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Developing STEM competencies for pre-service mathematics teachers

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Abstract: In the context of ongoing educational reform in Vietnam, STEM education has emerged as a significant direction in mathematics teacher preparation. This study investigates the current state and effectiveness of developing STEM competencies among pre-service mathematics teachers through an experimental–control pre-test–post-test design conducted at Hai Duong University (Hai Phong, Vietnam). The participants included over 200 undergraduate students majoring in Mathematics Education from cohorts K13, K14, and K15 who engaged in STEM-integrated course modules. Data were collected through questionnaires, classroom observations, analysis of learning products, and competency assessments. The findings indicate significant improvements in students' STEM competencies after the intervention, particularly in real-world problem solving, the design of integrated instructional activities, and the application of technology in mathematics teaching ($p < 0.05$). Nevertheless, some students continued to face challenges in meaningfully integrating mathematical concepts with scientific and engineering contexts. The study provides empirical evidence supporting the implementation of STEM-oriented instructional models in mathematics teacher education and offers recommendations to enhance STEM competency development in university-level teacher preparation programs.

Keywords: *Integrated teaching, Mathematics teacher education, Pre-service mathematics teachers, STEM competencies, STEM education.*

1. Introduction

In recent decades, rapid advances in science and technology within the context of globalization have increased demands on education systems to prepare learners with the competencies needed for the twenty-first century. Consequently, STEM education has become a central focus in educational reform worldwide [1, 2]. Rather than treating science, technology, engineering, and mathematics as separate disciplines, STEM education emphasizes their purposeful integration to foster problem solving, creativity, critical thinking, and the application of knowledge to authentic real-world situations [3, 4]. Research has shown that effective STEM implementation can enhance instructional quality, strengthen the relevance of learning experiences, and better align education with the demands of innovation and digital transformation [5, 6].

Within integrated STEM education, mathematics occupies a central and cross-cutting role. Beyond functioning as an independent discipline, mathematics serves as a fundamental tool for modeling, data analysis, and decision-making in scientific and engineering contexts [7, 8]. Consequently, mathematics teachers play a pivotal role in organizing and implementing integrated STEM learning activities in schools [9, 10]. However, empirical studies consistently indicate that both in-service and pre-service mathematics teachers face significant challenges in designing and implementing integrated STEM instruction, particularly in connecting abstract mathematical concepts with engineering design, technological applications, and real-world problems [11, 12]. These challenges reflect limitations in

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traditional mathematics teacher education programs, which tend to prioritize disciplinary knowledge over interdisciplinary integration and applied problem solving.

Addressing these issues requires substantial reform in mathematics teacher education. Recent studies emphasize that STEM-oriented teacher preparation should involve not only curriculum innovation but also transformations in instructional approaches and competency-based assessment practices [13, 14]. Instructional strategies such as project-based learning, problem-based learning, and engagement with the engineering design process have been identified as effective means for developing integrated STEM competencies among pre-service teachers [4, 13]. In parallel, the meaningful integration of digital technologies, including modelling tools, simulations, and collaborative platforms, has been recognized as an essential component of university-level STEM instruction, supporting both conceptual understanding and interdisciplinary collaboration [15, 16].

In Vietnam, STEM education has been explicitly identified as a key focus in the new General Education Curriculum, increasing expectations on teacher education institutions, especially those training mathematics teachers. Despite this policy emphasis, research on STEM education within university-level mathematics teacher education remains limited. Existing studies mainly focus on conceptual discussions, instructional models, or descriptive accounts of teaching practices, while empirical investigations, particularly experimental studies examining the effects of STEM-oriented instruction on pre-service teachers' competencies, are scarce [17, 18]. This lack of empirical evidence constrains the development of evidence-based reforms in mathematics teacher education.

Against this backdrop, the present study investigates the development of STEM competencies among pre-service mathematics teachers through surveys and pedagogical experiments conducted at Hai Duong University (Hai Phong, Vietnam). The study aims to examine the current status of students' STEM competencies, evaluate the effectiveness of integrating STEM-oriented instruction into selected mathematics teacher education courses, and propose directions for enhancing the quality of mathematics teacher education in the context of ongoing educational reform.

This study contributes to the literature on STEM-oriented mathematics teacher education in three main respects. First, it develops and implements a STEM-oriented mathematics teaching model grounded in the 6E instructional framework within a university-level teacher education context. Second, it provides empirical evidence on the impact of this model on the development of STEM competencies among pre-service mathematics teachers using a controlled experimental design. Third, it offers practical recommendations for implementation at both institutional and national levels. These contributions address an important gap in the Vietnamese context while also providing insights relevant to international research on STEM-based mathematics teacher preparation.

2. Literature Review and Context

2.1. Overview of Related Studies

Over the past two decades, STEM education has become a prominent area of educational research, with a shared emphasis on purposeful integration across science, technology, engineering, and mathematics rather than isolated disciplinary instruction. Foundational studies consistently underline that integrated STEM education aims to develop learners' problem-solving competence, creativity, and capacity to apply knowledge in authentic contexts [1, 2, 7]. The coherence and depth of interdisciplinary integration are widely regarded as key determinants of STEM education effectiveness [3].

Within theoretical frameworks of STEM education, mathematics is recognized as a central and cross-cutting component that supports modelling, data analysis, and decision-making across STEM disciplines Wang et al. [8] and Roehrig et al. [9]. Kelley and Knowles [4] emphasize that effective STEM learning is typically organized around real-world problems in which mathematics functions as both content and an integrative tool. This perspective is reflected in the STEM Road Map framework proposed by Moore et al. [13], which positions mathematics as a continuous element throughout the engineering design and problem-solving process.

A growing body of research addresses STEM teacher education, particularly the preparation of pre-service teachers for integrated STEM instruction. Moore and Smith [10] argue that STEM-oriented teacher education requires systematic reforms in curriculum design, instructional organization, and competence assessment. Empirical evidence indicates that pre-service mathematics teachers often experience difficulties applying mathematical knowledge within interdisciplinary and engineering-related contexts, despite possessing relatively strong subject-matter foundations [11, 12].

Recent review studies highlight an increase in STEM teacher education research but also point out persistent gaps. While many studies focus on perceptions and attitudes toward STEM education, empirical investigations evaluating the development of STEM competencies through experimental or intervention-based designs remain limited [17, 18]. In addition, a lack of consensus on STEM competency frameworks and assessment approaches continues to constrain the comparability of findings across studies [19].

Overall, existing literature provides strong theoretical support for integrated STEM education and emphasizes the central role of mathematics in STEM teacher preparation. However, empirical evidence on the impact of STEM-oriented instruction on developing STEM competencies among pre-service mathematics teachers remains scarce, especially in reform-oriented contexts such as Vietnam. This gap offers the theoretical and practical rationale for the present study.

2.2. STEM Education at the University Level in Mathematics Teacher Education

STEM education at the university level, particularly within teacher education programs, plays a crucial role in ensuring the quality and sustainability of STEM implementation in schools. Compared with STEM education at primary and secondary levels, university-level STEM education places a stronger emphasis on the integrated development of subject-matter knowledge, pedagogical competence, and interdisciplinary integration capacity within specific professional contexts [10, 14]. In mathematics teacher education, STEM education aims not only to broaden interdisciplinary understanding but also to prepare pre-service teachers to use mathematics as a central tool for organizing, analyzing, and implementing STEM teaching activities.

Despite its importance, the implementation of STEM education in university-level mathematics teacher preparation faces significant challenges. Empirical studies indicate that while pre-service mathematics teachers often possess solid mathematical knowledge, they experience difficulties in applying this knowledge to interdisciplinary, real-world problems involving engineering and technology [11]. Furthermore, differences in how lecturers and students conceptualize the role of mathematics within STEM education have been reported, leading to inconsistencies in curriculum design, instructional strategies, and assessment practices across teacher education programs [12].

From a curricular perspective, researchers emphasize that STEM education should be systematically integrated into both subject-matter and pedagogical courses, rather than implemented as isolated modules or short-term activities [4, 13]. In mathematics teacher education, such integration needs to be closely aligned with core mathematical content, contemporary approaches to mathematics teaching, and the competency requirements of general education curricula [9, 11].

Instructional approaches also play a decisive role in the effectiveness of STEM education at the university level. Methods such as project-based learning, problem-based learning, and engagement with the engineering design process have been widely recognized as appropriate for integrated STEM instruction, as they provide pre-service teachers with opportunities to engage in authentic, interdisciplinary problem solving [6, 20]. Through these approaches, pre-service mathematics teachers can develop both their own STEM competencies and their capacity to design STEM-oriented lessons for future classroom practice.

Alongside pedagogy, technology is considered a key enabling factor in university-level STEM education. Technology-enhanced learning environments support modeling, simulation, collaboration, and interdisciplinary learning, thereby strengthening the integration of mathematics with other STEM domains [15]. Recent studies also highlight the potential of emerging technologies, including artificial intelligence, to support STEM competency development among pre-service teachers, while simultaneously raising new demands for digital competence [16].

From a competency-based perspective, STEM education in mathematics teacher preparation should foster mathematical competence, pedagogical competence, and STEM integration competence in a coordinated manner [19, 21]. However, recent review studies indicate that empirical research evaluating the effects of STEM-oriented instructional models on the development of STEM competencies among pre-service mathematics teachers remains limited, especially in educational systems undergoing reform [17, 18].

In summary, existing literature highlights both the potential and challenges of implementing STEM education in university-level mathematics teacher education. The limited availability of context-specific empirical studies underscores a critical research gap, providing a clear theoretical and practical foundation for the present study.

2.3. STEM Competencies of Pre-service Mathematics Teachers

STEM competency has been conceptualized in various ways in educational research; however, there is broad agreement that it involves the integrated use of interdisciplinary knowledge, higher-order thinking skills, and the ability to apply knowledge to solve authentic, real-world problems [4, 21]. In teacher education, STEM competency extends beyond participation in STEM activities to encompass the professional capacity to design, organize, implement, and evaluate STEM-oriented teaching in alignment with curricular objectives and learners' characteristics [10, 19].

For pre-service mathematics teachers, STEM competency has distinctive features arising from the central role of mathematics in STEM education. Mathematics functions not only as a disciplinary knowledge base but also as a fundamental tool for modeling, data analysis, quantitative reasoning, and decision-making in scientific and engineering contexts [8, 9]. Consequently, pre-service mathematics teachers are expected to apply mathematical knowledge flexibly across disciplines and to establish meaningful connections between abstract concepts and real-world contexts. Nevertheless, empirical studies indicate that many pre-service teachers encounter difficulties in integrating mathematics with technology and engineering components within STEM learning activities [11].

Synthesizing previous research, the STEM competency of pre-service mathematics teachers can be viewed as a multidimensional construct. Core cognitive dimensions include mathematical subject-matter competence, interdisciplinary integration competence, and thinking and problem-solving competence, encompassing critical thinking, creativity, and data-based reasoning [4, 21]. Beyond these, STEM pedagogical competence represents the ability to design, organize, and assess STEM-oriented learning activities in mathematics classrooms, closely linked to inquiry-based instruction and competency-oriented assessment [13, 19]. Technological competence is also increasingly recognized as an essential supporting component, enabling effective use of digital tools, modeling software, and technology-enhanced learning environments in STEM instruction [15, 16].

The assessment of STEM competencies remains a challenging issue in teacher education. Review studies show that current assessment practices rely on diverse methods, such as performance tasks, learning products, classroom observations, and self-assessment, yet there is still a lack of standardized frameworks specifically tailored to pre-service mathematics teachers [17, 18].

In summary, STEM competency of pre-service mathematics teachers is best understood as a multidimensional construct comprising mathematical competence, interdisciplinary integration competence, thinking and problem-solving competence, pedagogical competence, and technological competence. Despite growing theoretical discussion, empirical evidence on how these competencies develop during mathematics teacher education is still limited. This gap provides the conceptual basis for the present study to construct a STEM competency framework and to investigate competency development through surveys and pedagogical experiments in subsequent sections.

3. Research Methodology

3.1. Research Design

This study adopts a mixed-methods research design that integrates quantitative and qualitative approaches to ensure both breadth and depth of analysis. The use of a mixed-methods design enables the study to describe the current status of STEM competencies among pre-service mathematics teachers while simultaneously examining the effects of pedagogical interventions aimed at integrating STEM education at the university level.

From a quantitative perspective, data were collected through questionnaire surveys and a pedagogical experiment. The survey was conducted to examine lecturers' perceptions, readiness, and challenges related to the implementation of STEM education, as well as to assess the baseline STEM competencies of pre-service mathematics teachers. The pedagogical experiment followed a pre-test–post-test design with an experimental group and a control group, allowing for a systematic comparison of learning outcomes and an evaluation of the impact of STEM-oriented instructional interventions embedded in selected mathematics teacher education courses.

From a qualitative perspective, the study employed classroom observations and analysis of students' feedback during their participation in STEM-oriented learning activities. These qualitative data were used to complement and interpret the quantitative findings by providing deeper insights into changes in students' learning behaviors, perceptions, and manifestations of STEM competencies throughout the experimental process.

The research was implemented in two main phases. The first phase involved a situational survey that gathered data on lecturers' experiences, perceptions, and constraints in implementing STEM education, alongside an assessment of the initial STEM competency levels of pre-service mathematics teachers. The second phase consisted of a pedagogical experiment in which STEM-oriented teaching approaches were systematically integrated into selected subject-matter and pedagogical courses to evaluate the effectiveness of the proposed instructional model.

The instrument used to assess STEM competencies among pre-service mathematics teachers was developed based on a synthesis of existing research on STEM competency frameworks in teacher education. The scale comprised five components: (1) application of mathematical knowledge in real-world contexts; (2) integrated thinking and problem-solving competence; (3) competence in designing STEM-oriented teaching activities; (4) competence in using technology to support teaching and learning; and (5) collaboration and communication competence in STEM learning. Each component was measured using items on a five-point Likert scale. The reliability of the instrument was examined using Cronbach's alpha, with an overall coefficient exceeding 0.80, indicating satisfactory internal consistency. Content validity was established through expert review by specialists in mathematics education and STEM education prior to the administration of the survey and the implementation of the pedagogical experiment.

3.2. Participants and Sample

The participants in this study were lecturers and students from the Mathematics Teacher Education program at Hai Duong University (Hai Phong, Vietnam). Participant selection was intended to reflect the actual context of university-level mathematics teacher education in Vietnam during the implementation of STEM-oriented instructional reforms.

The lecturer sample consisted of faculty members responsible for teaching both mathematics content courses and mathematics pedagogy courses. Participation was voluntary, and all lecturers had experience in higher education instruction. The lecturer survey focused on perceptions of STEM education, levels of readiness for STEM implementation, and perceived challenges in integrating STEM approaches into mathematics teacher education programs.

The student sample included 200 pre-service mathematics teachers from cohorts K13, K14, and K15. Students were selected using convenience sampling, which was appropriate given the practical constraints of the training environment and the organization of existing classes. To ensure an adequate sample size for statistical analysis, Yamane's formula was employed to calculate the minimum required number of participants.

$$n = \frac{N}{1 + N.e^2}$$

where e = 0.05 represents the acceptable sampling error.

With a total population of approximately 300 students across the three cohorts, the minimum required sample size was calculated to be 171 students. The actual sample exceeded this requirement, supporting the reliability of subsequent quantitative analyses.

In terms of sample characteristics, the participating students were relatively evenly distributed across cohorts and included second-, third-, and fourth-year students, representing different stages of professional preparation in mathematics teacher education. The proportion of female students was higher than that of male students, consistent with the demographic characteristics of mathematics teacher education programs in Vietnam. Most participants reported limited prior experience with systematically integrated STEM instruction before the implementation of this study.

For the pedagogical experiment, students were assigned to experimental and control groups based on intact classes to maintain the feasibility and authenticity of the educational setting. The experimental group participated in STEM-oriented instructional activities, while the control group received traditional instruction. Both groups completed pre-test and post-test assessments using STEM competency instruments, allowing for a comparative analysis of the effects of the instructional intervention.

4. Research Results and Proposed Directions

4.1. Results of the Survey of Lecturers and Undergraduate Students in Mathematics Teacher Education

The survey of lecturers in the Mathematics Teacher Education program indicates an overall positive perception of the role of STEM education in teacher preparation. Most lecturers agreed that STEM education is essential for developing students' problem-solving abilities, integrated thinking, and capacity to apply mathematical knowledge in secondary school teaching contexts. However, despite this positive perception, the actual implementation of STEM-oriented teaching remains limited and uneven across courses.

Table 1.
Lecturers' perceptions of STEM education in mathematics teacher education.

Survey items	Agree/Strongly agree (%)	Neutral (%)	Disagree (%)
STEM is necessary in mathematics teacher education	86.7	10.0	3.3
STEM enhances students' professional competence	83.3	13.4	3.3
STEM can be integrated into mathematics courses	68.4	21.6	10.0
STEM teaching is regularly implemented	36.7	23.3	40.0

As shown in Table 1, a clear gap exists between lecturers' beliefs and their instructional practices. While a large majority acknowledged the importance and feasibility of STEM integration, only about one-third reported regularly implementing STEM-oriented teaching. This discrepancy highlights a tension between reform-oriented perspectives and practical constraints in mathematics teacher education. Lecturers identified several major barriers to STEM implementation, including insufficient course time, a lack of instructional materials and supporting equipment, and the absence of a clear and unified framework for STEM instruction in mathematics teacher education programs.

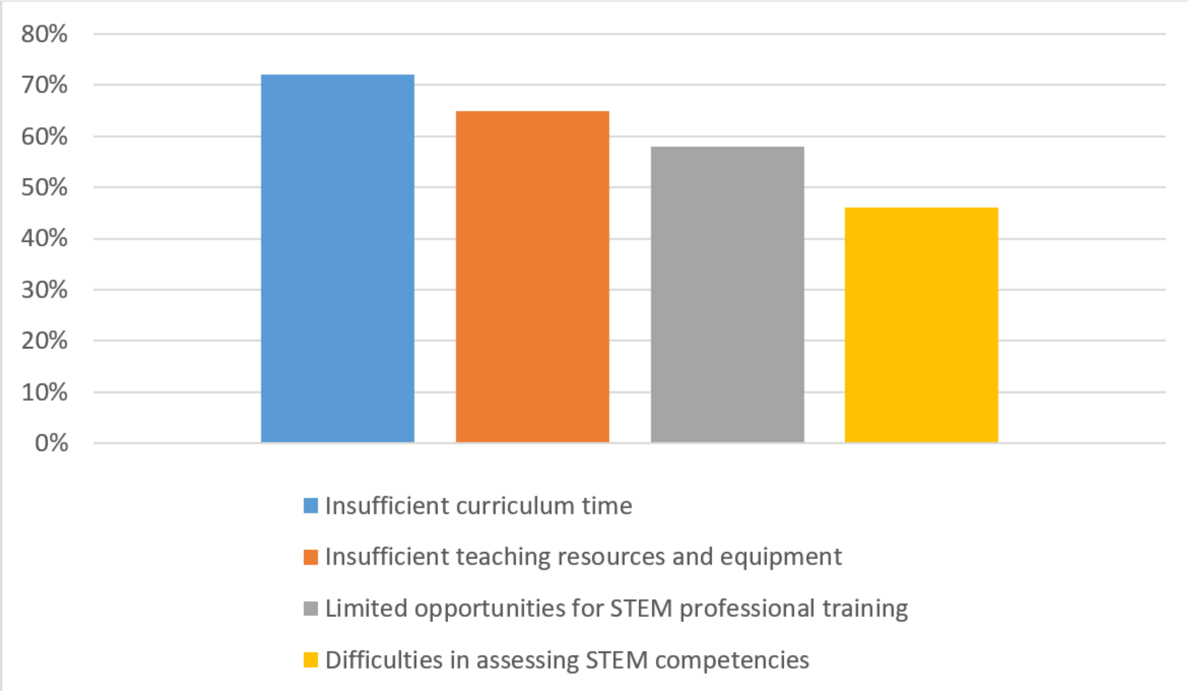

Figure 1.
Major difficulties faced by lecturers in implementing STEM education.

The survey results of undergraduate students in Mathematics Teacher Education reveal that students' understanding of STEM education is generally at a moderate level. Although most students reported having heard of STEM education, many indicated that they had not fully understood its integrated nature and experienced difficulties in applying STEM principles to the design of mathematics lessons.

Table 2.
Level of STEM understanding and experience of pre-service mathematics teachers.

Survey items	High (%)	Moderate (%)	Low (%)
Understanding of STEM education	24.5	51.0	24.5
Participation in STEM learning activities	29.0	38.5	32.5
Confidence in designing STEM-oriented mathematics lessons	18.0	42.0	40.0

The data indicate that students' confidence in designing STEM-oriented mathematics lessons remains relatively low. Many respondents reported that STEM-related activities in their training program were fragmented and not organized into dedicated courses or coherent instructional modules, limiting opportunities for systematic competency development.

Students' self-assessment of STEM competence further reveals uneven development across different components.

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Table 3.
Students' self-assessment of STEM competence (5-point scale).

Survey items	Mean score
Mathematical knowledge	3.78
Real-world problem solving	3.41
Use of technology	3.12
Design of integrated STEM activities	3.05
Interdisciplinary teamwork	2.98

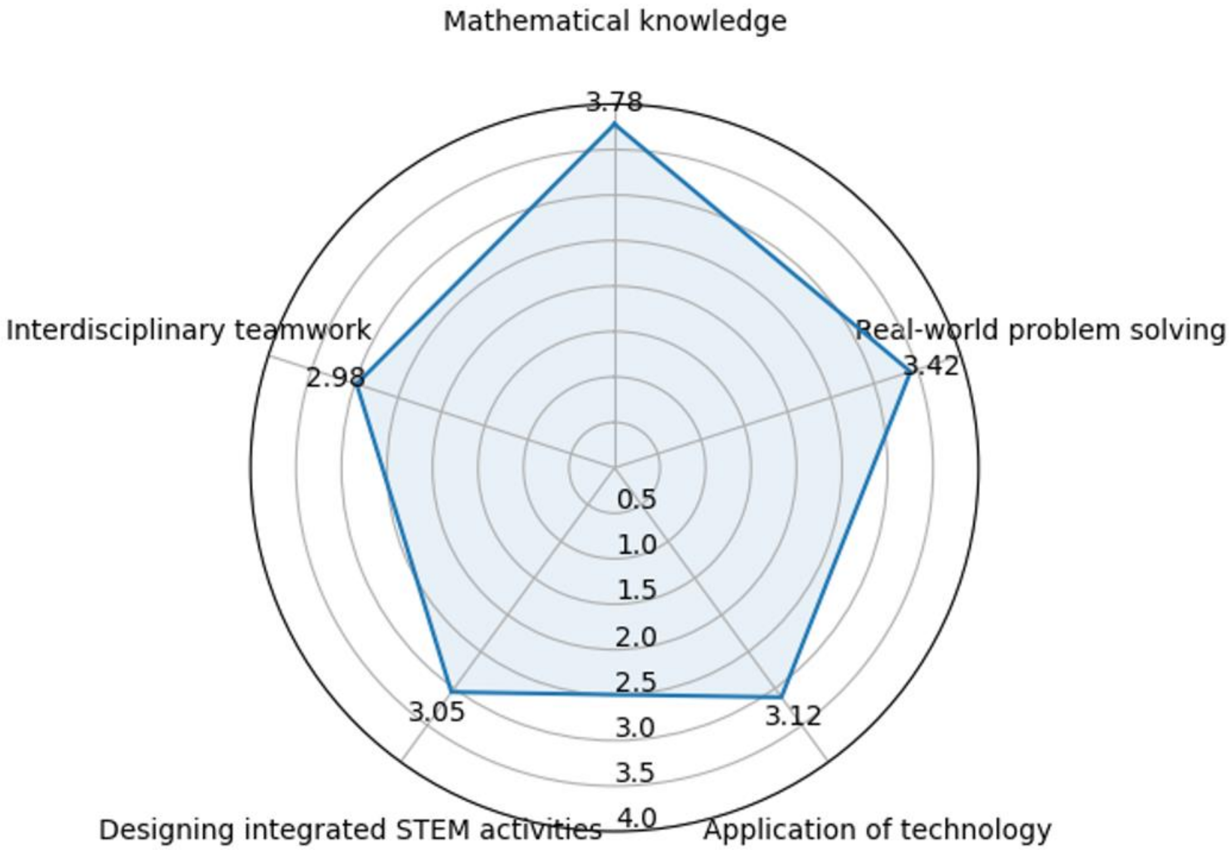

Figure 2.
Development levels of students' STEM competence components.

As illustrated in Figure 2, students rated their mathematical knowledge more highly than other components related to interdisciplinary integration, technology use, and collaboration. This imbalance suggests that current teacher education programs continue to emphasize disciplinary mathematical knowledge while providing limited opportunities to systematically develop integrated STEM competencies.

Overall, the combined survey findings from lecturers and students indicate that STEM education is widely recognized as a necessary and meaningful orientation in mathematics teacher education. Nevertheless, its implementation is constrained by organizational conditions, instructional capacity, and resource limitations. Furthermore, the STEM competencies of pre-service mathematics teachers remain uneven across components, particularly in areas related to interdisciplinary integration, technology use, and collaborative practice. These findings provide a critical empirical foundation for the design and implementation of the pedagogical experiment aimed at enhancing STEM competencies among pre-service mathematics teachers, as presented in the subsequent sections.

4.2. Effectiveness of STEM-Oriented Mathematics Teaching Based on the 6E Learning Cycle

To examine the effectiveness of mathematics teaching oriented toward STEM education, a pedagogical experiment was implemented using a teaching process structured around the 6E instructional cycle. The mathematical content was organized through a real-world problem at the university level, serving both as a learning task for pre-service mathematics teachers and as a model that can be adapted for secondary-school STEM instruction.

4.2.1. Real-World Problem as the Basis for STEM-Oriented Instruction

The central task selected for the experiment was the design of a lighting system for a school corridor, a practical problem closely related to the educational environment and relevant to the future professional context of mathematics teachers. The problem requires mathematical modeling, optimization, and interpretation of results in relation to technical constraints.

Assume a straight corridor of length L with ceiling height h, where n lamps are installed along the corridor axis. The illumination intensity at a point located at a horizontal distance x from a lamp can be modeled by the function:

$$I(x) = \frac{I_0}{x^2 + h^2}$$

where I_0 is a constant determined by the lamp's luminous power. If the lamps are placed at positions x_1, $x_2, \ldots, x_n$, the total illumination at a point x is given by:

$$E(x) = \sum_{i=1}^{n} \frac{I_0}{(x - x_i)^2 + h^2}$$

The task for students is to determine the number and placement of lamps so that the average illumination along the corridor satisfies technical standards while minimizing total energy consumption. Solving this problem requires the application of functions, derivatives, and optimization techniques, as well as an understanding of how mathematical results relate to practical engineering considerations.

4.2.2. Teaching Process Based on the 6E Cycle

At the *Engage* stage, the instructor introduced the practical context of lighting design for school facilities, supported by visual materials and basic technical requirements. Students were asked to discuss why mathematical modeling is necessary in this situation and to identify variables that might influence illumination quality. This stage aimed to stimulate interest and clarify the relevance of mathematics to real-world decision-making.

During the *Explore* stage, students worked collaboratively to analyze the problem, formulate mathematical models, and experiment with different lamp configurations. Using digital tools and simulations, they investigated how changes in the number and positions of lamps affected the illumination function E(x). Emphasis was placed on exploration and hypothesis testing rather than immediate formal solutions.

In the *Explain* stage, student groups presented their models and solution strategies. They justified their choices using mathematical reasoning, while the instructor supported discussion by formalizing key concepts related to functions, derivatives, and optimization. This stage helped consolidate mathematical understanding and clarify links between theoretical results and practical requirements.

The Engineer stage focused on developing and refining a feasible lighting design. Students employed technological tools such as spreadsheets or dynamic mathematics software to test their models under different constraints and to optimize lamp placement. At this point, mathematics functioned explicitly as a tool for solving an engineering-oriented problem, highlighting the integrative nature of STEM learning.

At the *Elaborate* stage, students were required to transform the university-level task into a STEM learning activity suitable for secondary-school mathematics. They designed a lesson outline, identified learning objectives, and specified expected student outcomes. This activity contributed directly to the development of pedagogical and professional competencies related to STEM teaching.

Finally, during the *Evaluate* stage, students' STEM competencies were assessed using a combination of pre- and post-tests, analysis of learning products, classroom observation, and self-reflection. The assessment focused not only on mathematical accuracy but also on problem-solving processes, integration across disciplines, and the ability to design STEM-oriented instructional activities.

4.2.3. Instructional Sequence Aligned with the 6E Cycle

Table 4.
STEM-oriented mathematics teaching process based on the 6E cycle.

6E phase	Student learning activities	Core mathematical content	STEM competencies developed
Engage	Analyze the lighting problem context	Identification of variables	Problem awareness, integration
Explore	Model and simulate illumination	Functions, modelling	Problem-solving, collaboration
Explain	Present and justify solutions	Derivatives, optimization	Mathematical reasoning, communication
Engineer	Design and optimize the lighting system	Applied mathematics	STEM integration, technological competence
Elaborate	Design a STEM mathematics lesson	Knowledge transfer	Pedagogical STEM competence
Evaluate	Reflect and assess learning outcomes	Competency assessment	Self-evaluation, professional reflection

The experimental results indicate that the STEM-oriented teaching approach based on the 6E cycle positively influenced the development of STEM competencies among pre-service mathematics teachers. Compared with the control group, students in the experimental group demonstrated stronger abilities in modeling real-world problems, integrating mathematical concepts with technical constraints, and designing STEM-based mathematics lessons. These findings confirm the effectiveness and applicability of the proposed instructional model within university-level teacher education.

4.3. Proposed Integrated Teaching Model for Mathematics Teacher Education

Based on the survey results and pedagogical experiments, this study proposes an integrated teaching model aimed at developing STEM competence for students in Mathematics Teacher Education. The model is constructed by integrating STEM education with the 6E teaching cycle, with the goal of closely connecting mathematical knowledge to meaningful scientific, technological, and engineering contexts relevant to pedagogy.

Structurally, the proposed model positions mathematics as the central axis of STEM teaching activities, while science, technology, and engineering components function as supporting elements that extend application contexts. The 6E cycle (Engage – Explore – Explain – Engineer – Enrich – Evaluate) is employed as a pedagogical framework to organize learning activities in an experiential, problem-solving, and product-design-oriented manner, aligned with the professional competence requirements of future mathematics teachers.

Experimental results indicate that applying the STEM-oriented mathematics teaching model based on the 6E cycle leads to significant improvements in students' STEM competence. Students' STEM competence was assessed before and after the experiment using the same competence test and learning product evaluation scale.

Table 5.
Comparison of STEM competence assessment results before and after the experiment.

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Gain	T (paired)	p-value
Experimental	6.85 ± 0.76	8.47 ± 0.71	+1.62	10.96	< 0.001
Control	6.79 ± 0.73	7.05 ± 0.69	+0.26	2.08	0.042

Table 5 shows that students in the experimental group demonstrated a significant improvement in STEM competence after participating in teaching activities based on the proposed model ($\Delta M = +1.62$; $p < 0.001$), whereas progress in the control group was limited. This result indicates that the integrated STEM teaching model based on the 6E cycle has a positive impact on the development of STEM competence among pre-service mathematics teachers.
A post-test comparison between the two groups further confirms the effectiveness of the model.

Table 6.
Comparison of post-test results between experimental and control groups.

Group	Post-test (Mean ± SD)	t	df	p-value
Experimental	8.47 ± 0.71	8.21	198	< 0.001
Control	7.05 ± 0.69			

The statistical test results indicate that the post-test mean score of the experimental group was significantly higher than that of the control group ($t = 8.21$; $p < 0.001$). This demonstrates that the integrated teaching model improves learning outcomes and enhances students' ability to apply mathematical knowledge in lesson design and solving STEM problems.

In addition to quantitative data, classroom observations and analyses of learning products reveal that students in the experimental group were more actively engaged in learning activities. They proactively proposed ideas, designed learning tasks connected to real-world contexts, and used technological tools (dynamic geometry software, spreadsheets, and online tools) to support the design of STEM-oriented mathematics lessons. This shift from knowledge-reception-based learning to experiential learning contributed to increased motivation and the development of professional competence.

From a theoretical perspective, the findings support the integration of content, pedagogy, and technology in teacher education, aligning with the TPACK framework and previous research on STEM education in teacher preparation. This study adds empirical evidence from the Vietnamese context, demonstrating that combining the 6E learning cycle with STEM education is a feasible approach to narrowing the gap between teacher education theory and the practical demands of secondary school mathematics teaching.

Overall, the integrated STEM teaching model based on the 6E cycle not only enhances STEM competence among pre-service mathematics teachers but also promotes the development of core competencies of future mathematics teachers, including integrated thinking, lesson design competence, and adaptability to educational innovation. This provides an important foundation for further refinement and expansion of the model in mathematics teacher education programs at higher education institutions.

4.4. Recommendations for Implementation at Institutional and National Levels

Drawing on survey results, pedagogical experiments, and the proposed integrated STEM teaching model, this study offers recommendations to support the effective, systematic, and sustainable implementation of STEM education in mathematics teacher education at both institutional and national levels.

4.4.1. Recommendations at the Institutional Level

First, teacher education institutions should integrate STEM education into Mathematics Teacher Education curricula systematically, rather than through fragmented or short-term initiatives. STEM integration should be embedded in core components such as mathematics teaching methodology courses, practicum and internship modules, and applied or interdisciplinary courses. Training programs need to explicitly articulate learning outcomes related to STEM competencies, with particular emphasis on pre-service teachers' ability to design, implement, and evaluate STEM-oriented mathematics lessons.

Correspondingly, assessment criteria and tools should be developed in alignment with competency-based training objectives and the specific characteristics of teacher education.

Second, the professional capacity of university lecturers plays a decisive role in the effectiveness of STEM implementation. Institutions should provide regular professional development opportunities focusing on STEM-oriented lesson design, particularly using structured frameworks such as the 6E learning cycle, methods for assessing STEM competencies, and the effective use of digital technologies in mathematics instruction. Establishing professional learning communities or communities of practice within mathematics education departments can further support experience sharing, peer learning, and greater consistency in STEM implementation across courses.

Third, adequate infrastructure and learning resources are essential to ensure the feasibility of STEM-oriented teaching. Universities should gradually invest in flexible learning spaces, technological equipment, subject-specific software, and digital learning materials that support project-based and interdisciplinary activities. In parallel, pre-service teachers should be encouraged to engage in project-based learning tasks connected to local and authentic contexts, which can enhance professional experience and strengthen the application of mathematical knowledge in teaching practice.

4.4.2. Recommendations at the National and Policy Level

At the national level, coherent policy orientations are required to guide the integration of STEM education in teacher education in general, and in mathematics teacher education in particular. The Ministry of Education and Training should consider developing and issuing a unified STEM competency framework for teachers and pre-service teachers, serving as a foundation for curriculum design, instructional organization, and competency assessment in teacher education institutions. Clear guidelines on integrating STEM education into mathematics teacher education programs would help ensure alignment between university-level teacher preparation and the requirements of the general education curriculum.

In addition, national investment priorities should include the development of technological infrastructure, the creation of open educational resources for STEM education, and the implementation of large-scale professional development programs for university lecturers. Research projects and pilot initiatives focusing on STEM education models in teacher preparation should be expanded and systematically evaluated, allowing for contextual adaptation across regions and institutions.

Finally, collaboration among teacher education universities, research institutions, and secondary schools should be strengthened through formal partnerships and professional networks. Such collaboration can provide pre-service mathematics teachers with sustained opportunities to engage in STEM teaching practice and contribute to the development of a coherent and sustainable STEM education ecosystem linking teacher education with school-based implementation.

In conclusion, the effective implementation of STEM education in mathematics teacher education requires coordinated efforts at both institutional and policy levels. The recommendations proposed in this study are grounded in empirical findings and aligned with current educational reform orientations, thereby offering practical directions for improving the quality of mathematics teacher education and supporting the successful implementation of STEM education in schools.

5. Conclusion

This study examined the current state of STEM competence development among undergraduate students in Mathematics Teacher Education and proposed solutions to enhance STEM-oriented training in the university context. Based on surveys of lecturers and pre-service mathematics teachers, along with a pedagogical experiment conducted at Hai Duong University, the study clarified levels of awareness, implementation practices, and major challenges associated with STEM education in mathematics teacher preparation in Vietnam.

The experimental findings demonstrate that mathematics instruction organized according to a STEM-oriented approach grounded in the 6E learning cycle has a positive and measurable impact on the development of STEM competencies among pre-service mathematics teachers. Students in the experimental group showed significant improvement in real-world problem solving, interdisciplinary integrated thinking, the ability to design STEM-oriented teaching activities, and the effective use of technology in mathematics instruction. Statistically significant differences between the experimental and control groups provide empirical evidence supporting the feasibility and effectiveness of the proposed integrated STEM teaching model within undergraduate mathematics teacher education programs.

On the basis of these results, the study proposed a STEM-oriented instructional model and formulated recommendations for implementation at both institutional and national levels. These proposals offer practical guidance for innovating curriculum design, instructional strategies, and competency-based assessment in mathematics teacher education, thereby responding to the demands of teacher professional development within the context of educational reform and digital transformation.

Nevertheless, several limitations should be acknowledged. The study was conducted at a single teacher education institution, which restricts the generalizability of the findings. Moreover, the duration of the pedagogical experiment was insufficient to assess the long-term impact of the proposed model on graduates' professional competencies after entering school practice. Future research should extend the scope to multiple institutions, lengthen the intervention period, and employ more diversified assessment approaches to more comprehensively evaluate the effectiveness and sustainability of STEM-oriented models in mathematics teacher education.

Overall, this study contributes empirical evidence on the role of STEM education in undergraduate mathematics teacher preparation in Vietnam and provides both theoretical and practical foundations for implementing integrated, competency-oriented teaching approaches. The findings offer valuable references for teacher education institutions and policymakers seeking to improve the quality and relevance of mathematics teacher education in response to contemporary STEM education demands.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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