

Research Article

Developing an Integrated Framework for Creativity-Enhanced STEM Out-of-School Activities: A Case Study of Lanna Lantern Making

Pathompong Chummongkol, Jiraporn Tupsai*, Chockchai Yuenyong

Science Education Department, Faculty of Education, Khon Kaen University, Khon Kaen 40002, Thailand

* Corresponding author: tjrap@kku.ac.th

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ABSTRACT

This study addresses the lack of a coherent framework that integrates STEM instruction, creativity development, and culturally responsive pedagogy within out-of-school learning contexts. A three-phase Design and Development Research approach was adopted. Phase one involved documentary analysis and expert consultation to identify STEM elements embedded in traditional Lanna lantern making. Phase two focused on systematic framework construction by aligning a seven-stage STEM inquiry model with an A-to-E creativity framework. Phase three consisted of expert validation through a structured focus group involving five purposively selected specialists, applying a consensus-based evaluation with an 80% agreement threshold. The findings demonstrated substantial STEM integration across science, technology, engineering, and mathematics domains, particularly in light transmission, material properties and selection, structural design, and geometric measurement. The resulting framework was translated into a six-hour instructional module comprising 20 structured sub-activities for upper primary learners, with explicit alignment between STEM inquiry processes and creativity indicators. Expert evaluation confirmed the framework's conceptual coherence, cultural relevance, and practical feasibility for implementation. This study provides a validated pedagogical framework that systematically integrates creativity and inquiry-based STEM learning within a culturally meaningful out-of-school setting. The framework offers educators a practical tool for designing contextualised STEM experiences that promote creative thinking alongside structured investigation. Future research should focus on empirical implementation with students to evaluate learning outcomes and creativity enhancement.

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1. INTRODUCTION

The Fourth Industrial Revolution (4IR), driven by advances in Artificial Intelligence, automation, and digital technology has fundamentally reshaped workforce demands (Brown, 2024; Di Battista et al., 2023). Technical STEM knowledge alone is no longer sufficient; modern economies require transferable, high-order competencies such as creative problem-solving and innovation. The urgency is amplified by the need to address complex global challenges including climate change, resource scarcity, and public health crises, requiring generations capable of applying integrated knowledge to ambiguous problems (Ghani et al., 2026; Kennedy & Sundberg, 2020). Consequently, the core function of contemporary education has shifted from knowledge transmission to the systematic cultivation of adaptive capacities. However, traditional classroom STEM instruction remains structurally ill-equipped for this goal. Institutional constraints rigid curricula, limited instructional time, and standardized testing pressures encourage teacher-centered delivery and fragmented topic coverage that prioritize procedural knowledge over transferable problem-solving skills (National Research Council, 2012; Taha & Subramaniam, 2020). While integrated, inquiry-based approaches have been shown to enhance student engagement and scientific creativity, their implementation is consistently undermined by inadequate teacher preparation and institutional inertia (Permanasari et al., 2024; Thao et al., 2024; Erkan & Duran, 2023; Toma & Greca, 2018). This creates a persistent gap between what research recommends and what classrooms deliver. Contemporary frameworks such as the Next Generation Science Standards (2013) and the Framework for K-12 Science Education (2012) advocate integrating core concepts with scientific and engineering practices, yet these standards were designed for formal school contexts and do not address the specific pedagogical needs of non-formal or culturally situated learning environments.

Empirical evidence offers a pathway forward: active learning in hands-on, non-formal settings such as makerspaces and design-based learning significantly enhances creativity, self-efficacy, and critical thinking (Peleg & Levy, 2025; Panergayo & Prudente, 2024; Hebebcı & Usta, 2022). Crucially, research demonstrates that creativity develops through sustained, open-ended engagement rather than short, answer-focused exercises and is further strengthened when integrated with design practices and iterative reasoning (Shernoff, 2024). Yet these studies establish the conditions for creativity development without providing a structured pedagogical tool that connects specific creativity indicators to specific STEM inquiry stages particularly for out-of-school implementation. The effectiveness of such active approaches is significantly enhanced when grounded in local culture. In Thailand, STEM reform has increasingly focused on connecting learning with local communities and cultural heritage as culturally contextualized instruction helps students link abstract concepts to their daily lives, making learning more meaningful and sustainable (Khureerung & Thao-Do, 2022; Yuenyong, 2019). Northern Thailand provides a compelling context: the region was the historical center of the Lanna Kingdom, an independent Tai polity flourishing from the 13th to 18th centuries whose cultural influence extended into southern China, eastern Myanmar, and northern Laos (Grabowsky, 2005, 2015; Johnson, 2010; Penth, 2001). The Lanna lantern (*Khom Lanna*), a traditional craft central to Northern Thai ceremonies such as the Yi Peng festival, embodies rich STEM content geometry, material properties, and structural design confirmed by research on ethnomathematics and indigenous knowledge as a foundation for place-based education. This approach directly supports the OECD/UNESCO (2016) goal of simultaneously preserving cultural heritage and developing 21st-century skills.

Despite this converging evidence, the field suffers from a critical fragmentation: previous research has validated each element in isolation informal learning environments creativity in STEM, and culturally responsive teaching but no unified framework systematically connects them (Gomes & McCauley, 2021; Roberts et al., 2018). Specifically, the A-to-E Creativity Framework (Murcia et al., 2020) provides well-defined creativity indicators but does not link them to a structured STEM inquiry process. The 7-stage STEM inquiry model offers pedagogical structure but does not incorporate systematic creativity development. Existing large-scale standards target formal K-12 classrooms and rarely provide detailed guidance linking creativity to structured STEM processes for out-of-school activities (Plucker, 2023; Zhou et al., 2022). This leaves practitioners without a coherent tool for designing effective, measurable, and culturally meaningful out-of-school STEM learning experiences. This study directly addresses this gap. The novelty lies in the systematic integration of three previously fragmented elements into a single pedagogical tool: the A-to-E creativity indicators, the 7-stage STEM inquiry structure, and culturally embedded STEM content from Lanna lantern making designed specifically for out-of-school implementation. By mapping assessable creativity behaviors to every stage of a structured STEM inquiry process within a culturally authentic context, this framework provides what none of the existing models achieve individually: a unified, implementable, and measurable instructional design for creativity-enhanced STEM learning outside the formal classroom.

This study pursues two key objectives. The first objective is to identify and analyze the intrinsic STEM elements and principles embedded within the traditional Lanna lantern-making process, serving as the cultural context for the activity. The second objective is to develop an Integrated Framework for creativity-enhanced STEM out-of-school activities by systematically aligning the A-to-E Creativity Framework with the 7-stage STEM inquiry model.

2. METHODOLOGY

2.1. Research Approach and Design

This study employs a qualitative research approach, specifically utilizing Design and Development Research (DDR) methodology (Tracey, 2009). DDR is particularly appropriate for educational research that aims to create, validate, and refine instructional products, processes, or frameworks based on systematic analysis and expert evaluation (Richey, 2006). The research is contextualized within the unique cultural heritage of Northern Thailand, specifically focusing on the traditional craft of Lanna lantern making as a vehicle for STEM learning. The design is descriptive and developmental in nature, comprising three sequential and interconnected phases (Bridges & Hallinger, 1995). The research employs qualitative methods throughout all phases, including documentary analysis, expert interviews, content analysis, and focus group validation. This approach aligns with DDR's emphasis on context-sensitive development grounded in empirical investigation and expert judgment rather than experimental testing (Van den Akker et al., 2006). The research was structured in three sequential phases aligned with the core DDR processes of analysis, design, and evaluation. The first phase involved analyzing and identifying the STEM content embedded within the cultural context through ethnographic and documentary methods. The second phase focused on developing an Integrated Framework by systematically mapping cultural content to established pedagogical models. The third phase validated this framework through expert consensus using focus group methodology. This three-phase structure culminated in a validated educational artifact ready for implementation (Richey & Klein, 2014).

2.2. Research Procedures

2.2.1. Phase 1: Identification and Analysis of STEM Elements

The first phase was dedicated to identifying and analyzing the underlying STEM elements and scientific principles embedded within the Lanna lantern making process. This phase utilized documentary analysis of existing ethnomathematics research and cultural studies pertaining to Lanna crafts (Gay, 2018). This was followed by expert consultation involving structured interviews with local Lanna craftsmen and cultural heritage experts (Patton, 2014). The data collected were then subjected to content analysis by the research team to formally categorize and align the identified techniques with established principles in Geometry, Material Science, Physics, and Engineering, establishing the foundational cultural context necessary for the subsequent framework development.



Figure 1. Lanna lantern

2.2.2. Phase 2: Integrated Framework Development

The second phase involved the development of the Integrated Framework for creativity-enhanced STEM out-of-school activities. The framework was constructed based on a systematic

integration of three core components derived from the literature and Phase 1 analysis (Table 1). The first component was the cultural STEM content, comprising the Lanna lantern-making elements identified in Phase 1. The second component was the A-to-E Creativity Framework, which was selected as the theoretical foundation for enhancing creative thinking (Murcia et al., 2020). The third component was a 7-stage structured model of STEM inquiry, which provided the pedagogical structure for the activities (Table 2).

Table 1. The 'A' to 'E' of creativity: A framework for young children's creativity

PROCESS: Characteristics of children's creative thinking				
Agency	Being Curious	Connecting	Daring	Experimenting
Displaying self-determination (A1)	Questioning (B1)	Making connections (C1)	Willing to be different (D1)	Trying out new ideas (E1)
Finding relevance and personal meaning (A2)	Wondering (B2)	Seeing patterns in ideas (C2)	Persisting when things get difficult (D2)	Playing with possibilities (E2)
Having a purpose (A3)	Imagining (B3)	Reflecting on what is and what could be (C3)	Learning from failure (resilience) (D3)	Investigating (E3)
Acting with autonomy (A4)	Exploring (B4)	Sharing with others (C4)	Tolerating uncertainty (D4)	Tinkering and adapting ideas (E4)
Demonstrating personal choice and freedom (A5)	Discovering (B5)	Combining ideas to form something new (C5)	Challenging assumptions (D5)	Using materials differently (E5)
Choosing to adjust and be agile (A6)	Engaging in "what if" thinking (B6)	Seeing different points of view (C6)	Putting ideas into action (D6)	Solving problems (E6)

Table 2. Summary of the 7-Stage STEM Inquiry Teaching Approach based on Sutaphan and Yuenyong (2019)

Stage	STEM Inquiry Stage	Summary	Key Student Activities
1	Identification of Social Issues	Students explore real-world problems from local social, cultural, or technological contexts. Teachers use images, videos, or VDO clips to help students identify and discuss key issues such as disasters, pollution, health, energy, or product design challenges.	View pictures/videos of social issues; brainstorm and ask questions to identify problems; set questions independently; engage in Q&A discussion about the problem context.
2	Identification of Potential Solutions	Students develop possible solutions using their existing knowledge, skills, experience, and creativity. They analyze their available resources through the 5 Capitals (physical, financial, social, human, natural) and use 5W1H questioning (What, Where, When, Who, Why, How) to plan their designs systematically.	Discuss and brainstorm about the 5 Capitals; use 5W1H to plan designs; explore prior knowledge and research new information; clarify what science and math knowledge is needed for designing prototypes.
3	Need for Knowledge	Learning activities focus on the scientific and mathematical knowledge required to solve the identified problem. STEM concepts are taught through demonstrations, experiments, and inquiry-based activities to build the knowledge base for decision-making and design.	Conduct hands-on experiments and demonstrations; study science and math concepts relevant to the solution; search, study, and present possible solutions; build interdisciplinary STEM knowledge in context.
4	Decision-Making	Students apply scientific, mathematical, and other knowledge to analyze alternatives. They discuss advantages and disadvantages of each option, argue and justify their choices, and select the most appropriate solution through systematic comparison.	List and present possible solutions; debate pros and cons of each alternative; share research findings and justifications; select the best solution based on evidence and group consensus.
5	Development of Prototype or Product	Students build models, simulations, or actual products based on their chosen solution. Activities integrate engineering design processes (EPD), linking conceptual knowledge ('knowing that') with procedural knowledge ('knowing how') through design-based learning.	Plan and design prototypes; construct models or products using engineering design processes; integrate science and math knowledge into the build; present and explain design innovations.
6	Test and Evaluation of the Solution	Students develop methods to test and evaluate their prototypes based on science, mathematics, human needs, and real-world usability. They conduct experiments, create mathematical models, and run simulations to verify effectiveness.	Design testing methods and criteria; conduct experiments and simulations; apply science and math to evaluate results; prepare presentations (e.g., short films, stories) to demonstrate proof of concept.
7	Socialization and Completion Decision	Students present their design process and final product to share with society. They reflect on what they learned, receive feedback from peers and the community, validate their STEM knowledge application, and identify ideas for future redesign and improvement.	Present products and processes publicly; exhibit solutions to the community; reflect on learning and gather feedback; report what was learned from validation and socialization; write reflections and plan redesign.

The integration was achieved through a matrix alignment process, where each stage of the 7-stage STEM inquiry model was systematically mapped to corresponding creative processes within the 'A' to 'E' model, ensuring that every practical activity inherently fostered creative output alongside

scientific practice (Reigeluth & Carr-Chellman, 2009). The systematic alignment of the A-to-E Creativity Framework with the 7-stage STEM inquiry model was documented in a detailed instructional plan, which is presented as the primary research artifact. This finalized Integrated Framework document is presented in the Results and Discussion section.

2.2.3. Phase 3: Framework Validation

The third phase employed an expert validation approach to critically evaluate and refine the Integrated Framework developed in Phase 2. A focus group methodology was selected as the primary validation strategy, as it facilitates in-depth collective examination and generates rich qualitative feedback through interactive discussion among experts (Krueger & Casey, 2015).

Expert Panel Composition: Five experts were purposively selected using criterion-based sampling (Etikan et al., 2016). Each panelist was required to meet at least two of the following criteria: (a) a minimum of fifteen years of professional experience in STEM education, science education, or cultural heritage pedagogy; (b) an active research record with peer-reviewed publications in STEM teaching, creativity, or indigenous knowledge; and (c) direct practical experience designing or facilitating learning activities for primary-level students. The resulting panel comprised one expert in local context-based STEM teaching at the primary education level, one expert in science project management, one expert in STEM education, and two university lecturers conducting research in STEM teaching and science literacy. A panel size of five is consistent with established guidelines for expert validation in educational design research, which recommend three to five specialists when panelists possess high domain expertise and the evaluation focus is on qualitative refinement of a framework at the design stage (Skulmoski et al., 2007). This composition ensured comprehensive coverage of the framework's pedagogical, cultural, and scientific dimensions.

Validation Procedure: The validation process followed a two-stage approach. First, the complete instructional activity plan (developed in Phases 1 and 2) was distributed to all panel members in advance for individual review, allowing each expert to conduct independent analysis based on their specific area of expertise (Morgan, 1997). Second, a structured focus group session was convened where experts engaged in systematic collective discussion. Each expert presented their individual critique and recommendations in turn, followed by open deliberation where all participants could respond, question, and build upon each other's perspectives. This interactive process continued until convergence on key recommendations was achieved through expert consensus. The entire session was audio-recorded and transcribed verbatim for subsequent analysis (Stewart & Shamdasani, 2014). Expert feedback from the focus group was analyzed using qualitative content analysis to systematically identify patterns of critique and actionable recommendations (Elo & Kyngas, 2008). The transcripts were analyzed to extract: (1) areas of consensus regarding framework strengths, (2) identified weaknesses or gaps requiring modification, and (3) specific expert-recommended improvements. These findings were synthesized thematically and prioritized based on frequency of mention and degree of expert agreement (Hsieh & Shannon, 2005).

Consensus was operationally defined as agreement among at least four of the five panelists (80%) on a given recommendation; items on which experts disagreed were discussed further until a shared position was reached (Kitzinger, 1995). For each of the 20 sub-activities, the panel reached a collective decision to either retain the activity as designed, retain with specific modifications, or remove and replace it. The focus group concluded with a final round of confirmation in which all experts reviewed the consolidated recommendations and formally endorsed the revised framework as ready for implementation. The framework was then iteratively revised based on these consolidated recommendations. This qualitative consensus-based approach is consistent with established practices for expert validation in the design phase of DDR, where the primary objective is to refine the quality and coherence of the educational artifact through in-depth professional judgment rather than statistical measurement (McKenney & Reeves, 2018).

3. RESULTS AND DISCUSSION

3.1. STEM Elements Embedded in Lanna Lantern Making

The analysis of the traditional Lanna lantern-making process through documentary review and expert consultation revealed a rich array of STEM content naturally embedded within the craft. These elements were categorized across four domains: Science, Technology, Engineering, and Mathematics. Table 3 summarizes the identified elements. In Science, the craft involves understanding light transmission properties when selecting translucent covering materials such as sa paper and thin fabric, as well as convection currents demonstrated by the Khom Phat (rotating lantern), in which hot air from

the candle rises and draws cooler air inward to spin the lantern body. In Technology, artisans apply knowledge of material properties and fitness for purpose when choosing bamboo, wire, and fabric for different structural and aesthetic functions, while the integration of LED lights in place of traditional candles introduces considerations of electrical safety and energy efficiency. In Engineering, constructing the bamboo or wire frame requires attention to structural integrity and load distribution, with triangular bracing identified as the most resistant to deformation, and the entire making process models an iterative engineering design cycle of sketching, building, testing, and refining. In Mathematics, lantern frames are based on three-dimensional geometric shapes such as prisms, pyramids, and cylinders, requiring students to apply measurement skills and area formulas to calculate material dimensions and quantities.

Table 3. STEM Elements Identified in the Lanna Lantern-Making Process

STEM Domain	Specific Element	Lantern-Making Context	Key Concepts
Science	Light transmission	Selecting covering materials (sa paper, fabric, plastic) that allow light to pass through	Transparent, translucent, and opaque materials; light absorption and reflection
Science	Convection currents	Khom Phat (rotating lantern): hot air rises from the candle, cool air enters, creating airflow that spins the lantern	Heat transfer; convection; air density and temperature
Technology	Material selection and tool use	Choosing appropriate materials (bamboo, wire, sa paper, fabric) based on function; using cutting, measuring, and joining tools	Material properties; fitness for purpose; tool safety
Technology	LED integration	Replacing traditional candles with LED lights for improved safety and durability	Electrical circuits; energy efficiency; fire safety
Engineering	Structural design	Constructing the bamboo or wire frame to support the lantern shape under load	Structural integrity; load distribution; triangular bracing
Engineering	Design process	Iterative prototyping: sketching, building, testing, and refining the lantern	Engineering design cycle; constraints; trade-offs
Mathematics	Geometric shapes	Lantern frames use 3D shapes: prisms, pyramids, cylinders, and polyhedra with symmetry	2D/3D geometry; symmetry; polygon properties
Mathematics	Measurement and calculation	Measuring dimensions, calculating area of covering material, and estimating material quantities	Area formulas; perimeter; volume; units of measurement

These findings confirm that Lanna lantern making is not merely a cultural craft but a context rich with genuinely embedded STEM content. The STEM content is not artificially imposed on the craft but arises naturally from its traditional production processes, demonstrating how local heritage can serve as an authentic context for integrated STEM learning. This supports research on ethnomathematics and indigenous knowledge systems and the argument that culturally contextualized STEM education enhances both the meaningfulness and sustainability of learning (Payadnya et al., 2024; Taptamat, 2023; Sutaphan & Yuenyong, 2019).

3.2. The Integrated Framework for Creativity-Enhanced STEM Out-of-School Activities

Based on the STEM content identified above, the Integrated Framework was developed by systematically aligning the 7-stage STEM inquiry model with the A-to-E Creativity Framework. The resulting framework was operationalized as a detailed 6-hour out-of-school activity plan for upper primary students (ages 9-11), comprising 20 sub-activities organized across seven progressive stages (Table 4). Each sub-activity is explicitly mapped to both a STEM inquiry stage and specific A-to-E creativity indicators, making the framework both implementable and measurable. This directly addresses the documented gap in unified pedagogical tools for out-of-school STEM activities, offering practitioners a practical guide that links broad creativity goals to concrete, assessable activities.

Table 4. Alignment of the 7-Stage STEM Inquiry Model with the A-to-E Creativity Framework

Stage	STEM Inquiry Stage	Creativity Components (A-E)	Key Activities	Duration
1	Identification of Social Issues	A (Agency), B (Being Curious)	View real lanterns and photos; discuss cultural significance; identify social issues (waste, safety, loss of identity); vote on priority problems	40 min (Activities 1.1-1.3)
2	Identification of Potential Solutions	A (Agency), B (Being Curious), C (Connecting), D (Daring), E (Experimenting)	Analyze 5 capitals (physical, financial, social, human, natural); apply 5W1H questioning; draft initial lantern designs and present to peers	40 min (Activities 2.1-2.3)
3	Need for Knowledge	A (Agency), B (Being Curious), C (Connecting), E (Experimenting)	Hands-on experiments on light transmission through materials; build and test structural shapes (triangles, squares, hexagons); measure and calculate material quantities	60 min (Activities 3.1-3.3)

4	Decision-Making	A (Agency), C (Connecting), D (Daring), E (Experimenting)	Analyze pros and cons of designs using structured criteria (shape, materials, strength, light, safety, aesthetics); revise and finalize the design	40 min (Activities 4.1–4.2)
5	Development of Prototype	A (Agency), C (Connecting), D (Daring), E (Experimenting)	Prepare materials and assign roles; construct the lantern frame, attach covering and decorations; conduct initial light tests and make adjustments	100 min (Activities 5.1–5.3)
6	Test and Evaluation	B (Being Curious), C (Connecting), D (Daring), E (Experimenting)	Design testing criteria and scoring rubrics; test lanterns at 4 stations (strength, weather, light, safety); analyze results and make improvements	40 min (Activities 6.1–6.3)
7	Socialization and Completion	A (Agency), B (Being Curious), C (Connecting), D (Daring), E (Experimenting)	Prepare presentations and posters; host a lantern exhibition with peer and visitor feedback; reflect on learning and plan future improvements	40 min (Activities 7.1–7.3)

3.2.1. How the Framework Integrates STEM Inquiry with Creativity

The framework ensures that every stage of STEM inquiry simultaneously engages multiple creativity components. Stage 1 (Identification of Social Issues) activates Agency (A) and Being Curious (B) by immersing students in the cultural context of Lanna lanterns, where they view real lanterns, hear stories from craftsmen, and identify real-world problems such as structural fragility, fire risk from candles, waste from damaged lanterns, and the loss of local identity. Through group discussion and democratic voting, students take ownership of the problem they will address.

Stage 2 (Identification of Potential Solutions) brings in Connecting (C) and Daring (D) as students analyze their available resources using the “5 Capitals” framework and systematically plan their design through 5W1H questioning. Drafting initial designs and presenting them to peers requires students to dare to propose unconventional ideas and connect knowledge from different sources.

Stage 3 (Need for Knowledge) is the core knowledge-building phase where Experimenting (E) takes center stage alongside Being Curious (B) and Connecting (C). Three hands-on activities teach essential STEM content: a light transmission experiment where students test various materials with flashlights (Science), structural strength testing where students build and load geometric frames (Engineering), and measurement and calculation of materials needed (Mathematics). Students directly investigate, discover, and connect findings to their design needs.

Stage 4 (Decision-Making) engages Connecting (C) and Daring (D) as students apply knowledge gained in Stage 3 to evaluate their designs using a structured pros-and-cons analysis covering shape, materials, strength, lighting, safety, and aesthetics. Students revise their designs based on evidence, demonstrating willingness to change initial ideas when data suggests improvements.

Stage 5 (Development of Prototype) is the longest phase (100 minutes) and activates all five creativity components as students physically construct their lanterns. Agency (A) is evident in students independently managing their work roles and schedules. Experimenting (E) and Daring (D) are engaged as students encounter unexpected construction challenges and must adapt. Students integrate their science knowledge of light, engineering knowledge of structure, and mathematical calculations into a single tangible product.

Stage 6 (Test and Evaluation) brings Experimenting (E) and Connecting (C) to the forefront. Students design their own testing procedures and scoring rubrics, then evaluate lanterns at four testing stations: structural strength, weather resistance, light quality, and safety. Cross-group evaluation promotes fairness and exposes students to different perspectives. Results drive a final round of evidence-based improvements.

Stage 7 (Socialization and Completion) engages all five components as students present their work in a mini-exhibition. Students prepare posters summarizing their entire process, demonstrate their lanterns, receive feedback from peers and visitors, and write individual reflections on what they learned and what they would change. This stage connects the product back to the community and cultural context, reinforcing the social relevance of the activity.

In summary, the seven stages demonstrate a deliberate progression in how creativity is integrated with STEM inquiry. The early stages (Stages 1–2) emphasize Agency and Being Curious as students identify problems and explore possibilities. The middle stages (Stages 3–5) shift toward Connecting, Daring, and Experimenting as students acquire knowledge, make evidence-based decisions, and physically construct their designs. The later stages (Stages 6–7) bring all five creativity components together as students test, evaluate, present, and reflect. This progressive structure ensures that creativity is not introduced as an isolated activity but is systematically woven into every phase of the STEM inquiry process, with each stage building upon the creative capacities developed in the preceding one.

3.2.2. Coverage of the A-to-E Creativity Components Across the Framework

A key design principle of the framework is that each creativity component appears in multiple stages, ensuring sustained and varied engagement. Table 5 summarizes how each component is addressed. The activity plan documents specific behavioral indicators for every activity, drawn directly from the sub-components of the A-to-E framework. For example, Agency is observed not only in students' initial group formation (A4) but also in their independent management of construction tasks (A4), workspace organization (A5), and goal-directed planning (A3). Similarly, Experimenting manifests in diverse forms: trying new material combinations (E1), testing structural possibilities (E2), conducting systematic investigations (E3), revising designs based on evidence (E4), using materials creatively (E5), and solving problems through iterative testing (E6).

Table 5. Coverage of A-to-E Creativity Components Across the Activity Plan

Creativity component	Description	Example Indicators from Activities
A – Agency	Students show initiative, make independent choices, and act with purpose	Self-selecting groups (A4); setting goals for design (A3); independently managing workspace (A5); choosing materials freely (A4)
B – Being Curious	Students ask questions, wonder, imagine, and explore new ideas	Asking whether lanterns function practically (B1); pondering material possibilities (B2); discovering new design patterns (B5); engaging in “what if” thinking (B6)
C – Connecting	Students link ideas, see patterns, share perspectives, and combine knowledge	Linking experiment data to design needs (C1); categorizing materials by properties (C2); combining science and art in decoration (C5); seeing different viewpoints from peer feedback (C6)
D – Daring	Students take risks, persist through difficulty, learn from failure, and tolerate uncertainty	Designing non-traditional lantern shapes (D1); persisting when prototypes fail (D2); learning from test results to improve (D3); handling uncertain conditions like rain scenarios (D4)
E – Experimenting	Students try new approaches, test possibilities, investigate, and refine solutions	Trying new material combinations (E1); testing structural strength with weights (E2); conducting light transmission experiments (E3); revising designs based on data (E4); using materials creatively (E5); solving problems through testing (E6)

The framework's emphasis on extended, hands-on engagement with open-ended problems aligns with findings that creativity and adaptive thinking develop through sustained practice rather than short, answer-focused exercises (Conradty & Bogner, 2020). The 6-hour duration, spread across seven progressive stages, allows students to experience the full design cycle, including the often-overlooked stages of reflection, evaluation, and socialization that are critical for deep learning. Furthermore, the framework's design as an out-of-school activity intentionally circumvents the institutional constraints of formal classrooms, such as rigid curriculum schedules, standardized testing pressures, and limited instructional time, that research has identified as barriers to effective integrated STEM instruction (Windschitl, 2003). The non-formal setting provides the flexibility necessary for open-ended inquiry and iterative design that the formal classroom often cannot accommodate. Expert validation through a focus group of five specialists confirmed the framework's pedagogical coherence and implementation readiness. While this study provides a validated framework, it is important to acknowledge that the current research focuses on the design and expert validation phases of the DDR process. Future research should implement the framework with actual student participants to empirically assess its impact on creativity development, STEM learning outcomes, and cultural engagement. Additionally, adapting the framework to different cultural crafts and regional contexts would test its generalizability and broaden its applicability.

4. CONCLUSION

This study developed and validated an Integrated Framework that systematically aligns the 7-stage STEM inquiry model with the A-to-E Creativity Framework using Lanna lantern making as a culturally authentic vehicle for out-of-school STEM learning. The analysis confirmed that the traditional craft contains rich, genuinely embedded STEM content across all four domains, supporting research on indigenous knowledge systems as foundations for place-based education. The resulting 6-hour activity plan, comprising 20 sub-activities validated by a five-member expert panel, ensures that every STEM inquiry stage simultaneously targets specific, assessable creativity indicators, promoting the use of local identity as a meaningful context for out-of-school STEM activities. Unlike conventional STEM activities that typically rely on decontextualized problems and generic materials, this framework grounds every stage in a culturally authentic practice, enabling students to engage with STEM concepts through their own heritage rather than abstract scenarios. Theoretically, the framework advances the field by demonstrating that creativity development and structured STEM inquiry are not competing priorities but

mutually reinforcing processes when integrated within a single coherent design, consistent with evidence that sustained, hands-on engagement with open-ended problems cultivates adaptive thinking more effectively than short, answer-focused exercises. Practically, the framework provides educators with a ready-to-use tool that circumvents the institutional constraints of formal classrooms while offering a replicable methodology for extracting STEM content from traditional cultural practices adaptable to other indigenous crafts and regional contexts. The study is limited to the design and expert validation phases of the DDR process; future research should implement the framework with student participants to empirically assess its impact on creativity, STEM learning outcomes, and cultural engagement.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest

AUTHOR CONTRIBUTION

Pathompong Chummongkol: Conceptualization, methodology, data collection, writing original draft. Jiraporn Tupsai: Visualization, investigation, supervision. Chockchai Yuenyong: Reviewing and editing

DATA AVAILABILITY

All data generated or analyzed during this study are included in this published article.

DECLARATION OF GENERATIVE AI

During the preparation of this work, the author(s) used Claude AI to assist with language accuracy checking. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

ETHICS

This study was reviewed and approved by the Center for Ethics in Human Research, Khon Kaen University, under the project title "Enhancing Students' Creativity Through STEM Out-of-school Time" (Reference No. HE673163). All research procedures were conducted in accordance with the approved ethical guidelines.

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