



## The Effectiveness of Stem Education through the Club Model: A Case Study in Thai Nguyen

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### Abstract

This paper presents a case study on the effectiveness of an extracurricular STEM club model at Thai Nguyen High School for the Gifted, Vietnam. Amidst a national push for educational reform, this study investigates how a specialized, project-based club serves as a vehicle for implementing modern STEM pedagogy. Using a mixed-methods approach, a survey was administered to 42 student members to quantitatively assess their perceptions of the club's activities and its impact on their competency development. The findings reveal a highly positive evaluation of the club's practical, technology-rich content and its supportive learning environment, which is significantly enhanced by a strategic partnership with local university experts. The most notable result is the students' self-reported improvement in 21st-century skills, with critical thinking and problem-solving abilities showing the most significant gains ( $M = 4.24$  on a 5-point Likert scale). The study concludes that the STEM club is a highly effective model, successfully translating a well-structured program and strong mentorship into tangible student competencies. This research provides valuable empirical evidence for the efficacy of extracurricular clubs as a powerful tool for STEM education in the Vietnamese context.

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### Introduction

In the context of the Fourth Industrial Revolution, which is reshaping the global economy and society, developing a high-quality workforce, particularly in the fields of Science, Technology, Engineering, and Mathematics (STEM), has become an urgent requirement and a strategic goal for many nations, including Vietnam. STEM education, with its nature as an interdisciplinary, integrated approach aimed at equipping students with the ability to mobilize comprehensive knowledge to solve practical problems, is considered a breakthrough solution to achieve this goal. Recognizing this importance, Thai Nguyen province has demonstrated strong political commitment, identifying STEM education as a key task linked to its strategies for science and technology development, innovation, and digital transformation.

Within the educational ecosystem, flexible, extracurricular forms of learning play a crucial role in realizing the philosophy of STEM education. Among them, the club model has emerged as an ideal experiential learning space, operating based on the voluntary participation and passion of students. The STEM club allows students to "learn through play and play through learning," freeing them from the constraints of a fixed curriculum and becoming an "innovation lab" for piloting creative teaching methods and implementing long-term projects.

Although the roles of STEM education and the club model have been affirmed, research in Vietnam still lacks in-depth, systematic, and evidence-based analyses of the effectiveness of this model's implementation in a specific context. In particular, a comprehensive evaluation of the STEM club model within an ecosystem featuring a strong link between K-12 and higher education, such as in Thai Nguyen, remains a research gap. Therefore, an in-depth case study in this locality is necessary to provide scientific evidence of its effectiveness and to identify success factors that can be replicated.

For these reasons, this study was conducted to answer the following main questions:

1. How is the STEM club model implemented in Thai Nguyen province within the specific context of its policies and support ecosystem?
2. How does this model impact the development of students' core competencies and academic achievements?
3. What are the key success factors and existing challenges, and what recommendations can be made for sustainable development?

To answer these questions, the study sets out the following specific objectives: (1) To analyze the current implementation of the STEM club model at typical schools in Thai Nguyen; (2) To evaluate the model's effectiveness in developing student competencies and its achievements; (3) To identify success factors, limitations, and propose strategic solutions for replicating and sustainably developing the model.

The object of study is the effectiveness of the club model in implementing STEM education. The scope of the study is limited to Thai Nguyen province, focusing on an in-depth analysis of typical cases at various educational levels during the period from the 2020-2021 to the 2024-2025 school years.

## 2. Literature Review

### 2.1. Theoretical Framework

#### 2.1.1. STEM Education and the Interdisciplinary Approach

STEM education is not a mechanical sum of the four separate fields of Science, Technology, Engineering, and Mathematics, but rather an educational philosophy that emphasizes their integration and connection (Bybee, 2013). According to the U.S. National Research Council (2012), the essence of STEM education lies in simulating real-world contexts where problems do not exist within isolated disciplinary frameworks. Instead, students are placed in the role of scientists and engineers to apply a synthesis of knowledge and practical processes (such as asking questions, designing solutions, and analyzing data) to solve these challenges (Akcan *et al.*, 2023; Chan & Nagatomo, 2022). This approach helps transform learning from passive memorization to active knowledge construction, consistent with the direction of Vietnam's 2018 General Education Program (Ministry of Education and Training, 2018).

#### 2.1.2. Development of 21st Century Student Competencies

The core objective of STEM education is to form and develop in students the competencies necessary for the 21st century. This competency framework, often known as the "4Cs," includes Critical Thinking, Creativity, Collaboration, and Communication (Arshad, 2021). STEM learning projects

require students to analyze problems (critical thinking), propose novel solutions (creativity), work together to realize ideas (collaboration), and present and defend their products (communication). This process not only reinforces specialized knowledge but also cultivates essential soft skills, a critical demand of the modern labor market (Abdi, 2012; Hán & Đỗ, 2023).

#### 2.1.3. The Club Model as a Community of Practice

Vygotsky's (1978) social constructivist learning theory emphasizes that learning is a social process where knowledge is constructed through interaction. Expanding on this, Lave and Wenger (1991) proposed the concept of a "Community of Practice," describing a group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly (Lave & Wenger, 1991; Vygotsky, 2018). The STEM club model is a typical manifestation of this community of practice. In the club, students learn not only from teachers but also from each other, with more experienced members guiding new ones. The club's informal, voluntary, and low-pressure environment creates ideal conditions for exploration, experimentation, and accepting failure as part of the learning process, thereby fostering confidence and a passion for science (Bozkurt Altan & Tan, 2021).

## 2.2. Review of Related Research

Globally, numerous studies have confirmed the positive impact of extracurricular STEM activities. Roberts and Bybee showed that students participating in summer STEM programs had significantly more positive perceptions of STEM learning and demonstrated increased interest in related careers (Roberts & Bybee, 2011, p. 201). Similarly, a study other found that 80% of students in after-school STEM programs reported that these activities helped them see the real-world utility of math and science (Chai, 2019). These studies provide strong evidence that informal learning environments like clubs are highly effective in promoting positive attitudes and career orientation in STEM.

In Vietnam, STEM education has received significant attention in recent years, especially since the implementation of the 2018 General Education Program. Domestic research has primarily focused on several key areas: (1) developing and implementing STEM topics and lessons integrated into the formal curriculum (Nguyễn & Trần, 2023); (2) enhancing the capacity of teachers to meet the demands of STEM teaching (Lê & Nguyễn, 2020); and (3) assessing the perceptions and attitudes of teachers and students towards STEM education.

However, a significant research gap can be identified. Current works often focus on the formal classroom context, with few in-depth, systematic studies on the effectiveness of extracurricular models, particularly the club model. Furthermore, research on the effectiveness of a comprehensive STEM education ecosystem—where there is synergy between macro-level policies, the efforts of K-12 schools, and professional support from universities—remains very limited. Therefore, conducting a case study in Thai Nguyen, a locality with distinct features in these aspects, will provide valuable practical evidence, contributing to the enrichment of the scientific basis for implementing STEM education in Vietnam.

### 3. Methodology

This study was conducted using a case study design with a mixed-methods approach to provide a comprehensive and in-depth understanding of the issue. The choice of a mixed-methods approach allows for the combination of the strengths of quantitative and qualitative data, enabling both the objective measurement of the model's effectiveness and a deep interpretation of the context and implementation process of the STEM Club's activities at Thai Nguyen High School for the Gifted.

To collect data, the study combined a literature review with a survey questionnaire. The literature review was used to analyze, synthesize, and systematize scientific documents, research works, and official directives, forming a solid theoretical foundation for the research. The survey questionnaire served as the primary tool for collecting empirical data from the research subjects. The survey population was defined as all 42 student members of the STEM Club at Thai Nguyen High School for the Gifted during the 2024-2025 school year. The survey instrument was designed with several main sections: general information, evaluation of the club's activities, and self-assessment of the development of core 21st-century competencies. The evaluation items were primarily constructed using a 5-point Likert scale, supplemented with open-ended questions to gather more detailed student opinions. Before official deployment, the reliability of the scales was tested using Cronbach's Alpha to ensure the consistency of the measurement tool.

The data analysis process was carried out in two parallel streams. Quantitative data from the questionnaire was processed using the statistical software SPSS. Descriptive statistics such as frequency, percentage, mean, and standard deviation were used to summarize the current situation and students' evaluations. In addition, inferential statistical tests such as T-tests or ANOVA were considered to compare differences between student groups. Concurrently, qualitative data from open-ended questions and related documents were analyzed using content analysis. Opinions and remarks were coded and categorized by theme to enrich and provide deeper interpretation for the quantitative results, thereby offering multi-faceted evidence of the STEM club model's effectiveness.

### 4. Results

This section presents the analysis of the survey data collected from 42 student members of the STEM Club at Thai Nguyen High School for the Gifted during the 2024-2025 school year. The analysis begins with an assessment of the survey instrument's reliability, followed by a detailed presentation of

the findings corresponding to the three main research areas: the club's content and organization, the learning environment, and the development of students' personal competencies.

#### 4.1. Reliability of the Survey Instrument

To ensure the internal consistency and reliability of the survey questionnaire, a reliability analysis was conducted. The Cronbach's Alpha coefficient for the 11 items on the Likert scale was calculated to be .884. As this value is significantly higher than the commonly accepted threshold of .70, it indicates that the survey instrument possesses a high degree of reliability and the collected data is consistent and suitable for further analysis.

#### 4.2. Students' Perceptions of the Club's Content and Organization

The first part of the survey aimed to gauge students' evaluations of the club's activities, including the relevance of topics, the connection to classroom knowledge, the organizational format, and access to technology. The results indicate a generally positive perception from the students.

**Table 1:** Descriptive Statistics for Club Content and Organization (N=42)

		QR1	QR2	QR3	QR4
N	Valid	42	42	42	42
	Missing	0	0	0	0
Mean		4.0476	3.8810	3.8333	4.0000
Std. Error of Mean		.17024	.16766	.14425	.15241
Median		4.0000	4.0000	4.0000	4.0000
Mode		4.00	4.00	4.00	4.00
Std. Deviation		1.10326	1.08656	.93487	.98773
Minimum		1.00	1.00	1.00	1.00
Maximum		5.00	5.00	5.00	5.00
Percentiles	25	4.0000	3.7500	3.7500	4.0000
	50	4.0000	4.0000	4.0000	4.0000
	75	5.0000	5.0000	4.0000	5.0000

As shown in Table 1, the statement that "The topics/projects in the Club are novel, engaging, and highly practical" (QR1) received the highest mean score ( $M = 4.05$ ), suggesting that students found the content to be relevant and stimulating. Similarly, students agreed that the club provided good opportunities to access modern technology (QR4,  $M = 4.00$ ). The aspects related to reinforcing classroom knowledge (QR2,  $M = 3.88$ ) and the effectiveness of organizational formats (QR3,  $M = 3.83$ ) also received positive ratings, though slightly lower. The standard deviations for this group of questions were relatively low, indicating a general consensus among the members.



**Fig 1:** Some pictures of STEM club activities at Thai Nguyen High School for the Gifted

### 4.3. Evaluation of the learning environment and support system

The second group of questions focused on the learning atmosphere, specifically the support from teachers and the quality of peer collaboration. The findings suggest a supportive and collaborative environment, which is crucial for the success of such extracurricular activities.

**Table 2.** Descriptive Statistics for Learning Environment and Support (N=42)

		QR5	QR6	QR7
N	Valid	42	42	42
	Missing	0	0	0
Mean		4.0238	3.7381	3.5000
Std. Error of Mean		.15045	.17397	.18432
Median		4.0000	4.0000	4.0000
Mode		4.00	4.00	4.00
Std. Deviation		.97501	1.12747	1.19450
Minimum		1.00	1.00	1.00
Maximum		5.00	5.00	5.00
Percentiles	25	4.0000	3.0000	3.0000
	50	4.0000	4.0000	4.0000
	75	5.0000	5.0000	4.0000

According to the data in Table 2, students highly valued the support they received from supervising teachers and experts (QR5,  $M = 4.02$ ). The perception of a friendly and open environment that encourages mutual learning (QR6) was also rated favorably ( $M = 3.74$ ). The item assessing the effectiveness of collaboration among members (QR7) had the lowest mean score in this section ( $M = 3.50$ ), although still positive. This suggests that while collaboration is happening, it might be an area with potential for further improvement.

### 4.4. Self-Assessed Competency Development

The final and most critical part of the survey asked students to self-assess their improvement in core 21st-century skills after participating in the STEM club. The results strongly indicate that the club has had a significant positive impact on students' competency development.

**Table 3.** Descriptive Statistics for Self-Assessed Competency Development (N=42)

		QR8	QR9	QR10	QR11
N	Valid	42	42	42	42
	Missing	0	0	0	0
Mean		4.2381	3.5238	3.8571	4.1190
Std. Error of Mean		.13115	.19941	.16893	.14934
Median		4.0000	4.0000	4.0000	4.0000
Mode		5.00	4.00	4.00	5.00
Std. Deviation		.84995	1.29234	1.09481	.96783
Minimum		2.00	1.00	1.00	2.00
Maximum		5.00	5.00	5.00	5.00
Percentiles	25	4.0000	2.7500	3.0000	4.0000
	50	4.0000	4.0000	4.0000	4.0000
	75	5.0000	5.0000	5.0000	5.0000

The data presented in Table 3 reveals that students perceived the most significant improvement in their critical thinking and problem-solving skills (QR8), which received the highest mean score of the entire survey ( $M = 4.24$ ). This is a key finding, as it aligns directly with the primary goals of STEM

education. Communication skills (QR11) also saw a substantial perceived improvement ( $M = 4.12$ ). Students also felt they had developed their collaboration skills (QR10,  $M = 3.86$ ) and creativity (QR9,  $M = 3.52$ ). While all competencies were rated positively, the results highlight the club's exceptional effectiveness in fostering higher-order thinking skills like problem-solving

### 5. Discussion

The findings from this study provide compelling evidence for the effectiveness of the STEM club model at Thai Nguyen High School for the Gifted as a vehicle for enhancing student competencies. The discussion will interpret these findings by linking them to the theoretical framework and previous research, highlighting the key factors contributing to the club's success.

The highly positive student perceptions of the club's content and organization ( $M = 4.05$  for novelty and practicality) underscore the importance of a curriculum that is grounded in real-world applications. This aligns with the core philosophy of STEM education, which advocates for moving beyond abstract theory to engage students in authentic problem-solving (Bybee, 2013). The access to modern technologies, also rated highly ( $M = 4.00$ ), appears to be a significant motivating factor and a crucial component of the club's appeal, allowing students to bridge the gap between academic concepts and tangible, technologically advanced applications.

A key element of the club's success appears to be its supportive learning environment. The strong appreciation for the guidance from teachers and external experts ( $M = 4.02$ ) validates the effectiveness of the school's strategy to collaborate with university lecturers. This model directly addresses a common challenge in secondary STEM education: the need for specialized expertise that may not be available within the school's faculty (Hoàng & Lê, 2022). This mentorship transforms the club into a dynamic "community of practice" where students learn through interaction with more experienced practitioners (Lave & Wenger, 1991). While still positive, the slightly lower score for peer collaboration ( $M = 3.50$ ) may suggest that while a collaborative atmosphere exists, there is room to further structure group projects to maximize the effectiveness of teamwork.

The most significant finding of this research is the club's profound impact on the development of 21st-century skills. The highest-rated outcome, an improvement in critical thinking and problem-solving skills ( $M = 4.24$ ), demonstrates that the club is successfully fostering higher-order cognitive abilities. This result is consistent with studies by Roberts *et al.* (2018), which found that extracurricular STEM programs enhance students' problem-solving capabilities. The project-based nature of the club's activities forces students to move beyond rote memorization and engage in a cycle of inquiry, design, testing, and refinement, which is the very essence of developing critical thought. The strong development of communication skills ( $M = 4.12$ ) further suggests that the club provides a valuable platform for students to articulate and defend their ideas, a skill often underdeveloped in traditional classroom settings.

Interestingly, while still rated positively, creativity ( $M = 3.52$ ) received the lowest score among the four core competencies. This could indicate that while the projects are

practical and technologically advanced, they may follow a structured process that, while excellent for developing problem-solving skills, might offer fewer opportunities for open-ended, divergent thinking. This does not diminish the club's success but rather points to a potential area for future pedagogical refinement, perhaps by incorporating more "blue-sky" brainstorming or design-thinking challenges.

In summary, the results suggest that the STEM club at Thai Nguyen High School for the Gifted is a highly effective educational model. It succeeds by combining engaging, practical content with a robust support system that leverages external expertise. Most importantly, it translates these inputs into tangible outputs in the form of enhanced critical thinking, problem-solving, and communication skills, thus fulfilling the central promise of modern STEM education.

**6. Conclusion and Recommendations**

In conclusion, this case study confirms that the STEM club at Thai Nguyen High School for the Gifted is a highly effective model for implementing STEM education. The club successfully provides an engaging, practical, and technologically rich learning environment that is strongly supported by both internal teachers and external university experts. The most significant outcome is the demonstrable development of students' 21st-century competencies, particularly in critical thinking and problem-solving. The findings affirm that extracurricular clubs, when well-structured and supported, serve as powerful catalysts for moving beyond traditional pedagogy and fostering the skills necessary for future success in STEM fields. This study contributes empirical evidence to the literature by showcasing a successful implementation of a STEM club within the specific context of a specialized high school in Vietnam.

While this study provides valuable insights, its findings are based on a single case and a relatively small sample size,

which limits generalizability. Therefore, it is recommended that future research could conduct comparative studies across different types of schools or longitudinal studies to track student development over time. Based on the findings, we recommend that the school's administrators continue to foster the valuable partnership with local universities. For the club's coordinators, we suggest exploring strategies to enhance peer collaboration and intentionally integrating more open-ended activities to further stimulate student creativity. For other educational institutions, the success of this model suggests that investing in extracurricular STEM clubs with strong external mentorship is a worthwhile strategy for cultivating the next generation of innovators.

**Appendix**

**Survey Form**

**(Re: Evaluating the effectiveness of the STEM Club's activities at Thai Nguyen High School for the Gifted, school year 2024-2025)**

Dear members of the STEM Club,

For the purpose of evaluating the effectiveness and improving the quality of the Club's activities in the future, the research team would be grateful for your sincere feedback through this survey. All information you provide will be kept strictly confidential and used only for scientific research purposes.

Thank you for your cooperation!

**Instructions:** Please read each statement below carefully and mark (X) in the box that best fits your level of agreement according to the following scale:

- + 1 = Strongly Disagree
- + 2 = Disagree
- + 3 = Neutral / No Opinion
- + 4 = Agree
- + 5 = Strongly Agree

**Part 1: Evaluation of the Club's Content and Organization**

Statement	1	2	3	4	5
1. The topics/projects in the Club are novel, engaging, and highly practical.					
2. The Club's activities help me reinforce and expand upon the knowledge I've learned in class.					
3. The organizational formats of the activities (specialized training, group projects, hands-on practice...) are diverse and effective.					
4. The Club provides many opportunities for me to access modern technologies and equipment (such as 3D printing, robot programming...).					

**Part 2: Evaluation of the Learning Environment and Support**

Statement	1	2	3	4	5
5. I always receive enthusiastic guidance and support from the supervising teachers and experts (university lecturers).					
6. The Club's environment is friendly, open, and encourages discussion and mutual learning among members.					
7. Club members collaborate effectively when carrying out common tasks/projects.					

**Part 3: Self-Assessment of Personal Competency Development**

After joining the Club, I feel I have improved in my:	1	2	3	4	5
8. Critical thinking and problem-solving skills (the ability to analyze, evaluate, and find solutions to a problem).					
9. Creativity (coming up with new ideas and unique solutions).					
10. Collaboration skills (teamwork, delegating, and coordinating tasks effectively).					
11. Communication skills (confidently presenting and defending my ideas/products).					

