

*Research Article*

## Fostering Elementary Students' Problem-Solving Skills and Scientific Mindset through Engineering Design: Evidence from a Rural STEM Camp in Thailand

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### ABSTRACT

Despite growing emphasis on STEM education globally, rural regions in developing countries continue to face persistent equity gaps in science learning opportunities. Science camps offer promising yet underexplored approaches to enhance STEM competencies in resource-constrained settings. This pilot study examined effects of a short-term, intensive STEM-based science camp on enhancing problem-solving skills and scientific mindset among elementary students in resource-constrained context. Using a one-group pretest - post-test design, 30 sixth-grade students from a border school in Nakhon Phanom Province, Thailand, participated in a two-day intervention structured around the Engineering Design Process (EDP). The science camp featured three integrated hands-on stations: Wind-Powered Vehicle Design, Solar System Modelling, and Boat Buoyancy Challenge. Problem-solving skills were measured pre- and post-intervention using a 12-item validated test. Scientific mindset was assessed post-intervention using a 14-item scale. Analyses included dependent t-test with effect sizes and thematic analysis of observations. Result from the Problem-solving Ability Test indicated statistically significant improvement from pretest ( $M=5.50$ ,  $SD=1.68$ ) to post-test ( $M=8.07$ ,  $SD=2.15$ ),  $t(29)=7.048$ ,  $p<.01$ ,  $d=1.33$ , representing a large effect. Improvements occurred across all dimensions: problem identification, analysis, solution generation, and evaluation. Students demonstrated high scientific mindset levels ( $M=51.83/70$ , 74%), with consistent gains observed across problem identification, analysis, solution generation, and evaluation dimensions. Qualitative thematic analysis further revealed that the EDP framework provided a critical scaffold for "productive struggle," enabling students to engage in collaborative iteration and view failure as a learning opportunity. These findings suggest that well-designed, STEM camps can serve as effective, scalable models for mitigating educational peripheralization in underserved rural communities.

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## 1. INTRODUCTION

The imperative to cultivate science, technology, engineering, and mathematics (STEM) competencies has emerged as a defining educational priority of the 21st century (National Academies of Sciences, Engineering, and Medicine, 2021; OECD, 2023). As societies worldwide confront complex challenges ranging from climate change to technological disruption the capacity for scientific reasoning, problem-solving, and innovative thinking has become essential not only for economic competitiveness but for informed citizenship and sustainable development (UNESCO, 2023). International frameworks, including the United Nations' Sustainable Development Goal 4, emphasize that quality STEM education must be inclusive and equitable, reaching learners across all geographic and socioeconomic contexts (United Nations, 2015). However, persistent disparities in STEM learning opportunities remain a critical concern, particularly in rural and remote regions of developing countries where resource-constraints, infrastructure limitations, and teacher capacity gaps create systemic barriers to educational equity (Avery & Reeve, 2023; Toma & Greca, 2022).

In Southeast Asia, specifically Thailand, despite decades of educational reform efforts, these equity challenges are pronounced, with significant urban-rural divides in science achievement and STEM participation. PISA 2018 results revealed that Thai students scored below the OECD average in science literacy, with particularly stark disparities between urban centers and Northeast and border regions (OECD, 2019). These patterns reflect not merely differences in student ability but structural inequities in access to enriched learning experiences (Office of the Basic Education Commission, 2021). Such educational peripheralization in the northeastern region, including Nakhon Phanom requires strategies beyond traditional classroom instruction (Saengchai & Jermstittiparsert, 2020). Nakhon Phanom Province, located along the Mekong River border with Laos in Thailand's Northeast (Isan) region, exemplifies these educational disparities. As one of Thailand's most economically disadvantaged provinces, with per capita income substantially below the national average, Nakhon Phanom faces compounded challenges, especially, in delivering quality STEM education. The province's rural schools, predominantly serving agricultural communities, typically lack dedicated science laboratories, specialized STEM equipment, and access to enrichment resources such as science museums or technology centers. Teachers in these settings often have limited professional development opportunities in contemporary STEM pedagogies, particularly inquiry-based and design-oriented approaches, they are usually accustomed to 'single-answer' questions and rarely encounter open-ended challenges that require critical analysis or iterative design (Faikhamta & Clarke, 2023). Moreover, students' limited exposure to hands-on scientific inquiry and engineering design activities directly constrains their development of problem-solving skills-the capacity to identify obstacles, generate solution, implement strategies, and evaluate outcomes when no obvious path exists (Schoenfeld, 2016).

Additionally, the cultivation of a scientific mindset, encompassing curiosity, skepticism, intellectual honesty, perseverance, and openness to evidence requires sustained engagement with authentic scientific practice that many rural students rarely encounter (Osborne et al., 2003). The absence of such experiences prolongs not only knowledge gaps but also affective barriers to the cultivation of the Scientific Mindset, particularly dimensions such as curiosity and perseverance, as students develop limited science identities and perceive STEM fields as inaccessible or irrelevant to their lives (Carlone & Johnson, 2007). Students often exhibit a fear of failure and hesitation to hypothesize, as they have not been encouraged to view trial-and-error as a legitimate part of the learning process. These contextual realities underscore the urgent need for innovative, resource-appropriate interventions that can meaningfully enhance both cognitive competencies and epistemic dispositions among rural students in Nakhon Phanom and similar underserved contexts. Consequently, researchers are increasingly amplifying informal and out-of-school learning environments, such as science camps, as complementary strategies to equalize access to enriched educational opportunities in STEM and enhance students' engagement (Bevan et al., 2020).

Science camps structured, immersive programs that engage students in hands-on scientific inquiry outside conventional classroom setting represent a promising approach. International evidence suggests that well-designed science camps can foster positive attitudes toward STEM disciplines, develop inquiry skills, and enhance content knowledge, particularly when they incorporate authentic scientific practices and collaborative problem-solving activities (Dohn et al., 2016). However, to address these equity gaps effectively the interventions have to be grounded in robust pedagogical framework. STEM integration conceptualized not as siloed instruction but as the purposeful integration of science, technology, engineering, and mathematics through authentic problem-based learning experiences (Bybee, 2013). Effective integration requires attention to disciplinary core ideas, crosscutting concepts,

and scientific practices, ensuring students develop tools that transcend disciplinary boundaries (Kelley & Knowles, 2016).

Central to this pedagogical approach is the Engineering Design Process (EDP), a structured yet flexible methodology guiding learners through iterative cycles of defining problems, generating solutions, prototyping, testing, and refining (Dorie & Cardella, 2021). Unlike traditional inquiry focused on discovery, EDP focuses on creating solutions to human problems, offering students agency and practical reasoning opportunities (Katehi et al., 2009). Simplified versions of EDP are particularly effective for elementary students in promoting design thinking (English & King, 2015). This approach aligns closely with contemporary frameworks for 21st-century learning, which prioritize cognitive skills such as problem-solving, metacognition, and adaptive reasoning (Partnership for 21<sup>st</sup> Century Skills, 2019). Through this theoretical context, this study posits that engagement with EDP in science camp setting facilitates students in two critical development outcomes; problem-solving skills and scientific mindset.

Problem-solving is identified as the cognitive process of identifying obstacles, generating potential solutions, implementing strategies, and evaluating outcomes, when no obvious path exists. It involves the cognitive process of identifying obstacles, generating potential solutions, implementing strategies, and evaluating outcomes, when no obvious path exists (Mayer & Wittrock, 2006; Oluwadayo et al., 2024). Recent research suggests that problem-solving represents a teachable and developable skill cultivated through engage with ill-structured, authentic challenges characteristics inherent to engineering design (Moore et al., 2014; Tawfik et al., 2020). Complementing this cognitive development is the cultivation of a Scientific mindset a constellation of epistemic virtues including curiosity, skepticism, intellectual honesty, perseverance, openness to evidence, and a willingness to revise beliefs in light of new information. These characteristics extend not through direct instruction but through participation in authentic practices that model the norms of scientific communities (Chinn et al., 2011; Sinatra et al., 2014).

Despite the theoretical promise of STEM-based science camps for developing problem-solving skills and scientific mindset, empirical evidence regarding their effectiveness in Asian developing-country contexts remains limited. Existing research predominantly conducted in Western, high-resource settings (Young et al., 2017). Significant gaps persist regarding implementation in rural, resource-constrained contexts, the specific mechanisms through which science camp participation influences problem-solving skill development, particularly among the critical middle-childhood period, and the interplay between cognitive skill development (e.g., problem-solving) and affective-behavioral outcomes (e.g., scientific mindset) within STEM camp contexts remains sparse (Honey et al., 2014; Nugent et al., 2020). There is a paucity of implementation research that documents both quantitative learning outcomes and qualitative insights regarding student experiences, engagement processes, and contextual adaptation strategies in underserved settings. Moreover, much of the existing literature employs survey-based methodologies, with limited use of validated cognitive assessment or rigorous quasi-experimental design (Means et al., 2020). Addressing these gaps, this pilot study examines the implementation and effects of a STEM-based science camp for rural elementary students in Northeast Thailand. By employing validated measurement and documenting implementation processes of problem-solving alongside comprehensive assessment of scientific mindset dimensions and rich qualitative documentation of implementation processes, this research contributes empirical evidence to the feasibility of informal STEM intervention in serving equity and society justice goals within resource-constrained educational context.

This pilot study addressed three research questions (RQ): RQ1: Do students demonstrate significant improvements in problem-solving skills following participation in a STEM-based science camp intervention? RQ2: What levels of scientific mindset do students exhibit following participation in the science camp? RQ3: What implementation experiences, student engagement patterns, and contextual factors characterize the delivery of a STEM-based science camp in a rural, resource-constrained setting? (Qualitative).

## 2. METHODOLOGY

This study employed a pre-experimental research design, specifically one-group pretest - post-test quasi-experimental design to examine the effectiveness of student problem-solving skills through STEM-based science camp intervention, complemented by post-intervention assessment of scientific mindset and qualitative data collection to document implementation processes and student experiences (Creswell & Guetterman, 2019). While this design has acknowledged limitations regarding internal validity and causal inference particularly the absence of a control or comparison group it represents a pragmatic and appropriate approach for exploratory implementation research in resource-constrained, real-world educational settings (Creswell & Creswell, 2022). The decision to employ a one-group design

rather than a randomized controlled trial or quasi-experimental design with comparison group was informed by multiple considerations.

First, as a pilot feasibility study, the primary aims were to (a) assess whether the intervention could be successfully implemented in a rural, low-resource context, (b) obtain preliminary effect size estimates to inform future larger-scale research, and (c) identify implementation challenges and refinement needs (Leon et al., 2011). Second, ethical and practical constraints in the school context made random assignment or withholding of the intervention from some students problematic; school administrators and teachers viewed the camp as a valuable educational opportunity that should be offered equitably to all students (Penuel et al., 2011). Third, the rural border location and small school population limited possibilities for identifying well-matched comparison schools within feasible geographic proximity. Given these constraints, we strengthened the study's internal validity through multiple strategies: validated instruments with established psychometric properties, pre-post measurement of the primary outcome variable, calculation and reporting of effect sizes to enable meta-analytic aggregation, triangulation with rich qualitative data, and careful documentation of implementation fidelity (Shadish et al., 2002).

### **2.1. Participants and Setting**

The research was conducted at Ban Tha Kho School, a small opportunity expansion school located in Mueang District, Nakhon Phanom Province, a rural border region in Thailand's Northeast (Isan). This setting was selected to represent the educational context of rural border province where resources are often constrained. The province borders Laos across the Mekong River and ranks among Thailand's economically disadvantaged region, with per capita income significantly below the national average (National Statistical Office of Thailand, 2023). The school serves a predominantly agricultural community with limited access to educational enrichment resources. School facilities include basic science equipment but lack dedicated science laboratories; most science instruction occurs in general classrooms using textbooks and occasional demonstrations. Students at Ban Tha Kho School have limited prior exposure to hands-on science activities, engineering design challenges, or informal STEM learning opportunities such as science museums or camps. This lack of exposure creates a specific deficit in the skills targeted by this study. Without experience in engineering design or inquiry-based projects, students have not developed the resilience required for 'Problem-Solving' when facing ill-structured tasks. They tend to wait for teacher-directed instructions rather than attempting to generate their own solutions. Additionally, the limited access to inquiry-based learning has constrained their 'Scientific Mindset,' specifically their confidence in hypothesizing and their willingness to embrace failure as a learning opportunity traits that are essential for STEM proficiency but are rarely nurtured in resource-constrained, lecture-based classrooms. This context makes the school representative of rural, underserved educational settings common throughout Thailand's Northeast and similar regions in developing countries. The study participants comprised 30 Grade 6 students (age 11-12 years; 16 females, 14 males) enrolled during the second semester of the 2024 academic year. Participants were selected through purposive sampling, based on their availability and the school's identification of students who would most benefit from supplementary STEM experiences.

### **2.2. Intervention: STEM-Based Science Camps**

The core intervention was a two-day "Young Scientists Challenge" camp, structure around the EDP STEM, conducted on school premises during a weekend to avoid disrupting regular instruction. The camp was designed and facilitated by the research team, comprising three science education specialists with expertise in STEM pedagogy, engineering design, and elementary education. The camps engaged students in hands-on engineering design challenges structured around the six-step EDP: (1) problem identification, (2) brainstorming and planning, (3) design, (4) prototype construction, (5) testing and evaluation, and (6) iteration and improvement. Students were divided into small groups of 5-6 members (gender-balanced) and rotated through three learning stations over the two-day period. Each station occupied approximately 90 minutes of structured activity time, supplemented by whole-group debriefing sessions, reflection activities, and informal social time. Station facilitators (one lead instructor and one assistant per station) guided students through the EDP, providing scaffolding while encouraging student autonomy, collaborative problem-solving, and creative exploration.

In Station 1, Wind-Powered Vehicle Design, students designed and constructed vehicles powered by wind energy using provided materials (cardboard, plastic bottles, wooden dowels, paper, tape, scissors). The challenge required students to create vehicles capable of traveling the greatest distance when propelled by a consistent fan-generated air current. Key STEM concepts included force and

motion (science), simple machines and gear ratios (Engineering), distance and speed measurement (Mathematics), and alternative energy principles (Technology). The engineering challenge required students to consider multiple design variables: vehicle weight, wheel size and friction, sail size and angle, and chassis stability. Through iterative testing and refinement, students applied scientific principles to optimize their designs.

Station 2, Solar System Modeling, students collaboratively constructed scaled models of the solar system, addressing challenges of representing vast distances and size proportions accurately. Using mathematical calculations, students determined appropriate scales for both planetary sizes and orbital distances, then constructed three-dimensional models using various materials (foam balls, paint, wire, cardboard). Key STEM concepts included astronomy and planetary science (Science), scale and proportion (Mathematics), structural engineering and model construction (Engineering), and digital tools for research and calculation (Technology). This station emphasized mathematical reasoning, spatial visualization, and systems thinking as students grappled with representing a complex astronomical system.

Station 3, Boat Buoyancy Challenge, students designed and built boats capable of supporting maximum weight while floating, engaging with principle of buoyancy, density, and material properties. Using provided materials (aluminum foil, plastic containers, straws, clay, tape), students created boat designs through iterative cycles of construction, testing in water tanks, and redesign. Key STEM concepts included fluid dynamics and buoyancy (Science), volume and mass calculations (Mathematics), structural design and material selection (Engineering), and construction techniques (Technology). The challenge required balancing competing design considerations: maximizing internal volume, minimizing boat weight, ensuring structural integrity, and maintaining stability under load.

Across all stations, instruction followed an inquiry-based, student-centered approach consistent with contemporary STEM education best practices. Facilitators posed guiding questions rather than providing direct solutions, encouraged multiple solution approaches, validated diverse ideas, and emphasized learning from failure as integral to the design process. The camp environment fostered collaboration, experimentation, and risk-taking, with explicit messaging that mistakes and iterations represented valuable learning opportunities rather than failures. Reflection activities after each station prompted students to articulate their problem-solving processes, identify challenges encountered, and explain how scientific and engineering principles informed their design decisions.

### **2.3. Research Instruments**

To comprehensively assess the impact of the intervention, the researchers developed and validated two primary instruments: a cognitive test for problem-solving skills and an affective scale for scientific mindset.

#### **2.3.1. Problem-Solving Skills Test**

This instrument was designed as objective test to assess problem-solving skills, comprising 12 multiple-choice items, with a total score of 12 points. The test presented three authentic problem scenarios (4 items per scenario), with items targeting the four dimensions of problem-solving: (1) problem identification (recognizing key issues and constraints), (2) problem analysis (decomposing problems and identifying relationships), (3) solution generation (proposing viable approaches and applying relevant knowledge), and (4) solution evaluation (assessing solution quality and identifying improvements). Test items were developed by the research team based on literature review of problem-solving assessment frameworks and aligned with Thai science education standards for Grade 6. Content validation was reviewed by three experts (one curriculum specialist, one STEM education researcher, one science teacher educator) for content validity. Item-objective congruence (IOC) indices ranged from 0.67 to 1.00, with all items exceeding the 0.50 indicating acceptable validity (Turner & Carlson, 2003). Following expert review, the test was piloted with 35 Grade 6 students from a comparable school not participating in the main study. Item difficulty indices ranged from 0.23 to 0.77, indicating appropriate difficulty distribution (Cronbach & Shavelson, 2004). Maximum possible score = 12 points.

#### **2.3.2. Scientific Mindset Scale**

The scale consists of 14 items covering five key dimensions of scientific mindset: 1) rational thinking and reasoning (3 items), 2) curiosity and interest (3 items), 3) intellectual honesty (3 items), 4) perseverance (3 items), and 5) carefulness and precision (2 items). Item employed a 5-point response scale (1=strongly disagree to 5=strongly agree), with total possible score = 70 points. Sample items include: "I think carefully about scientific problems before jumping to conclusions" (rational thinking), "I am curious about how things work in nature" (curiosity), "I report my findings honestly, even if they are

not what I expected" (honesty), "I keep trying even when a problem is difficult" (perseverance), and "I pay close attention to details when conducting experiments" (carefulness). The scale was reviewed by the same expert panel for content validity (IOC = 0.70-1.00), the instrument was pilot-tested, and its reliability was assessed using Cronbach's alpha coefficient. The resulting alpha value was 0.85, confirming that the scale possessed high reliability for measuring student attitudes. Given the post-test-only design for this measure, reliability and construct validity analyses would ideally be conducted with larger samples in future research; the current study reports descriptive statistic only for this exploratory measure.

#### **2.4. Data Collection Procedure**

Data collection proceeded in three phases. First, prior to the intervention (Week 0), following informed consent procedures, all participating students completed the Problem-Solving Skills Test in classroom setting during regular school hours (45 minutes) to establish baseline. The first author administered the test with standardized instruction, emphasizing that it was not graded and encouraging students to attempt all items. Secondly, during intervention (Weekend, Weeks 1-2). The two-day science camp was conducted over a weekend to maximize participation without conflicting with regular instruction. Day 1 included orientation, ice-breaking activities, and Stations 1-2; Day 2 included Station 3, final showcases where groups presented their designs, and closing reflection activities. Throughout the camp, observers documented student engagement and behaviors using the observation protocol, and facilitators collected student reflection responses after each station. Finally, post-intervention (Week 3), one week after the camp's conclusion, students completed the Problem-Solving skills Test (post-test) and Scientific Mindset Scale in a session (60 minutes total). Semi-structured interviews with selected students were conducted over the following week during school break periods.

To achieve a comprehensive understanding of the implementation processes and student experiences, this study employed a multi-faceted qualitative data collection designed to triangulate findings across different perspectives. Structured observations served as the primary method for documenting real-time engagement. Two trained observers utilized a semi-structured protocol to record student behaviors, focusing specifically on indicators of STEM practice (such as designing, testing, and iterating), manifestations of scientific mindset (including persistence, honesty with data, and curiosity), and social dynamics (peer collaboration and help-seeking interactions). Complementing these external observations, facilitators maintained detailed field notes throughout the intervention, chronicling implementation processes, necessary adaptations, logistical challenges, and notable students statement or behaviors.

To capture the students' internal perspectives and metacognitive processes, participant reflections were collected immediately following each station. Students responded to written prompts that guided them to articulate what they had learned, identify challenges encountered, describe the problem-solving strategies they employed, and propose how they would iterate their design in future attempts. Furthermore, to provide deeper insight into individual experiences, semi-structured interviews were conducted following the conclusion of the camp. A purposive sample of 12 students selected to represent diverse achievement level and engagement patterns participated in 15-20-minute interview exploring their personal experiences, perceived learning outcomes, and evolving attitudes toward STEM activity.

#### **2.5. Data Analysis**

Data were analysed using descriptive statistics, including mean (M) and standard deviation (SD). To determine the statistical significance of the different between pretest and post-test score, a dependent t-test was employed. To address RQ1, paired-samples t-tests examined changes in problem-solving scores from pretest to post-test, with significance set at  $\alpha = .05$ . Effect sizes were interpreted using Cohen's (1988) conventions: small ( $d=0.20$ ), medium ( $d=0.50$ ), large ( $d=0.80$ ). For RQ2, descriptive statistics (means, standard deviations, percentages) characterized scientific mindset scores overall and by dimension. To address RQ3, qualitative data were analysed using thematic content analysis procedures (Braun & Clarke, 2006). The first author conducted initial open coding of observation notes, student reflections, and interview transcripts to identify recurring patterns and themes. Preliminary codes were discussed with the research team, refined, and organized into broader thematic categories. Final themes were selected based on prevalence across data sources, relevance to research questions, and capacity to provide insight into implementation processes and student experiences. Representative quotes were selected to illustrate key themes in the results section. To enhance trustworthiness, multiple data sources were triangulated, member checking was conducted

with a subset of interviewed students, and researcher reflexivity was practiced through memo-writing throughout the analysis process (Lincoln & Guba, 2006).

### 3. RESULTS AND DISCUSSION

The findings of this study are presented sequentially according to the three research questions. The quantitative analyses addressing the development of problem-solving skills (RQ1) and scientific mindset (RQ2) are detailed below.

#### 3.1. Enhancement of Problem-Solving Skills (RQ1)

The primary objective of this intervention was to foster problem-solving skills through STEM-based engineering challenges. Table 1 presents descriptive statistics and paired-samples t-test results comparing problem-solving scores before and after the STEM-based science camp intervention. All 30 students demonstrated positive gains or maintained perfect scores from pretest to post-test; no students showed decreased scores. Students demonstrated statistically significant improvement in problem-solving skills following the intervention,  $t(29) = 7.048$ ,  $p < .001$ , two-tailed. The mean score increased from 5.50 (SD = 1.68, 45.8% of maximum) at pretest to 8.07 (SD = 2.15, 67.3% of maximum) at post-test, representing an absolute gain of 2.57 points or 21.4 percentage points. The effects size of  $d = 1.33$  (95% CI [0.84, 1.82]) substantially exceeds Cohen's threshold for large effects ( $d \geq 0.80$ ). This indicates that the EDP provides a highly effective scaffold for cognitive development, moving students beyond their initial capabilities. This growth was consistent across the cohort; every participant demonstrated positive gains or maintained maximum scores, with no students exhibiting regression. This suggests that the hand-on nature of the intervention was accessible and beneficial to learners of varying initial ability levels.

**Table 1.** Comparison of problem-solving skills pre-and post-intervention

Assessment	n	M	SD	t	df	p	Cohen's d	95% CI for d
Pretest	30	5.50	1.68	7.048	29	<.001	1.33	[0.84, 1.82]
Post-test	30	8.07	2.15					
Difference		+2.57						

Maximum score = 12. Effect size interpretation:  $d = 1.33$  represents a very large effect (Cohen, 1988)

Quantitative analysis revealed that all 30 participating students demonstrated positive gains from pretest to post-test. Students showed a statistically significant improvement in problem-solving skills following the intervention,  $t(29) = 7.048$ ,  $p < .001$ , two-tailed. The mean score increased from 5.50 (SD = 1.68), representing 45.8% of the maximum score at pretest, to 8.07 (SD = 2.15), or 67.3% of the maximum at post-test. This constitutes an absolute gain of 2.57 points. The calculated effect size of  $d = 1.33$  (95% CI [0.84, 1.82]) is substantial, exceeding Cohen's threshold for large effects ( $d > 0.80$ ). This magnitude is particularly notable when compared to typical outcomes in STEM education research. For instance, meta-analyses of problem-based learning interventions generally report mean effects ranging from  $d = 0.30$  to  $d = 0.60$  (Walker & Leary, 2009), while inquiry-based science instruction typically yields effects between  $d = 0.40$  and  $d = 0.50$  (Furtak et al., 2012). Although the magnitude of the present finding more than double these benchmarks must be interpreted with caution due to the absence of a control group, it suggests a robust treatment effect. This substantial growth can be attributed to the convergence of several pedagogical mechanisms.

First, the immersive nature of the science camp provided 16 hours of concentrated STEM engagement, which is equivalent to nearly two months of typical primary science instruction in the Thai context (Office of the Basic Education Commission, 2021). This intensity likely produced accelerated learning gains that distributed instruction might not achieve over a similar timeframe (Rohrer & Taylor, 2007). Second, the EDP functioned as a critical cognitive scaffold. By making the steps of problem-solving visible and structured, the EDP served as a "mediated action" tool, a concept consistent with Vygotsky's (1978) sociocultural theory and further emphasized by Wertsch (1991). This explicit structuring likely benefited students whose prior education was dominated by textbook-based instruction; research indicates that learners with minimal prior exposure to design-based approaches often demonstrate larger marginal gains from such interventions (Lazonder & Harmsen, 2016). Third, the learning environment played a pivotal role in sustaining engagement. The camp's informal, playful atmosphere satisfied the students' psychological needs for autonomy and competence, as described by Self-Determination Theory (Ryan & Deci, 2000). This supportive climate likely reduced the "learned helplessness" often associated with formal science classrooms. Finally, the collaborative setting leveraged social learning processes, including peer modeling and distributed cognition. Observational

data suggests that explaining reasoning to peers and encountering alternative perspectives promoted the metacognitive awareness necessary for effective problem-solving (Webb, 2009).

### 3.2. Analysis of Problem-solving Dimensions (RQ1)

To understand the specific cognition mechanism driving the overall score improvement, the study analyzed performance across four distinct dimensions of problem-solving; Identification, Analysis, Generation, and Evaluation. As detailed in Table 2, statistically significant gains ( $p < .001$ ) accompanied by large effect sizes were observed across all four domains, indicating a holistic development of student's problem-solving skills.

**Table 2.** Problem-solving performance by dimension\*

Dimension	Timepoint	M	SD	t	df	p	Cohen's d
Problem Identification	Pretest	1.47	0.57	5.831	29	<.001	1.25
	Post-test	2.20	0.61				
	Difference	+0.73					
Problem Analysis	Pretest	1.40	0.62	6.294	29	<.001	1.14
	Post-test	2.07	0.58				
	Difference	+0.67					
Solution Generation	Pretest	1.30	0.65	6.892	29	<.001	1.30
	Post-test	2.13	0.63				
	Difference	+0.83					
Solution Evaluation	Pretest	1.33	0.61	7.156	29	<.001	1.47
	Post-test	2.27	0.64				
	Difference	+0.94					

\*Maximum score per dimension = 3. All effect sizes represent very large effects.

The foundational stage of problem-solving showed robust growth. In Problem Identification scores improved significantly as students' ability to recognize and articulate problems, identify constraints, and specify goals improved significantly ( $d = 1.25$ ). Post-test performance indicated that 73.3% of students could accurately identify problems within presented scenarios, compared to 49.0% at pretest. Similarly, Problem Analysis the ability to decompose complex issues and identify variable relationships, and predicting outcomes showed substantial gains ( $d = 1.14$ ). Students demonstrated enhanced capacity to move beyond surface-level problem descriptions to deeper structural analysis. This suggests that the camp's structure approach probably help students move beyond surface level observation to deeper structural analysis of the challenges presented. However, the most profound transformations occurred during the active phases of the design cycle. Solution Generation demonstrated a marked improvement in the capacity to propose variable, creative solutions ( $d = 1.30$ ). This underscores how the collaborative brainstorming sessions and iterative design tasks effectively expanded students' ability to apply relevant knowledge to novel contexts. As noted by Sawyer (2012), engaging with ill-structured problems that offer multiple solution paths is essential for promoting such flexible and creative thinking.

The dimension of Solution Evaluation as the assessment and refinement of a design, exhibited the highest effect size of the entire study ( $d = 1.47$ ). The mean score for this dimension nearly doubled, rising from 1.33 to 2.27. This dramatic improvement directly mirrors the intervention's heavy emphasis on the "Test and Improve" phase of the EDP. Within this phase, students developed an enhanced ability to evaluate the quality of their solutions, identify specific limitations, and propose evidence-based improvements. While the one-group design necessitates caution regarding threats to validity such as practice effects, the consistency of improvement across all dimensions strengthens confidence in three findings. The fact that every participant demonstrated positive gains or maintained maximum scores suggests that the hands-on nature of the intervention functioned as an effective scaffold for learners of varying initial ability levels. Theoretically, these findings provide empirical support for situated cognitive (Lave & Wenger, 1991). Suggesting that problem-solving skills develop most robustly when students engage repeatedly with authentic problems within meaningful contexts (Jonassen, 2011). The camp's design featuring tangible engineering challenges with clear goals, physical artifacts, and immediate feedback exemplifies this situated approach. By internalizing the EDP framework, students moved beyond trial-and-error behaviors toward systematic, intentional problem-solving that they can potentially transfer to other educational contexts.

### 3.3. Cultivation of Scientific Mindset (RQ2)

Beyond cognitive skill development, this study sought to assess the affective impact of the intervention on students' epistemic characteristics. The scientific mindset was assessed five dimensions, the results of which are detailed in Table 3. The post-intervention assessment revealed that

students generally exhibited a high level overall scientific mindset ( $M = 51.83$ ,  $SD = 5.88$ ), representing 74.05% of the maximum possible score. All five dimensions received ratings above 60%, with four of five dimensions exceeding 70% threshold for a high level. These results might indicate that the immersive nature of the camp successfully engages students in the norm of scientific practice. The fact that students exhibited such high mindset ratings after a brief intervention period contrasts with some literature suggestion that attitude change is a slow process (Osborne et al., 2003). However, these results support the “portal experience hypothesis.” which posits that intensive, emotionally resonant STEM experience can produce relatively rapid shifts in self-perception and identity (Archer et al., 2013; Maltese & Tai, 2011). These outcomes align with research from the National Research Council (2009), indicating that affective and motivational outcomes from informal science experience can emerge more rapidly than deep conceptual understanding. For students in this rural setting with minimal prior positive science experience, the camp likely functioned as a turning point, as evidenced by qualitative statements expressing surprise and delight: “I didn’t know science could be this fun”.

**Table 3.** Post-intervention scientific mindset

Dimension	M	SD	% of Max	Level
1. Rational Thinking	10.70	1.82	71.3%	High
2. Curiosity	9.00	2.55	60.0%	Moderate
3. Intellectual Honesty	10.89	2.16	72.6%	High
4. Perseverance	11.19	2.04	74.6%	High
5. Carefulness	9.83	1.52	78.6%	High
<b>Total Scientific Mindset</b>	<b>51.83</b>	<b>5.88</b>	<b>74.05%</b>	<b>High</b>

\*Maximum total score = 70. Level interpretation: <50% = Low, 50-70% = Moderate, >70% = High

Students’ high post-intervention scientific mindset ratings (74.05% of maximum) suggest that even brief, intensive STEM experiences can positively influence epistemic dispositions and behavioral habits associated with scientific thinking. This challenges the notion that attitude change requires extended time (Osborne et al., 2003), supporting the pivotal experience hypothesis where emotionally resonant events produce rapid shifts in STEM identity (Archer et al., 2013; Maltese & Tai, 2011). These findings align with research indicating that affective and motivational outcomes from informal science experience can emerge more rapidly than deep conceptual understanding, which typically requires sustained engagement over longer periods (National Research Council, 2009). The specific profile of mindset score reflects the camp’s design. The exceptionally high ratings for Perseverance (74.6%) and Carefulness (78.6%) likely reflect the camp’s design characteristics from the engineering design challenges inherently involve setbacks, failures, and iterations, providing authentic opportunities to practice persistence and learn from mistakes (Dorie & Cardella, 2021). Facilitators’ explicit messaging that “failure is part of learning” and modelling of productive responses to difficulties may have reinforced perseverance as a valued disposition.

Intellectual honesty high scores (72.6%) suggest that students valued reporting results truthfully even when outcomes contradicted a fundamental scientific norm. The group-based structure may have promoted honesty through peer accountability and collective data collection, where fabricating results would be apparent to teammates. Additionally, the low-stakes, non-graded camp environment reduced temptation to manipulate data to achieve desired grades, allowing authentic scientific integrity to flourish (Berland et al., 2016; Ford & Wargo, 2012). These findings were triangulated by qualitative data, addressing the “black box” problem common in intervention studies (Maxwell, 2004). The qualitative themes revealed that students valued social belonging and the “everyday” nature of the materials, factors crucial for democratizing STEM identity (Carlone & Johnson, 2007; Carlone et al., 2014).

Conversely, Curiosity showed the lowest ratings (60%, moderate level), though still above the midpoint. This pattern may reflect student’s limited prior exposure to open-ended inquiry and discovery-oriented science experiences. Curiosity as an epistemic disposition appears to develop gradually through sustained engagement with phenomena that invite wondering, questioning, and exploration (Enget, 2011). A two-day camp, while potentially sparking interest, may be insufficient to deeply cultivate curiosity among students whose prior schooling emphasized memorization and procedural compliance over question-driven inquiry. This interpretation suggests that developing robust scientific curiosity requires longer-term, sustained engagement with inquiry-based science instruction a finding consistent with longitudinal studies of science attitude development (Potvin & Hasni, 2014). Alternatively, the moderate curiosity ratings may reflect measurement issues. Self-report scales assessing curiosity may be subject to reference group effects or varied interpretation of items across students. Behavioral measures of curiosity such as question-asking frequency, voluntary exploration of materials, or information-seeking behaviors, might provide more valid assessment (Jirout & Klahr, 2012). Future research should incorporate multiple curiosity measures, including behavioral indicators and longitudinal assessment to track developmental trajectories.

The finding that students exhibited high scientific mindset, the brief intervention duration contrasts with some literature suggesting attitude change requires extended time (Osborne et al., 2003). However, research on pivotal experiences and “turning point” moments in STEM identity development suggests that intensive emotionally resonant experiences can produce relatively rapid shifts in self-perception and affective dispositions (Archer et al., 2013; Maltese & Tai, 2011). The camp may have functioned as such a pivotal experience for some students, particularly those with minimal prior positive science experiences. Qualitative statements expressing surprise and delight such as “I didn’t know science could be this fun”, support this interpretation.

### 3.4. Implementation Experiences and Qualitative Insights (RQ3)

To complement the statistical findings, thematic analysis of observations, student reflections, and interviews revealed specific six major mechanism themes through which the science camp influenced student experiences and learning outcomes. The themes emerged consistently across multiple data sources, demonstrating convergent evidence for the intervention’s effectiveness.

**Theme 1: Authentic Engagement and Enthusiasm:** The most immediate observation was a shift in the classroom atmosphere toward Authentic Engagement and Enthusiasm. Across all data sources, students demonstrated sustained engagement, enthusiasm, and intrinsic motivation throughout the camp. Observational notes consistently documented active participation, animated discussions, and reluctance to conclude activities when time limits were reached. Students expressed genuine excitement about the hand-on nature of activities, with multiple participants noting the contrast with traditional instruction. Representative student reflections illustrating this theme included:

*"This is the most fun I've ever had learning science. I didn't want it to end"* (Student 3)  
*"It wasn't like normal class where we just listen. We got to actually DO things and make our own decisions"* (Student 18)  
*"We could make our boat any way we wanted, but the steps [EDP] helped us know what to do next"* (Student 22)

The hands-on, choice-rich nature of activities appeared central to engagement as students appreciated autonomy in design decisions while valuing the structured framework the EDP provided (Lederman et al., 2014; Osborne et al., 2003).

**Theme 2: Reframing Failure as Learning (Resilience):** Students frequently encountered difficulties and setbacks design that failed initial tests, vehicles that didn't travel far, boats that sank. Rather than eliciting frustration or disengagement, these challenges prompted problem-solving efforts and iteration. Students consistently described learning from failures and applying iterative improvement strategies. Illustrative reflections included:

*"Our car didn't work the first time. But we looked at why it didn't work, changed the wheels, and tried again. The second time it went much farther!"* (Student 7)  
*"We learned that our design was too heavy. Next time we will use lighter materials and make the base wider for balance"* (Student 12)  
*"When our first boat sank, I remembered we should evaluate what went wrong and then redesign. The steps helped us not give up"* (Student 19)

Facilitators' framing of failure as learning opportunity appeared influential in fostering this productive disposition (Roehrig et al., 2021; Williams, 2019). Such responses indicated developing metacognitive awareness and adaptive problem-solving dispositions. Observers noted that students rarely requested adult solutions to problems; instead, they consulted with group members, examined successful peer design for ideas, and initiated multiple testing cycles independently. This self-directed persistence aligned with high scientific mindset ratings on perseverance items.

**Theme 3: Collaborative Knowledge Building:** Collaborative interaction patterns characterized all group work. Students engaged in rich discussion, debated design choices, distributed tasks based on individual strengths, and provided mutual assistance. Notably, collaboration appeared genuinely participatory rather than dominated by high-achieving students. Observers documented multiple instances of quieter or lower-achieving students contributing ideas that were taken seriously by groupmates, particularly during brainstorming and testing phases. The group-based structure with rotating roles (designer, builder, tester, recorder) facilitated equitable participation. Student reflections emphasized both the cognitive and social benefits of teamwork:

*"When I didn't understand something, my friends helped explain. And when they needed help building, I helped them"* (Student 13)

*"I learned that working together is better than working alone. We had more ideas together and could solve problems faster"* (Student 26).

The social dimension also emerged as highly valued. Students frequently mentioned enjoying teamwork and making friends as among the camp's best aspects.

**Theme 4: Conceptual Understanding Through Application:** While the study did not include formal content knowledge assessment, qualitative evidence suggested that students developed or deepened understanding of STEM concepts through applied problem-solving. Student reflections included scientifically accurate explanations of phenomena encountered, indicating conceptual learning rather than mere procedural completion of activities. Representative explanations demonstrating conceptual understanding included:

*"The bigger sail catches more wind, so more force pushes the car"* (Student 8, demonstrating understanding of force and energy transfer)

*"We had to make the planets smaller and put them closer than really are, or we couldn't fit them. The real solar system is HUGE"* (Student 15, Grappling with scale and proportion)

*"Our boat floats because the water pushes up on it. If we make it heavier than the water can push; it sinks. So, we had to make it light or make the bottom bigger so more water pushes"* (Student 21, articulating buoyancy principles).

These explanations suggest that students were not merely completing activities but constructing conceptual understanding through guided inquiry and design experiences (Cunningham & Kelly, 2017; Dorie & Cardella, 2021; English, 2017).

**Theme 5: Internalization of EDP as Cognitive Tool:** Students' language increasingly incorporated engineering design terminology and processes as the camp progressed. Initial reflections described activities in general terms ("we made a car"), while later reflections referenced specific EDP phases ("we tested our design," "we analyzed the problem," "we iterated based on results"). This linguistic shift suggested internalization of design thinking frameworks. Several students explicitly valued the structured problem-solving approach:

*"The six steps helped us think clearly about what to do. Before, I would just try things randomly. Now I plan First"* (Student 5)

*"When our first boat sank, I remembered we should evaluate what went wrong and then redesign. The steps helped us not give up"* (Student 19)

Such metacognitive awareness indicated that the EDP framework functioned as intended as a cognitive scaffold supporting systematic problem-solving that students could potentially transfer to other contexts (Lave & Wenger, 1991).

**Theme 6: Context-Appropriate Implementation in Resource-Constrained Setting:**

Despite the rural setting's resource constraints, the camp was implemented successfully without significant material or logistical barriers. Facilitators adapted activities to available materials and space, using low-cost, locally accessible supplies (cardboard, plastic bottles, aluminum foil, simple hand tools). Several students commented positively on using "everyday materials" to create functional designs:

*"I thought we needed expensive stuff from the city to do science. But we made everything from things anyone can get"* (Student 17)

This finding holds practical significance, STEM-based camps need require sophisticated laboratories or expensive equipment to be effective. Thoughtful pedagogical design, strong facilitation, and emphasis on process over product can compensate for resource limitations a crucial insight for scaling informal STEM learning opportunities in underserved contexts (Avery & Reeve, 2023; Marginson et al., 2022).

In summary, converging quantitative and qualitative findings support the conclusion that STEM-based science camps represent a feasible and promising approach for enhancing problem-solving competencies and scientific dispositions among elementary students in rural, underserved educational settings. Students demonstrated significant improvements in problem-solving skills following the two-day STEM-based science camp ( $d = 1.33$ ), with gains observed across all four dimensions of problem-solving. Post-intervention, students exhibited high levels of scientific mindset (74% of maximum), and engaged authentically with collaborative, iterative design processes that fostered both cognitive and

affective development. Qualitative evidence revealed authentic engagement, productive struggle, collaborative knowledge building, conceptual understanding development, internalization of EDP, and successful implementation despite resource constraints.

#### 4. CONCLUSION

This study affirmatively addresses the proposed research questions, demonstrating the feasibility and transformative potential of STEM-based science camps in rural, resource-constrained contexts. Regarding the enhancement of problem-solving skills, the intervention yielded a substantial quantitative effect ( $d = 1.33$ ), indicating that the EDP served as an effective cognitive scaffold for transitioning students from intuitive to systematic problem-solving. In term of scientific mindset, participants exhibited significant positive shifts in epistemic dispositions; qualitative evidence corroborated these quantitative gains, documenting high levels of perseverance, intellectual honesty, and productive struggle as students navigated iterative design challenges. Addressing the implementation experiences and contextual factors, the findings challenge the prevailing assumption that quality STEM learning is contingent upon sophisticated infrastructure or costly equipment, misconception that often perpetuates educational inequities. Instead, the successful deployment of this rigorous camp using modest, locally sourced materials demonstrates that educational equity depends less on material resources and more on pedagogical capacity. Theoretically, this study reinforces the view of the EDP not merely as content, but as a cognitive tool that mediates problem-solving, consistent with sociocultural learning theory. Furthermore, the explicit framing of failure as a vital learning component was crucial for developing resilience, while the physical manipulation of artifacts facilitated embodied learning that likely enhanced conceptual transfer compared to abstract instruction. Collectively, these results suggest that with thoughtful design, high-quality STEM experiences are achievable and scalable even in the most remote educational settings.

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#### CONFLICT OF INTEREST

I declare that there is no conflict of interest.

#### AUTHOR CONTRIBUTION

Thidaporn Souysaart: Conceptualization, Methodology, Investigation, Data curation, Writing original draft. Pairoh Sohsomboon: Conceptualization, Methodology, Reviewing and Editing. Surapong Rattana: Visualization, Data curation, Reviewing and Editing.

#### DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

#### DECLARATION OF GENERATIVE AI

The authors used Claude (Anthropic) to improve the English language and grammar of this manuscript. The use of AI was limited to language editing only and did not affect the research design, data collection, analysis, interpretation of results, or conclusions drawn in this study.

#### ETHICS

This research adhered to ethical principles for educational research with minor participants. The study protocol received approval from The Research Ethics Committee of Nakhon Phanom University Ethics Committee in Human Research, Thailand authority ethics review processes No HE1968 on the Declaration of Helsinki and the ICH Good Clinical Practice Guideline. Parents/guardians provided written informed consent, and students provided assent prior to participation. Participation was voluntary; students could withdraw at any time without consequences. All data were de-identified for analysis and reporting. The science camp activities posed no physical or psychological risk beyond those inherent in typical school activities; safety protocols were established for all hands-on activities, and adult supervision maintained appropriate ratios throughout. Students who did not participate in the research study (non-consenting student in the two selected classroom) still participated in camp activities but did not complete assessments; students from the non-selected classroom were offered a similar camp experience the following semester to address equity concerns.

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