
The student has no modeling skills (0)	72.22	-
3. Model Comparison and Evaluation Stage		
The student has all the correct modeling skills (2)	25.36	83.33
The student has some of the correct modeling skills (1)	27.42	16.67
The student has no modeling skills (0)	47.22	-
4. Model Improvement Stage		
The student has all the correct modeling skills (2)	5.57	91.67
The student has some of the correct modeling skills (1)	19.43	8.33
The student has no modeling skills (0)	75.00	-

DISCUSSION

The findings of this study suggest that place-based STEM tasks that make mechanisms visible through modeling can significantly improve primary students' scientific explanation skills. Anchoring lessons in culturally familiar practices, such as local foods, not only increased engagement but also supported sense-making by providing phenomena that were meaningful and accessible to learners. This aligns with Shen and Linn's (2011) argument that connecting everyday observations with scientific explanations. Likewise, explicit scaffolds such as the Components–Interactions–Mechanism–Prediction template and the Claim–Evidence–Reasoning (CER) frames helped structure students' thinking, consistent with McNeill and Krajcik's (2011) emphasis on making reasoning practices visible. Peer critique further supported revision and refinement, creating conditions like the iterative cycles of construction and critique documented in prior modeling studies (Schwarz et al., 2009; Windschitl et al., 2008). The progression from descriptive sketches to mechanistic models observed in this study echoes Oh and Oh's (2011) synthesis, which describes how students develop modeling competence through repeated opportunities to revise representations. Similarly, Seok (2011) notes that teachers must help students distinguish between surface descriptions and deeper mechanistic accounts—a distinction clearly observable in the transition from early to later student work in this project. These results also resonate with Boyd (2019) findings, which showed that contextually relevant, culturally grounded tasks foster creativity, spatial reasoning, and sustained engagement. In our case, students in Phuket investigating Oh-Aew gelation, fruit acidity, and Apong fermentation engaged in authentic scientific practices—classification, measurement, prediction—consistent with the practices emphasized in the Next Generation Science Standards (NGSS Lead States, 2013) and Thailand's Basic Education Core Curriculum (Ministry of Education, 2008).

The observed connection between hands-on modeling and the development of scientific reasoning aligns with prior research showing that spatial visualization underpins STEM success (Ackerman, 1987; Chen et al., 2020; Cohen et al., 2018). The instructional supports embedded in this study further reflect evidence that spatial and representational skills can be intentionally cultivated through targeted activities (Sorby, 2009; Uttal et al., 2013). As students moved through model creation, comparison, and refinement, their work also illustrated Morgan and Wise's (2017) notion of narrative "unfolding in time," in which explanations become coherent through sequences of causally connected events rather than isolated descriptions. Narrative reasoning emerged as an essential—yet often overlooked—dimension of students' modeling, with learners frequently explaining phenomena such as fermentation or cooling by organizing events into story-like structures (Yang et al., 2021). This pattern aligns with Bruner's (1991) view of narrative as a fundamental mode of human sense-making, supporting learners in building causal frameworks from experience. Taken together, these findings reinforce De Loof et al.'s (2022) argument that high-quality learning occurs when students are supported to construct meaning through cognitively rich tasks that require explaining, connecting ideas, and justifying reasoning. By providing structured opportunities for modeling, explanation, and reflection, this study enabled students to progress from surface-level descriptions to coherent and mechanistic scientific explanations, demonstrating the power of cognitively demanding, narrative-supported modeling tasks in deepening conceptual understanding.

Banks (2016) similarly shows that narrative features persist even in scientific writing, highlighting temporal and causal language as central to explanation. In this study, narrative became a bridge between students' cultural experiences and scientific mechanisms, helping them articulate how and why changes occurred in familiar materials. The study also has implications for teacher practice. The most effective instructional moves were those that (a) sequenced tasks from concrete local phenomena to mechanistic models, (b) made CER structures explicit in talk and writing, and (c) incorporated peer critique to prompt refinement. These strategies align with research on ambitious science teaching (Cherbow et al., 2025; Windschitl et al., 2008) and with Seok's (2011) assertion that teachers must explicitly address what models are and what they are not. Challenges, such as students' inconsistent measurements or difficulty reconciling anomalies, mirror issues identified in earlier research on modeling (Henze et al., 2007; Justi & Gilbert, 2002a), underscoring the need for continued scaffolding and reflective routines.

In conclusion, this study demonstrates that place-based STEM learning, combined with explicit modeling and CER supports, can significantly improve primary students' scientific explanation skills. Beyond cognitive improvements, integrating cultural practices, narrative reasoning, and modeling fosters creativity, cultural identity, and sustainability awareness—outcomes aligned with international calls for relevant and equitable science education (UNESCO, 2017, 2020). By enhancing Grade 5 students' ability to develop mechanistic explanations rooted in their lived environment, the intervention directly supports SDG 4 (Quality Education) and SDG 13 (Climate Action), empowering young learners to see themselves as active participants in tackling sustainability challenges within their communities.

CONCLUSION

This study demonstrates that a short, locally grounded sequence of place-based STEM lessons can substantially strengthen Grade 5 students' scientific explanation skills. Through iterative PAOR cycles, students advanced from descriptive accounts to constructing coherent Claim–Evidence–Reasoning (CER) explanations and mechanistic, evidence-based models. Quantitative results showed that fully correct models increased from 5.15% before instruction to 84.72% after instruction. Qualitative analyses confirmed that students increasingly used traceable evidence, principled reasoning, and public revision of claims.

Several instructional features proved especially effective in supporting these gains. Explicit scaffolds, such as Components–Interactions–Mechanism–Prediction templates and CER sentence frames, helped structure reasoning and writing. Measurement protocols that emphasized tools, units, and replicates improved the evidentiary base for claims. Public comparison routines (e.g., gallery walks, Model A vs. Model B vs. Data matrices) promoted peer critique and deeper reasoning, while an anomaly protocol (find → explain → decide) supported mechanism-level revisions. Structured roles (data manager, modeler, skeptic) and formative rubrics distributed responsibility for evidence use, while bilingual key terms and visual word banks expanded accessibility. Anchoring tasks in culturally meaningful phenomena (Oh-Aew gelation, fruit classification, Apong fermentation) sustained engagement and provided usable variability for modeling.

Early challenges included reliance on descriptive drawings, inconsistent measurement practices, and difficulty weighing competing models. These were mitigated by supportive conditions: strong school–community partnerships that ensured relevance and access to local contexts, time and safety structures for outdoor learning, and practical teacher resources (templates, rubrics, comparison tools) that made the approach feasible. The findings show that place-based STEM lessons significantly improve both CER quality and modeling-based explanations, with gains accumulating across successive PAOR cycles. The most effective strategies were those that (a) made quality criteria visible and usable, (b) strengthened the link between data and mechanisms, and (c) embedded inquiry in culturally authentic contexts. For classroom practice, teachers should incorporate peer critique and public comparison through gallery walks and comparison matrices to help students weigh alternatives and justify revisions. Before fieldwork, students should be briefed on objectives, processes, and roles, with the teacher facilitating inquiry, ensuring measurement quality, and maintaining safety. To expand impact, future studies should explore integration with local wisdom and community practices, such as traditional foods, handicrafts, and natural resources. Such designs can drive community problem-solving, highlight local potential, and inform sustainable approaches to both curriculum and teacher professional development.

In summary, the evidence indicates that place-based STEM learning, when paired with explicit scaffolding and community integration, is both practical and scalable. It equips students not only with stronger scientific explanation skills but also with curiosity, cultural pride, and the ability to connect scientific concepts to everyday life. This study provides a replicable model for primary science education: anchor tasks in local contexts, embed modeling and CER as central routines, and guide inquiry through structured cycles of construction, application, comparison, and refinement.

Recommendation

The findings of this study indicate that place-based STEM instruction is most effective when it combines local cultural practices, clear modeling supports, and structured reasoning routines to help students understand. Linking scientific investigation to familiar contexts, such as Oh-Aew gelation or Apong fermentation, helps students connect mechanisms to everyday experiences, making learning more relevant and engaging. Clear supports, including Components–Interactions–Mechanism–Prediction templates, CER frames, and comparison charts, emphasize high-quality reasoning and enable students to explain their evidence more accurately. Peer review and public comparison of models promote deeper revisions, while community partnerships enhance fieldwork and provide real phenomena for investigation. Overall, these elements suggest that primary science teaching should deliberately integrate culturally relevant tasks with repeated modeling routines and explicit supports to develop students' science explanation skills.

Suggestion for Future Studies

Future studies should explore whether the gains in modeling and CER shown by students in this project persist over time and transfer to unfamiliar scientific phenomena. Research is also needed to identify professional development models that help teachers independently implement place-based STEM lessons, particularly those that integrate modeling, measurement, and community contexts. Comparative studies across different cultural regions would illuminate how local traditions shape scientific reasoning and engagement. The role of narrative logic, observed here as a natural bridge between cultural experience and mechanistic explanation, deserves deeper investigation. In addition, future work could examine how digital tools, such as iPad-based modeling apps or AR visualizations, support iterative modeling. Expanding place-based STEM tasks to broader community sustainability issues would also provide insight into how such approaches can cultivate scientific literacy, cultural identity, and local problem-solving skills.

Limitations of the Study

Despite the promising outcomes, several limitations related to community–classroom collaboration should be acknowledged. The study involved only one school community, and the nature of its cultural resources, traditional foods, local artisans, and supportive community leaders may not be fully representative of other communities. This limits broader generalization about how community partnerships function in place-based STEM learning. The intervention relied on strong collaboration between teachers, researchers, and local knowledge holders, raising questions about the sustainability of such partnerships in schools with fewer community ties or limited teacher support. Time constraints also restricted the depth of engagement with community members; thus, the study does not capture the long-term dynamics of maintaining school–community collaborations. Additionally, the short duration of the intervention means we do not yet know how deeply these partnerships influence students' lasting scientific literacy or community identity. These limitations highlight the need for further investigation into sustainable, scalable models of community-engaged STEM education.

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Ethical Considerations

This study received ethics approval from the school review board and written site permission from the school principal. Informed consent was obtained from all parents/guardians and assent from students before any data collection. Participation was voluntary, with the right to withdraw at any time without penalty. To protect privacy, all records were de-identified (pseudonyms used), and no personally identifiable information is reported. Data were stored securely with access limited to the research team, and all procedures aligned with institutional and national guidelines for minimal-risk educational research.

Competing Interests

The authors declare that they have no relevant financial or non-financial interests to disclose.

Author Contributions

Both authors contributed to the study's conception and design. They prepared the materials, collected, and analysed the data. Siriwan Chatmaneerungcharoen wrote the first draft of the manuscript, and Wendy Nielsen provided feedback on previous versions. Both authors read and approved the final manuscript.

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