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Original Research Article

A New 5C-AI Model and Selected Stem Teacher Education Models from the Past 20 Years: An International Review and Application Recommendations for Vietnam

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Abstract: Over the past two decades, STEM education (Science, Technology, Engineering, and Mathematics) has undergone significant transformations, especially in the field of pre-service teacher training. This systematic review analyzes prominent international STEM teacher education models from 2005 to 2025, aiming to identify effective pedagogical structures, interdisciplinary integration strategies, and competency assessment frameworks. Using the PRISMA protocol, 42 peer-reviewed articles from North America, Europe, Asia, and Australia were selected and analyzed. The models examined include UTeach (USA), NIE STEM (Singapore), STEM Studio (Australia), TPACK–PBL (South Korea), and STEM-TP (Europe). Findings highlight common features such as early teaching practice, inquiry-based learning, technology integration, and competency-based assessment. The article proposes policy implications and strategic recommendations for Vietnam, including the development of a 5C-AI competency framework and the establishment of STEM labs in teacher training institutions.

Keywords: STEM, 5C-AI, STEM teacher, STEM education.

1. INTRODUCTION

STEM education is becoming a central focus in global education reform in the 21st century, aiming to respond to rapid shifts in technology, the knowledge economy, and the demand for innovation in the workforce. At the heart of this reform lies the imperative to train teachers who possess interdisciplinary integration skills, technological proficiency, and critical thinking.

However, the training of STEM teachers faces multiple challenges. Most programs still follow a mono-disciplinary approach, leading to fragmented knowledge and a lack of integrative skills. To address this issue, many countries have developed integrated STEM teacher education models that emphasize practical experience, technological application, and pedagogical reflection.

While various individual models have been published, there remains a lack of systematic comparative studies that analyze STEM teacher education models across different regions and implementation trends. Notably, few studies have identified actionable lessons for developing countries such as Vietnam.

This study aims to synthesize and analyze global STEM teacher education models from 2005 to 2025. The guiding research questions include:

1. What are the most prominent STEM teacher education models worldwide?
2. What are the key pedagogical features and structural elements of these models?
3. What implications do these findings offer for teacher education reform in Vietnam?

2. RESEARCH METHODOLOGY

2.1. Research Design and Sources of Literature

This study adopts a systematic review approach, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility.

Literature was collected from the following databases: Scopus, Web of Science, ERIC, and Google Scholar. Search keywords included:

- "STEM teacher education"
- "pre-service teacher training AND STEM"
- "STEM education model"
- "Interdisciplinary STEM AND teacher training"

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The search was filtered by publication year (2005–2025), limited to peer-reviewed academic articles written in English.

2.2. Inclusion and Exclusion Criteria

To ensure the quality and relevance of the selected literature, the research team applied specific inclusion and exclusion criteria. Articles were included if they directly addressed STEM teacher education, targeted pre-service or in-service teachers, had a clearly defined research design (such as experimental, descriptive, or case studies), were written in English, and classified as peer-reviewed journal articles.

Conversely, articles were excluded if they focused solely on students or educational policy without addressing teacher training, if they were purely theoretical with no empirical evidence, written in languages other than English, or fell into categories such as these, blogs, or conference abstracts. These criteria served to guide the literature selection process and ensure the reliability and practical value of the reviewed sources.

2.3. Selection Process

A total of 1,257 articles were initially identified. After removing duplicates and screening titles and abstracts, 42 articles met the inclusion criteria and were selected for in-depth content analysis.

2.4. Data Analysis

Each selected article was coded based on the following elements: country of origin, program name, model characteristics, evaluation methods, and outcomes. The data were then subjected to thematic analysis to identify key patterns and insights across the studies.

3. Prominent STEM Teacher Education Models

3.1. UTeach Model – United States

The UTeach program, developed in 1997 at the University of Texas at Austin, has since been replicated at over 40 universities across the United States. It is considered one of the most widely cited STEM teacher education models globally.

Key Features:

- Early teaching practice: Students engage with classroom environments from their first semester, fostering pedagogical skills and confidence.
- Dual certification: Students earn a bachelor's degree in a STEM discipline (e.g., Mathematics, Biology) while simultaneously completing teacher education coursework for licensure.
- Inquiry-based instruction: Incorporates the 5E model (Engage, Explore, Explain, Elaborate, Evaluate) and collaborative lesson design.
- Strong collaboration with K–12 schools: University faculty and school teachers co-mentor student teaching experiences.
- Learning communities: Students work in peer groups that support collaborative learning and mutual growth.

Evaluation and Outcomes:

- UTeach graduates show higher retention rates in teaching compared to the national average.
- Graduates demonstrate strong pedagogical content knowledge (PCK) and interdisciplinary thinking.
- The program successfully recruits students from underrepresented groups in STEM.

Limitations:

- Difficult to scale in countries without similar licensing systems.
- Primarily focused on secondary education.

3.2. NIE STEM Program – Singapore

The National Institute of Education (NIE), Singapore's sole teacher education provider, began integrating STEM into its teacher training programs in the early 2010s as part of national education reforms.

Key Features:

- Interdisciplinary STEM courses: Modules such as "STEM and Society," "STEM Learning Design," and "Technology in STEM Classrooms" are embedded throughout the program.
- Epistemic fluency development: Teachers learn to understand and connect the thinking approaches of each STEM discipline.
- Lesson study methodology: Pre-service teachers design, teach, and reflect on lessons under expert supervision.
- Design Thinking: Encourages creative and human-centered problem-solving in educational contexts.
- 21st-century competencies: Includes creativity, collaboration, computational thinking, and technological proficiency.

Evaluation and Outcomes:

- Significant improvement in integrative thinking and creative STEM lesson planning.
- Pre-service teachers are well-prepared to apply interdisciplinary approaches in real classrooms.

Limitations:

- Tailored to a centralized and well-funded system like Singapore.
- Some STEM courses remain electives, not compulsory for all education students.

3.3. STEM Studio Model – Australia

Developed at major Australian universities such as Monash and Melbourne, the STEM Studio model emphasizes learning in simulated environments—innovative classrooms that replicate real teaching contexts.

Key Features:

- Design-based inquiry: Pre-service teachers ideate, test, and refine STEM lessons collaboratively.

- Flexible learning spaces: STEM Studios are open, high-tech classrooms that simulate integrated learning settings.
- Interdisciplinary collaboration: Students from various academic disciplines co-design instructional units.
- Real-world connections: Strong partnerships with schools and industry partners.
- Professional identity development: Teachers view themselves as agents of educational innovation rather than merely subject instructors.

Evaluation and Outcomes:

- Marked improvement in project-based lesson design skills.
- Greater adaptability in tailoring instruction to diverse learners.

Limitations:

- Requires substantial infrastructure—challenging to implement in remote or under-resourced areas.
- Some students struggle with the openness and ambiguity inherent in design processes.

3.4. TPACK + PBL Model – South Korea

In South Korea, STEM education reform in teacher preparation focuses on combining the TPACK (Technological Pedagogical Content Knowledge) framework with Problem-Based Learning (PBL). This model has been widely implemented in teacher colleges since the late 2000s, supported by national education innovation programs.

Key Features:

- TPACK integration: Teacher education programs blend content knowledge, pedagogy, and technology to help teachers use digital tools effectively in STEM classrooms.
- Problem-based learning: Pre-service teachers solve authentic problems through teamwork, using simulations, virtual labs, and programming languages.
- Technology-enhanced microteaching: Students practice with interactive whiteboards, LMS platforms, and video analysis tools.
- Co-design of curriculum: Pre-service teachers collaborate with university faculty and mentor teachers to create integrated lesson plans.
- Future orientation: Programs align with national priorities such as AI, computational thinking, and Education 4.0.

Evaluation and Outcomes:

- Substantial increase in self-efficacy related to TPACK competencies.
- Enhanced skills in designing, evaluating, and organizing innovative STEM learning environments.
- Many participants clearly identify as innovative educators.

Limitations:

- Rapid technological updates demand continuous system support.
- Inconsistency in training quality across teacher education institutions.

3.5. STEM-TP Program – European Union (EU)

The STEM-TP initiative, funded under the Horizon 2020 framework, involves teacher education institutions in Germany, Finland, Sweden, and the Netherlands. It aims to harmonize and innovate STEM teacher training across Europe.

Key Features:

- Interdisciplinary integration linked to global issues: Courses are designed around real-world challenges such as climate change and sustainable urban development.
- Practice in "STEM Innovation Schools": Pre-service teachers conduct action research in designated schools recognized as innovation hubs.
- Dual mentorship: Each pre-service teacher is guided by both a university faculty member and a school-based mentor.
- Equity and inclusion pedagogy: Focus on designing culturally responsive and gender-sensitive STEM curricula.
- Pan-European learning network: Participants engage in virtual seminars, academic exchanges, and cross-border lesson design.

Evaluation and Outcomes:

- Development of integrated teaching capabilities and a mindset geared toward social justice.
- Action research projects contribute to university curriculum renewal.
- Pre-service teachers gain confidence in addressing global issues through STEM and fostering civic responsibility.

Limitations:

- National differences in teacher education policies create challenges in standardization.
- Multinational coordination requires significant funding and logistical resources.

4. Analysis and Synthesis of Key Trends

By analyzing five prominent STEM teacher education models, several converging trends and region-specific distinctions have emerged. These trends reflect a broader shift from mono-disciplinary training toward integrated, practice-based, technology-enhanced, and learner-centered approaches.

4.1. Converging Trends Across Models

All models emphasize early classroom immersion for pre-service teachers, as seen in UTeach and STEM Studio. This approach helps build confidence, pedagogical competence, and reflective capacity throughout the teacher education journey.

The programs consistently adopt interdisciplinary integration of science, technology, engineering, and mathematics instead of teaching them in isolation. In places like Singapore and the EU, interdisciplinary modules are designed around real-world issues to foster authentic learning.

All models employ inquiry-based learning**,** problem-based learning (PBL), and design thinking strategies. These methodologies aim to cultivate critical thinking, problem-solving, and creativity among both teachers and students.

Technology integration—such as simulations, virtual classrooms, learning management systems (LMS), and artificial intelligence tools—is becoming foundational, particularly in contexts like South Korea and Australia.

The models also emphasize comprehensive assessment, including lesson plan design, microteaching sessions, reflective journals, student-produced learning artifacts, and action research projects.

Dual mentorship models (as seen in the EU, involving both university and school-based mentors) and collaborative learning communities (as implemented in Singapore and Australia) underscore the importance of building professional learning networks among stakeholders.

4.2. Regional Differences and Contextual Variations

Region	**Key Strengths**	**Main Challenges**
North America (USA)	Strong university–school partnerships, systematized training frameworks	Limited emphasis on educational equity and diversity
Asia (Singapore, South Korea)	Closely aligned with national policy, strong emphasis on technology integration	Difficult to scale in decentralized or resource-constrained systems
Europe (EU)	Focus on holistic education, social equity, and cross-border collaboration	Challenging to harmonize policies and programs across multiple countries
Australia	Innovation in learning spaces, promotion of creativity	High infrastructure costs, limited applicability in rural or remote areas

4.3. Emerging Challenges in STEM Teacher Preparation

While recent advancements in STEM teacher education represent significant pedagogical and structural innovations, several systemic challenges persist and require strategic attention:

Limited scalability of resource-intensive models: Advanced training frameworks—such as design-based environments (e.g., STEM Studios) and dual mentorship systems—demand considerable physical infrastructure and human capital. This renders large-scale implementation infeasible in regions with limited resources or administrative fragmentation.

Tensions between disciplinary depth and interdisciplinary breadth: Achieving an optimal balance between deep subject-matter expertise and cross-disciplinary adaptability poses a persistent dilemma. Traditional curriculum structures often lack the flexibility to cultivate both competencies simultaneously within constrained program durations.

Equity in program design and learner access: Structural inequities related to gender, socioeconomic status, and geographic disparities are insufficiently addressed in many pre-service programs, raising concerns about inclusivity and representational diversity within the future STEM teaching workforce.

Sustainability of cross-sectoral collaboration: Effective coordination among universities, K–12 schools, and industry stakeholders remains highly contingent on external funding and national policy frameworks. In the absence of institutionalized mechanisms, such partnerships may lack continuity and long-term impact.

5. Application for Viet Nam

As Viet Nam intensifies its efforts to promote STEM education at the general education level, reforming teacher education programs has become an urgent priority. These reforms must address the needs for interdisciplinary integration, technological competence, and pedagogical innovation. Drawing on the analysis of international models, this section offers key recommendations tailored to the Vietnamese context and proposes a competency framework for STEM teachers—referred to as the 5C-AI.

5.1. Urgent Issues in STEM Teacher Education in Viet Nam

Mono-disciplinary curriculum lacking integration: Many teacher education institutions continue to train future teachers within isolated subject silos (e.g., physics, mathematics), with limited emphasis on interdisciplinary knowledge or pedagogical strategies that bridge STEM domains.

Delayed and insufficient practicum experiences: Practical teaching is often relegated to the final year of study, depriving students of early classroom exposure and experiential learning necessary for pedagogical development.

Inequity in educational technology training: There exists a significant disparity in digital readiness across institutions. Many teacher-training programs lack the infrastructure and resources necessary to effectively prepare pre-service teachers to integrate technology into STEM teaching.

Absence of a national competency framework for STEM teachers: Viet Nam currently lacks a formalized, national-level framework that articulates the essential competencies required of STEM educators, leading to inconsistent expectations and fragmented training outcomes.

5.2. Policy Recommendations and Program Implementation Strategies

5.2.1. Establish a National STEM Teacher Competency Framework

It is imperative that Viet Nam adopt a nationally endorsed STEM teacher competency framework. While international models such as TPACK, NGSS, and PCK-STEM offer valuable references, the framework must be localized to align with Viet Nam's educational conditions and development goals.

The research team proposes the 5C-AI competency model, which identifies five core competencies:

- Content Knowledge – mastery of subject-specific disciplinary knowledge;
- Creativity – capacity for innovation in instructional design and problem-solving;
- Collaboration – ability to work across disciplines and with diverse stakeholders;
- Critical Thinking – analytical skills for evaluating information and designing meaningful learning experiences;
- Computational Thinking – proficiency in algorithmic thinking and using technology to model and solve problems;
- All of which are underpinned by a transversal competency:
- AI Literacy – the capacity to understand, evaluate, and apply artificial intelligence tools in teaching and learning.

5.2.2. Implement Early and Continuous Teaching Practicum

Teacher education institutions in Viet Nam should collaborate closely with secondary schools to ensure that pre-service teachers are exposed to authentic classroom settings as early as their first or second year of study. These practicum experiences should be structured as ongoing engagements that include regular feedback from mentor teachers, thereby fostering pedagogical growth through reflection and iteration.

Drawing inspiration from Australia's STEM Studio model and the European Union's STEM Innovation Hubs, Vietnamese universities are encouraged to invest in the development of STEM simulation classrooms. These spaces should be equipped with advanced educational technologies to enable students to design, experiment with, and reflect on STEM lessons in realistic, risk-free environments that foster technological fluency and creativity.

As demonstrated by the South Korean model, future teachers must be prepared to:

- Utilize AI tools such as ChatGPT, digital simulations, and data analytics platforms in their instructional design;
- Develop digitized teaching content that supports integrated STEM instruction;
- Undergo formal assessment of their competencies in educational technology and AI integration, with such skills recognized as key indicators of teaching proficiency.

5.3. Suggested Implementation Roadmap

Phase	Proposed Activities
Year 1	Develop the 5C-AI competency framework; pilot initial training modules at two teacher education institutions.
Year 2–3	Establish STEM laboratories at three major universities; integrate early practicum experiences beginning in the second year of study.
Year 4–5	Conduct impact evaluations of the implemented models; propose policy recommendations for nationwide scaling based on evidence and feedback.

6. CONCLUSION

Over the past two decades, STEM teacher education worldwide has undergone remarkable progress. Exemplary models such as UTeach (United States), NIE STEM (Singapore), STEM Studio (Australia), TPACK–PBL (South Korea), and STEM-TP (European Union) demonstrate that preparing teachers for the 21st century requires an interdisciplinary, practice-oriented, technology-integrated, and learner-centered approach.

Based on this comprehensive review, several key principles have emerged:

- Early and continuous teaching practicum is essential for building teacher confidence and strong pedagogical competence.
- Integration of content knowledge with interdisciplinary pedagogy is the foundation for effective STEM instruction.
- Competency-based assessment and reflective practice significantly enhance the quality of teacher preparation.

- Technological fluency and AI literacy are no longer optional but essential competencies for future educators.

For Viet Nam, these international experiences provide a concrete and actionable roadmap for substantive reform in STEM teacher education. The proposed 5C-AI framework is not only a strategic orientation but also a practical tool to support teacher capacity development in the context of digital transformation and global integration.

7. Directions for Future Research

- Develop and experimentally validate the 5C-AI competency framework at teacher education institutions in Viet Nam.
- Conduct case studies on locally piloted models of STEM teacher education to explore context-specific implementation.
- Undertake longitudinal studies to track the development of pre-service teachers' STEM competencies and examine their impact on student learning outcomes.
- Carry out cross-national comparative research on centralized versus decentralized teacher education systems to assess the effectiveness of STEM program implementation.
- In an era where science and technology shape every facet of life, STEM teachers are not merely knowledge transmitters—they are future builders. Investing in their training is no longer optional; it is an essential requirement for sustainable development.

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