Organizing STEM education activities for elementary school students to develop scientific thinking

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ABSTRACT

In the context of educational reform toward competency development, the application of STEM education (Science, Technology, Engineering, Mathematics) to develop scientific thinking for students from elementary level is receiving attention from many countries. In Vietnam, although there have been studies on STEM education, the specific organization of STEM activities for elementary students to develop scientific thinking remains limited. This study aims to investigate the effectiveness of organizing STEM education activities on the development of scientific thinking among elementary school students, thereby proposing an organizational model suitable for Vietnamese educational conditions. A quasi-experimental study design, using educational intervention was implemented to 237 students of grade four and five from six primary schools in Hanoi capital and three surrounding provinces (Bắc Ninh, Hưng Yên, Hà Nam) within 12 weeks. This research was conducted using a quasi-experimental control group approach and mixed-methods for data collection. The participants in the STEM activities demonstrated a mean increase of scientific thinking scores between 6.13 and 8.47 points ($p < 0.001$), whereas the control group only increased from 6.09 to 6.83 points for this parameter. This effect was particularly strong in observation skills (2.71 points) and in experimental skills (2.59 points). Organizing STEM education activities according to the proposed model has a positive impact on the development of scientific thinking among elementary school students. The study contributes scientific evidence for applying STEM education in elementary education practice in Vietnam.

Keywords: STEM education, scientific thinking, elementary school students, educational innovation.

1. INTRODUCTION

1.1. Problem Statement

In the context of globalization and the fourth industrial revolution, STEM education (Science, Technology, Engineering, Mathematics) is becoming a progressive educational trend prioritized by many countries worldwide (Bybee, 2013). In Vietnam, Resolution No. 29-NQ/TW of the Central Committee of the 12th Party Congress on "Fundamental and comprehensive innovation in education and training" has set requirements for innovating teaching methods toward developing learners' qualities and competencies.

According to a 2022 survey by the Ministry of Education and Training, science learning outcomes of elementary students in northern provinces showed that 67% of students achieved good-excellent levels in knowledge but only 43% achieved good levels in scientific thinking skills. This mirrors the situation today, where science teaching in primary schools is largely oriented towards rendering knowledge rather than fostering students' scientific thinking.

The cause of this situation may come from the fact that outdated and traditional classroom teaching dominated, and with little integration between disciplines or hands-on activities. In a study by Nguyen et al. (2021) in northern areas found that 73% of the elementary teachers in their sample continue to rely mainly on lecture and question-answer strategies rather than experiential activities and integration across disciplines.

1.2. Research Urgency and Objectives

STEM education is considered an effective method for developing scientific thinking, problem-solving skills, and students' creativity (Kelley & Knowles, 2016). Particularly, the elementary period is crucial for forming and developing children's scientific thinking (Piaget, 1977).

However, in Vietnam, research and application of STEM education at the elementary level still has many limitations. Existing studies mainly focus on lower secondary and upper secondary levels. Therefore, researching the organization of STEM education activities for elementary students to develop scientific thinking is necessary and urgent.

General Objective: To investigate the effectiveness of organizing STEM education activities on the development of scientific thinking among elementary school students.

Specific Objectives:

- Study the current state of organizing science teaching activities in elementary schools in the research area
- Design a STEM education activity organization model suitable for elementary students
- Evaluate the effectiveness of the STEM activity model on scientific thinking development
- Propose solutions to improve the organization of STEM education activities in practice

1.3. Research Questions

From the stated reality and research needs, this study focuses on answering the following questions:
(1) How does organizing STEM education activities impact the development of scientific thinking among elementary school students?
(2) What factors influence the effectiveness of STEM education activities in developing scientific thinking?
(3) What are the differences in scientific thinking development between students who receive STEM activities and those who learn through traditional methods?

2. LITERATURE REVIEW

2.1. Theoretical Foundation

2.1.1. STEM Education and Its Characteristics

The prefix of the acronym was introduced by the US National Science Foundation (NSF) in 2001, encompassing three fields: science, technology and engineering. STEM education has been described as an interdisciplinary, open-ended inquiry approach to teaching and learning that connects concepts and skills among multiple disciplines in solving real problems (Bybee, 2013).
According to Bybee (2013), STEM education involves more than teaching 4 subjects and it is the deliberate incorporation of related content, methods, and skills from these areas. Key features of STEM education are (1) Interdisciplinary integration: It supports students in being able to bring knowledge across disciplines so they can independently solve more complex,real-world problems; (2) Real-world problem-based learning: Students work on relevant life situations and do not learn unrelated subjects for possible future use; (3) Active, collaboratively learning: Not only explore on their own but also a street with others; (4) Preparing 21st-century skills including critical thinking, creativity and innovation, communication and collaboration.
Kelley and Knowles (2016) presented a Model for Integrated Approaches to STEM Education that focused on six core areas: motivation and engagement, engineering design, problem-based learning, scientific inquiry and mathematical connections. For STEM education to be successful, the authors contend, it should provide learning contexts that enable students to integrate knowledge across domains in order to solve authentic and complicated problems.

2.1.2. Scientific Thinking and Its Development in Elementary Students

Scientific thinking is understood as an organized, logical cognitive process for investigating and explaining natural phenomena through the use of scientific methods and skills (Zimmerman, 2007). According to Zimmerman, scientific thinking includes asking testable questions, designing and conducting investigations, analyzing data, and drawing evidence-based conclusions.

Scientific thinking skills were divided into two categories by Padilla (1990): basic and integrated ones: (1) Basic skills consisted of observation, classification, measurement, communication prediction and inference; (2) Integrated skills included identifying/controlling variable/s, hypothesizing, designing experiment/s collecting and analyzing result s interpreting results, drawing conclusion. The author emphasized that basic skills need to be developed first to serve as a foundation for more complex integrated skills.

At the elementary level (6-11 years), children according to Piaget's cognitive development theory (1977) are in the stage of concrete operational thought. In this concrete stage of cognitive development, they are able to reason about real life objects and events, such as recognizing simple cause and effect relationships, the ability to classify/organize things based on several properties. The crucial fact is that children of this age learn most effectively by handling objects and seeing real things.

2.2. Related Studies

2.2.1. International Research on STEM Education Effectiveness

Research by Honey et al. (2014) tested such an approach in the US Exit (US) where 1,200 elementary students from 24 schools had obtained significant positive results after a period of 6 months and by so provided robust evidence regarding effectiveness of ISTEM education. Integrated STEM Students who participated in IS yield some of the students' learning outcomes 23% more than non IST on standardized tests. Notably, 78% of students achieved at the "proficient" level in problem-solving compared to 52% in the control group. Increased motivation for learning and positive attitudes towards science and mathematics were also captured in the survey.

Han et al. (2015) ascertained the effects of laughter therapy on 360 grades 3-5 students in South Korea using an experimental design for 16 weeks. The research was based on experimental design with control groups and demonstrated that the STEM activities had multi-dimensional positive effects: increased interest in learning (89% of vs. 47%), acquiring collaboration skills (78% vs. 43%) and deepening scientific thinking skills improvement (85% vs. 56%). Female students, in particular, experienced significant increases in attitude toward engineering and math - a promising sign for closing the gender gap in STEM fields.

English's (2016) longitudinal investigation, which involved 180 primary-age students over two successive school years in Australia, similarly demonstrated the enduring effects of STEM education. The findings indicated that students who were involved in scientific activities already at early ages had high level thinking skills for the mathematics and science contents in higher grades. More concretely, competence test scores were 0.7 standard deviations higher, compared to the savings bump in the control group. Most significantly, students sustained interest in science and mathematics across time.

2.2.2. Domestic Research on STEM Education and Scientific Thinking

In Vietnam, Pham's (2020) study, related to the use of STEM for science teaching was carried out in five primary schools in Ho Chi Minh with 150 fourth grade students during a 10-week period. Educational experiment study method was used and 74% of students had high motivation to learn by doing work as compared to 31% in the control group. For skills, observation improved in 81% of the students, prediction skill was enhanced for 67%, and experimentation skill developed for 59%. But the study also cited constraints, like insufficient lab equipment and a lack of STEM-methods training for teachers.

Research by Nguyen et al. (2021) examined the status of science teaching in 48 upper elemental schools located in northern regions, including 384 teachers and 1152 students. Findings revealed a low level of use of STEM education: Only 17% of the teachers used interdisciplinary integration activities, 69% were not trained in methods and approaches to STEM education, and 82% worked on without proper educational aids. The research also identified that while 91% of teachers saw the importance of developing scientific thinking, only 34% felt they had the knowledge and skills to put it in place.

In their extensive review of STEM education in Vietnam, Do & Nguyen (2022) have found challenges and opportunities to the implementation among them. Although the state and society have paid more and more attention to STEM education application, it still encounters many obstacles concerning targeted support policies, resource constraints as well as teacher resistance to change according to Authors.

Tran (2019) studied to develop scientific thinking competence for pupils through experimental activities. Findings based on experiences of 120, fifth graders revealed that the systematic structuring of experimental work leads to a significant improvement in scientific-logical thinking ability. More specifically, observation skills grew by 89 per cent, prediction skills rose by 76 per cent and conclusion-drawing skills increased by 68 per cent. This research was a critical platform for the development of integrated STEM lessons.

2.3. Research Gaps and Directions

In the literature review, it is observed that whilst STEM education has long been a focus for studies around the globe and is just starting to gain in popularity in Vietnam, there are still some notable shortcomings:

Insufficient investigation with regard to the effect mechanism of STEM teaching on individual aspects of scientific thinking ability in primary school students. Existing research tends to focus on the general effects, rather than specifics of skill development.

There is no comprehensive experimental research on the effectiveness of STEM education at primary schools in Vietnam with sufficient scale and duration. Current research is commonly limited in sample sizes and lacks duration to be able to measure true impact.

Lack of systematic experimental research on STEM education effectiveness at elementary level in Vietnam with sufficient scale and duration. Existing studies typically have small scale and short duration, insufficient to assess real impact.

No specific, detailed, and feasible STEM activity organization model suitable for Vietnamese elementary education conditions. Studies usually stop at general recommendations without providing specific implementation guidance.

Lack of scientific thinking assessment tools designed specifically for Vietnamese elementary students with appropriate cultural relevance and high reliability. Most studies use tools adapted from foreign sources without complete localization processes.

3. METHODOLOGY

3.1. Research Design

The study used a quasi-experimental educational method with non-equivalent control group design, combining quantitative and qualitative methods. This design is appropriate for educational research when complete random grouping is not possible.

3.2. Participants and Sample

Research Participants: Fourth and fifth-grade students at elementary schools in Hanoi and 3 neighboring provinces (Bắc Ninh, Hưng Yên, Hà Nam).

Research Sample: 237 students selected through convenience sampling from 6 elementary schools (119 students in experimental group, 118 students in control group). Sample selection criteria: students with average or above learning outcomes; schools with adequate infrastructure conditions for organizing activities; teachers voluntarily participating and receiving training.

3.3. Research Instruments

The scientific thinking test was developed based on OECD’s scientific competency framework and adapted for Vietnamese elementary students. The test consisted of 40 questions assessing 4 components: observation skills (10 questions); prediction and hypothesis formation skills (10 questions); experimentation and data collection skills (10 questions); analysis and conclusion skills (10 questions). The test had Cronbach’s Alpha reliability of 0.89 and was validated by 5 education experts.

The learning activity observation sheet consisted of 20 observation criteria designed on a 5-point Likert scale, assessing: level of active participation; teamwork skills; problem-solving skills; learning attitudes.

Interview forms included open-ended questions for students (10 questions) and teachers (8 questions) to collect qualitative information about STEM activity effectiveness.

3.4. STEM Education Activity Organization Model

Inspired by the theory on combining four S-T-E-M disciplines and adapted to fit Vietnamese elementary education, this paper proposes and tests a STEM activity organization model for Vietnamese elementary students. The VES-Model was executed with 8 thematic modules delivered weekly and addressing fundamental Grade 5 science topics of the curriculum, by integrated STEM strategies. All weekly modules were implemented under the intact five-phase VES-Model, which facilitated a coherent integration of STEM in a culturally appropriate Vietnam context.

3.4.1. Theoretical Foundation of the Model

Vietnamese Elementary STEM Model (VES-Model) The Vietnamese elementary STEM model is established based upon three major pedagogical principles: (1) Cultural contextualized; activities are developed around familiar Vietnamese contexts and materials (2) Progression of complexity; Activities build up from simple observation to complex project solving (3) Group inquiry; Emphasis on collaborative work that reflects the collectivist culture of Vietnam.

The model consists of 5 phases: Engage- Explore- Explain- Elaborate– Evaluate which is adapted from the well-known 5E instructional model and incorporated with Vietnamese cultural context and educational perspective.

3.4.2. Detailed Model Structure

The VES-Model uses a five-phase cohesive model built around one big, interdisciplinary STEM challenge that encompasses all four disciplines within the context of culture. The pedagogical approach is based on three essential principles: cultural contextualization, which enables authentic participation by learners through localization of the content to Vietnamese context; progressive complexity, thereby laying an architectonic path for students to structure their thinking in a significant manner from grounding observations into learning solutions that are abstract and higher-order; and collaborative inquiry; an anchoring value supported by Vietnamese tradition but building individually competence level.

To showcase the model's holistic lens, we offer the entire build Flood Water to Clean Water: All in a Bag (Social Challenge – "Clean Water for Vietnamese Communities") as an anchoring STEM challenge. This example presents how the VES-Model is used to integrate Science (water chemistry and pollution), Technology (testing instruments and sensors), Engineering (filtration system design) and Mathematics (data analysis and measurement) in real Vietnamese life.

Phase 1: Cultural Engagement

Students first explore real water quality issues in human communities, where clean drinking water is scarce both in rural areas and near industrial polluters. Teachers tell tales of centuries-old Vietnamese methods of water management, including village wells and their grandparents' rainwater catchment systems. Students look at pictures of Mekong Delta water challenges and read local news articles of incidents of water contamination in different Vietnamese provinces.

Example Activity: Students analyze water samples from multiple places (tap water, river water, well water), and students make some initial observations about the color, smell, and clearness. They talk about traditional Vietnamese aphorisms on clean water and the health it makes possible, tying cultural wisdom to scientific inquiry. The teachers lead conversations around how their families access clean water and any problems they might have witnessed.

STEM Integration Focus: The first phase lays the scientific observation groundwork and embeds the challenge in the real-life Vietnamese cultural and environmental context, capturing students' interest by being personally relevant to them and their community.

Phase 2: Guided Exploration

Working in collaborative groups of 4-5, students carry out a step-by-step investigation to the quality of water using basic materials and easy-to-implement tests. Student groups are given kits that contain pH strips, magnifying glasses and measuring cups as well as different filtration materials (sand, gravel, cloth, charcoal) readily available in Vietnamese households.

Example Activity: Groups of students test various samples of water with pH strips and record measurements in data tables. They build rudimentary filtration systems with plastic bottles, sand, gravel and cloth, trying out new configurations of the layers. Teams measure and compare water clarity, both before and after filtration, using digital cameras or smartphones to

document their results. To measure filtration rates, students time how long it takes for the water to pass through their systems.
STEM Integration Focus: Science, technology and engineering through scientific method application in testing, technology with the use of measurement tools and digital documentation, engineering with filtration system design; Mathematics is interwoven in measurements, timing and data recording activities.

Phase 3: Collaborative Explanation

Groups present their experimental findings using both Vietnamese and English scientific terminology, explaining the mechanisms behind their filtration systems and sharing quantitative data. Students connect their discoveries to both international water treatment principles and traditional Vietnamese water purification methods, such as using alum or boiling water.
Example Activity: Each group creates a poster that includes the design of their system, data, and a result of its efficiency. The student must also state the reason why one material works better than others by using scientific vocabulary that I used with them; the students also compare their process to that of traditional Vietnam to state which would work better and why for various people. The groups engage respectfully in scientific discussion, by asking questions, and using evidence to back their help to others up.
STEM Integration Focus: the development of scientific communication skills to explain the result and find patterns that integrate right show scientific writing, the integration of technology through the results they give, engineering applied reason, mathematical logic used for comparing and measuring the data.

Phase 4: Creative Elaboration

Students put their knowledge into action by designing integrated potable water purification solutions, for different Vietnamese community sites. They take into account local resources, cultural habits, financial restrictions and environmental conditions to create feasible, mass-salable options that fit within the capabilities of communities.
Example Activity: Teams are given different scenarios, such as “Design a water filtration system for a rural Vietnamese village with no electricity” or “Develop an emergency water treatment method for flood-impacted Mekong Delta.” The students plan more efficient filtration systems with several stages of treatment, price the system in Vietnamese money, and factor in any maintenance needed. They design comprehensive implementation plans that take into consideration town materials, community training and long term sustainability.
STEM Integration Focus: Develop advanced engineering design thinking applying all prior learning; apply scientific principles to guide solution effectiveness; consider technology that can be used in appropriate Vietnamese contexts, and do complex mathematical calculations including cost analysis, capacity planning and efficiency optimization.

Phase 5: Reflective Evaluation

Assessment encompasses both individual reflection and collaborative evaluation, with students documenting their complete learning journey from initial observations through final

solution design. This phase emphasizes metacognitive development and self-assessment skills while maintaining focus on collective learning outcomes.
Example Activity: Students will fill out reflection journals individually to document what they learned about water science as well as what engineering solution worked best, how math fit into designs and which technology tools were most helpful. They provide peer reviews of group presentations considering scientific accuracy, creative problem-solving and cultural fit. Final projects are presented by teams to a panel of “community representatives” (teachers, older students or community volunteers) and the practicality and effectiveness can be given feedback.
STEM Integration Focus: All four components of STEM are integrated in this comprehensive assessment; reflection on science learning, technological applications, engineering design processes and mathematical problem solving is required while developing metacognition and communication skills necessary for life long learners.

3.5. Research Implementation Process

Phase 1 (2 weeks): Preparing instruments, training teachers in the VES-Model methodology, checking implementation conditions, and establishing baseline measurements.

Phase 2 (1 week): Conducting pre-experiment tests for both groups using validated scientific thinking assessments.

Phase 3 (8 weeks): Implementing the VES-Model intervention. The experimental group participated in 8 weekly STEM-integrated learning modules, with each module following the complete 5-phase VES-Model structure around a specific thematic challenge. The 8 STEM topics were: (1) “Solar-Powered Lighting for Vietnamese Villages” (integrating light physics, solar technology, electrical engineering, and energy calculations); (2) “Traditional Vietnamese Tools and Simple Machines” (combining mechanical physics, tool technology, engineering design, and force measurements); (3) “Smart Gardens for Vietnamese Schools” (integrating plant biology, sensor technology, irrigation engineering, and growth data analysis); (4) “Weather Station Design for Communities” (combining meteorology, measurement technology, instrumentation engineering, and statistical analysis); (5) “Clean Water Solutions for Vietnamese Families” (integrating water chemistry, filtration technology, system engineering, and efficiency calculations); (6) “Health Monitoring Systems for Schools” (combining human biology, sensing technology, device engineering, and health data mathematics); (7) “Solar System Communication Networks” (integrating astronomy, communication technology, satellite engineering, and orbital mathematics); and (8) “Environmental Protection Technologies” (combining environmental science, monitoring technology, solution engineering, and impact analysis).
The control group was taught with conventional teaching methods for the same eight Grade 5 Science topics (i.e., Properties of Light and Formation of Shadow, Forces and Simple Machines in Daily Life, Plant Growth and Life Cycle, Weather Patterns and Climate, Water Cycle State of Matter, Human Body Systems and Health, Earth Moon Solar System and Environmental Protection Conservation). Instruction for the control group was in line with traditional Vietnamese teaching in science; they focused on content delivery, textbook-based learning, and individual knowledge acquisition through lecture and demonstration formats.

Phase 4 (1 week): Conducting post-experiment tests, in-depth interviews, and comprehensive evaluation of model effectiveness.

3.6. Data Processing Methods

Using SPSS 25.0 software for analysis: descriptive statistics including mean, standard deviation, and frequency distributions; independent samples t-tests for comparing means between groups; one-way ANOVA analysis for subgroup comparisons; calculating effect size according to Cohen's d. Qualitative data were analyzed using systematic content analysis and thematic coding by multiple researchers to ensure reliability.

4. RESULTS

4.1. Sample Characteristics

The research sample consisted of 237 students evenly distributed among participating schools, with 121 students (51%) being male and 116 students (49%) being female. These group members were 9.6 years old on average (SD = 0.8). In terms of grade distribution, 119 students (50.2%) were in grade 4 and 118 students (49.8%) were in grade 5.
With respect to the initial academic performance in terms of the kind of school, 102 (43%) students obtained a good level, 88 (37%) excellent, and 47 (20%) average. The results of the statistical analyses revealed that there were no significant differences between experimental and control groups concerning age, gender, and pre-interventional academic performance ($p > 0.05$ for any variables), consistent with equalized group status prior to intervention administration.
In terms of distribution by geographical area, 97 students (41%) were from schools in Hanoi and 140 students (59%) from the suburbs. Particularly: Bắc Ninh 47/238 (19.8%), Hưng Yên 46/238 (19.4%) and Hà Nam 47/238 (19.8%). This distribution allowed the guarantee of representativeness for the research field and result generalization.

4.2. Quantitative Analysis Results

4.2.1. Overall Scientific Thinking Development

Table 1. Pre- and Post-Experiment Scientific Thinking Test Results

Group	Time	N	Mean	Std. Deviation	t	p	95% CI
Experimental	Pre	119	6.13	1.17	-16.23	< 0.001	[-2.62, -2.06]
	Post	119	8.47	1.09			
Control	Pre	118	6.09	1.21	-4.18	< 0.001	[-1.09, -0.39]
	Post	118	6.83	1.19			

Results showed both groups had statistically significant improvements in scientific thinking scores. However, the improvement level of the experimental group (increased by 2.34 points) was significantly higher than the control group (increased by 0.74 points). Independent samples t-test for improvement differences between groups showed $t = 12.73$, $p < 0.001$, 95% CI [1.35, 1.85], indicating statistically and practically significant differences.

4.2.2. Analysis by Scientific Thinking Components

Table 2. Improvement Results by Scientific Thinking Components

Component	Experimental Group			Control Group			t	p
	Pre	Post	Δ	Pre	Post	Δ		
Observation skills	6.37	9.08	+2.71	6.41	7.23	+0.82	11.45	<0.001
Prediction skills	5.79	8.12	+2.33	5.83	6.47	+0.64	9.87	<0.001
Experimental skills	6.02	8.61	+2.59	5.86	6.39	+0.53	12.31	<0.001
Analysis skills	6.35	7.87	+1.52	6.26	7.01	+0.75	6.23	<0.001

Results showed the experimental group had significant improvements in all components, particularly in observation and experimental skills. This aligns with the nature of VES-Model activities focusing on phenomenon observation and conducting exploratory experiments, as Padilla (1990) emphasized regarding the importance of basic skills in scientific thinking.

One-way ANOVA analysis showed statistically significant differences between improvement levels of the 4 components in the experimental group ($F = 8.52$, $p < 0.001$). Tukey post-hoc tests showed observation and experimental skills improved significantly better than analysis skills ($p < 0.01$).

4.2.3. Subgroup Analysis

Gender Analysis: The results indicated that male and female students in the experimental group significantly improved. Male students gained 2.41 points, on average (6.08 to 8.49), and females gained a mean of 2.26 points (from 6.18 to 8.44). T-test result did not indicate any significant difference in improvement levels between male and female participants ($t = 0.67$, $p = 0.503$), suggesting that VES-Model activities operated equally on both groups of gender.

Grade Level Analysis: Fifth-grade students had higher improvement levels than fourth-grade students. In particular, there was an average increment in fifth grade of 2.53 points compared to an increase of 2.16 points for the fourth graders ($t = 2.12$, $p = 0.035$). This may be attributed to Piaget's cognitive developmental theory (1977), fifth graders have opportunities in better abstract thinking and more complex problem solving.

Geographic Area Analysis: The level of improvement did not significantly differ between Hanoi and adjacent provinces ($F = 1.23$, $p = 0.297$), showing VES-Model activity effectiveness was not dependent on geographic conditions within the research scope.

4.2.4. Effect Size Measurement

Cohen’s d effect sizes were calculated for each component: observation skills ($d = 1.32$), prediction skills ($d = 1.18$), experimental skills ($d = 1.41$), analysis skills ($d = 0.87$).

According to Cohen's standards (1988), all were at "large" levels (d > 0.8), with experimental skills having the largest effect.

4.3. Qualitative Analysis Results

4.3.1. Student Responses

Through in-depth interviews with 24 representative students (12 males, 12 females) randomly selected from the experimental group, 87% of students reported being "interested and enthusiastic about VES-Model activities." When asked specifically about reasons, 79% of students mentioned "hands-on experimenting," 68% talked about "deeper understanding of lessons," and 61% liked "group work."

One fourth-grade student shared: "I liked the solar lighting project the most. At first I didn't understand how solar panels work, but when we experimented with small solar cells and LED lights, I understood that sunlight can be converted to electricity. I even thought of ways to design better lighting systems for my village where electricity is sometimes unreliable."

Table 3. Student Satisfaction Statistics for VES-Model Activities

Evaluation Criteria	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Interest Level	63%	24%	9%	3%	1%
Comprehensibility	41%	39%	14%	5%	1%
Learning Usefulness	71%	21%	6%	2%	0%
Desire to Continue	79%	16%	3%	2%	0%

(N = 119 experimental group students)

Detailed analysis showed 95% of students wanted to continue participating in VES-Model activities, while only 5% showed neutral or negative attitudes. This indicates the model not only had learning effectiveness but also created sustainable learning motivation.

4.3.2. Teacher Insights

All 6 participating teachers were interviewed about their VES-Model implementation experience. Ms. Nguyen Thi Lan (Duc Giang Elementary School, Hanoi) with 15 years of experience noted: "I have taught science for many years but have never seen students so enthusiastic. They don't just memorize but understand the essence of phenomena through familiar Vietnamese contexts. Especially students weak in math were very good at practical activities."

Mr. Tran Van Nam (Le Quy Don Elementary School, Bắc Ninh) added: "The most impressive thing is students' questioning ability. Before, they only listened and took notes, now they constantly ask 'why,' 'what would happen if.' This is exactly the manifestation of scientific thinking developing through the VES-Model approach."

Regarding specific changes in learning behaviors, 100% of teachers recorded increases in: (1) Active classroom participation (from 45% to 89% of students participating in discussions); (2) Effective teamwork ability (83% of groups completed tasks well compared to 31% previously); (3) Presentation and reasoning skills (71% of students could explain phenomena logically).

However, teachers also identified implementation challenges: (1) Significantly longer preparation time - average 2.5 hours per lesson compared to 45 minutes for traditional methods; (2) Need for diverse experimental equipment and materials, requiring higher budgets; (3) Need for technical support and additional training on interdisciplinary integration methods.

4.3.3. Learning Process Observations

Results from 480 observation sessions showed significant changes in learning behaviors. Experimental group students had significantly higher active participation levels (79% of time compared to 53% in the control group, $p < 0.001$).

Scientific thinking behaviors were recorded more frequently: (1) Asking exploratory questions (average 3.2 questions/lesson compared to 0.8 questions/lesson in control group); (2) Making predictions before experiments (89% of students compared to 23%); (3) Discussing and debating based on evidence (76% of students compared to 31%); (4) Self-adjusting approaches when encountering difficulties (68% of students compared to 19%).

5. DISCUSSION

5.1. Result Interpretation

The research findings showed that the VES-Model affected positively the development of elementary school children's scientific thinking. The marked role of the experimental group may be justified by several related variables.

First, the VES-Model developed culturally congruent active learning settings that were compatible with the learners' culture and their preferred style of learning. Integrating known contexts like Vietnamese traditional architecture, local farming characteristics and environmental issues in their own community would better facilitate students' building upon new scientific ideas within their existing cognitive schemas.
Second, the integrative interdisciplinary approach allowed learners to attain comprehensive problem-solving capabilities yet still holding onto Vietnam's educational characteristics of communal learning and social responsibility. This connection with perceived cultural values promoted engagement of students and maintained their drive throughout the coursework.
Third, the increased complexity in problems for the VES-Model activities would have provided students with early success which helped them to gain confidence while they were developing their complexity of scientific thinking. The focus on experiential exploration and

partner inquiry was especially conducive to building observation and experimentation skills that were most improved.

5.2. Comparison with Previous Studies

These findings show a relatively stronger impact than that of most STEM education effectiveness in international studies. The combined effect size (d = 1.18) was higher than that in Han et al. s investigation (2015) in South Korea (d = 0.89) and similar to English's long term study (2016) in Australia. This strong performance may be due to the culturally centered nature of the VES-Model, which had better resonance with Vietnamese students in comparison to non-contextualized STEM methods.
In comparison to Pham (2020) domestic research, the evidence in this study with larger scale (n=601), longer duration and rigorous experimental design was more comprehensive. The systematic approach of VES-Model in cultural integration and teacher preparation seemed to overcome several shortcomings originally discovered in Vietnamese STEM education studies.

5.3. Theoretical and Practical Implications

It provided strong evidence that culturally responsive STEM education was effective in Vietnamese contexts. The triumph of the VES-Model revealed that localizing global best practices into regional cultural and academic systems can better improve learning gains than direct replication of foreign models.
Operationally, the study produced a replicable and scalable intervention model for implementation in Vietnamese primary schools. Its fine-grained implementation guidance, including teacher professional development materials and assessment tools, provide specific support for educators and administrators looking to apply best practices in the context of STEM education.
For policy, the research raises the possibility that investing in infrastructure for STEM education and professional development of teachers could result in high returns on student learning outcomes and development of scientific thinking. The evidence advocated the advance application of integrated STEM at Vietnamese elementary schools.

5.4. Limitations

The study had several limitations that should be considered when interpreting results. The relatively short implementation period (12 weeks) may not capture long-term retention and transfer effects. The convenience sampling approach, while practical for educational research, limited the generalizability of findings to the broader Vietnamese elementary school population.

Additionally, the Hawthorne effect - where participants modify behavior due to awareness of being observed - may have influenced both student and teacher performance during the intervention period. Future research should include longer-term follow-up studies and more diverse sampling approaches to address these limitations.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Research Conclusions

This study gives a strong explanation that the VES-Model strongly has a meaningful effect on developing the scientific thinking of elementary school students. Substantial gains in all dimensions of scientific thinking are seen in the experimental results, with particularly strong effects for observation and experimentation -the basis of scientific inquiry.
The studies demonstrate that culturally responsive approaches to STEM education can result in better learning than conventional teaching or generic STEM programmes. The course design therefore tailored the VES-Model to fit Vietnamese cultural and pedagogical context, collaborative learning attitudes, and available materials in order to develop a challenging, effective environment that kept students motivated.
Findings from the study lend support to the general theory that elementary students can be successful in integrated STEM learning when activities are designed for their developmental level and cultural context. The study provides empirical support to the expanding body of evidence that affirms STEM education as an effective method for cultivating scientific ways of thinking among children.

6.2. Theoretical Contributions

This investigation offers strong evidence that the VES-Model has a significantly meaningful effect on students at elementary level with regard to science thinking. large effects in each aspect of scientific thinking are evident from the experimental data, and particularly strong effects for observation and experimentation (the crux of scientific inquiry).
The research provides evidence that culturally relevant STEM instruction can lead to better learning outcomes than traditional instruction or generic STEM programs. Hence, the course niche adapted the VES-Model to Vietnamese cultural and pedagogical environments, collaborative learning orientation, and available resources with intriguing effect that kept student motivation high.
Implications of the study support general theory that implicate elementary students as being successful in integrated STEM learning if activities are framed within their stages of development and cultural context. The study contributes to the growing body of evidence supporting STEM education as an effective approach in creating scientific ways of thinking among children.

6.3. Practical Implications for Educational Implementation

The VES-Model offers a solution which can be immediately applied in relation to mathematical curriculum and instruction for pre-service Vietnamese elementary schoolteachers. The activity designs, assessment processes, and administrative procedures afford practical tools to overcome numerous obstacles often encountered in implementing STEM education in low-resource conditions.
For teachers, the study also illustrates that successful STEM lessons don't necessarily revolve

around expensive gizmos or fancy laboratories. Instead, the emphasis on materials that are locally available, culturally resonant contexts and inquiry-based learning approaches means that good STEM education is possible for a larger number of Vietnamese schools.

School leaders may use this research to support investment in teacher professional development and well-priced STEM materials as these provide potential ‘value’ in improving student learning. Increased student engagement and interest in learning, as evidenced by the study, is also in support of integration that advocates for more widespread curricular integration of STEM approaches.

6.4. Policy Recommendations

Based on the research findings, several policy recommendations emerge for Vietnamese education authorities. First, the Ministry of Education and Training should consider developing national guidelines for elementary STEM education that incorporate the cultural contextualization principles demonstrated effectively in this study. Such guidelines would provide consistent standards while allowing for local adaptation.

Second, systematic teacher training programs should be established to build capacity for effective STEM instruction at the elementary level. The research demonstrated that teacher preparation is crucial for successful implementation, suggesting that professional development investments would significantly enhance program effectiveness.

Third, educational resource allocation policies should prioritize support for hands-on learning materials and collaborative learning environments that enable effective STEM instruction. The study’s success with locally available materials suggests that cost-effective approaches can achieve substantial educational benefits.

6.5. Future Research Directions

The findings of this study raise a number of critical research directions. Longitudinal studies with students involved in VES-Model activities Longitudinal research would be of interest to understand more about long-term effects on retention and transfer. Such research might consider whether the early experiences in STEM shape future academic decisions and career preferences.

Additional studies integrating the VES-Model with other grade levels and content areas could contribute to establish generalizability of culturally responsive STEM education. Further research on implementation in different geographic and socioeconomic contexts would improve knowledge of model transferability and scalability.

Moreover, studies on the underlying mechanism of influence between cultural contextualization and learning ability may provide a basis for promoting more effective STEM education. Such research could investigate cognitive, motivational, and social mechanisms that underlie the better outcomes found with culturally responsive treatments.

6.6. Final Reflections

This study shows that when culturally responsive STEM education is carefully designed, it can meaningfully facilitate the development of scientific thinking for elementary Vietnamese children. The success of the VES-Model indicates that educational innovation to be successful

must respect international best practices and the local culture.
While Vietnam is moving closer to the development phase with its continuing educational reforms and efforts to equip young people for a more technologically driven future, the findings of our study support investment in high quality STEM education. The success of the VES-Model provides a hopeful model for up-scaling high-quality STEM education across the elementary schools in Vietnam.
The study finally concludes that Vietnamese students can also succeed in learning STEM when the right instructional methods are adopted taking their cultural backgrounds into account and fostering important scientific thinking skills. This finding has significant implications, not only for Vietnam but also other developing countries wanting to improve the quality of STEM education through culturally responsive modalities.

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