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STEM Teaching Competency of General Education Teachers: Concept, Definition, and Theoretical Framework

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ABSTRACT

STEM education (Science, Technology, Engineering, and Mathematics) is a teaching orientation that has garnered global attention in the context of the Fourth Industrial Revolution. Currently, STEM education is being integrated into general education as an active teaching model aimed at developing students' competencies. This paper explores teaching models, the teaching competencies of general school teachers, and STEM education in general schools to formulate a concept, definition, and competency framework for STEM teaching for general school teachers. The result is the establishment of a STEM teaching competency framework with 3 standards (STEM subject knowledge, STEM pedagogical skills, and technology usage skills in STEM teaching), 8 criteria, 14 indicators, and 26 behavioral manifestations derived from these 3 standards of STEM teaching competency for general school teachers. The proposal of this STEM teaching competency framework is significant in the training and professional development of teachers, enabling effective implementation of STEM education and improving teaching quality in general schools.

Keywords: STEM, teaching competency, STEM teaching competency, general education teachers

INTRODUCTION

In the 21st century, the demands on individuals are not limited to knowledge or skills but also encompass understanding and work efficiency. Individuals of the 21st century are emphasized on creativity skills, critical thinking skills, collaborative working skills, and problem-solving skills (Koenig et al., 2012). 21st-century skills involve accessing information and utilizing knowledge, rather than merely knowing it, as well as respecting and coexisting with diverse cultures (Kan & Murat, 2018a). In order to train individuals who can meet the skills required in the 21st century, STEM education has become one of the widely mentioned educational models in many countries around the world in recent years (Jang & Paulson, 2015), attracting attention in both developed and developing countries.

STEM-oriented teaching is organized by integrating engineering and technology concepts into science and mathematics curricula (Yang & Baldwin, 2020). A promising approach is to use engineering design, engaging students in solving authentic problems while collaborating with others to build, design, or create practical solutions (Lou et al., 2011). The implementation of engineering design-based units into the STEM curriculum is an example of project-based learning, which has been found to increase learners' interest in STEM education (Hughes, 2018).

Despite the rapid expansion of STEM education, there is currently no standardized framework that defines the specific competencies general education teachers need in order to implement STEM effectively. Previous frameworks (e.g., TPACK, TPACK-STEM, STEM teacher skills) may not be completely in line with the general curriculum, how instructors are trained, and the conditions in schools. This gap leads to significant difficulties for teacher preparation, professional growth, and implementation of the curriculum. Thus, a framework for STEM teaching competency that is rooted in context is crucial.

This study analyzes STEM teaching in general schools and the theoretical frameworks regarding the teaching competencies of general school teachers, thereby constructing a STEM teaching competency framework for general school teachers to address the following research questions:

1) What is the concept of STEM teaching competency for general school teachers?
2) How is STEM teaching competency for general school teachers defined?
3) What standards, criteria, indicators, and behavioral manifestations are included in the STEM teaching competency for general school teachers?

LITERATURE REVIEW

STEM Education

STEM is an acronym used to refer to the fields of Science, Technology, Engineering, and Mathematics. STEM education is an educational approach aimed at equipping students with scientific knowledge connected to its practical applications (Bracey et al., 2013). STEM education has garnered research interest across countries worldwide, with the Americas being the origin of STEM education. The foundation of STEM education lies in science education. To promote workforce training in the STEM fields, Canada has adopted policies similar to those of the United States, focusing on enhancing STEM research for students at all levels to motivate them to choose careers as they transition to post-secondary education (DeCoito, 2016).

Countries in the Australasian region have also shown early interest in STEM education. Developed in 2013 through a collaboration between the ME Program, local industry, and STEM teachers at Maitland Grossmann High School, iSTEM is a student-centred, integrated STEM subject for Year 9 and 10 that has expanded from its initial implementation in seven Hunter region schools to more than 262 schools across New South Wales (Australia Education Council, 2019). New Zealand has also recognized the application of STEM education in teaching as a means to develop inquiry and exploration skills. New Zealand considers digital technology as one of the four core areas of STEM education within the curriculum, encompassing six themes: algorithms, programming, data representation, digital devices and infrastructure, digital applications, and human-computer interaction (Granshaw, 2016).

From 2010 to 2014, alongside the Americas and Australasia, STEM education emerged as a major thematic area in the educational orientation of European countries (Wong et al., 2016). In European countries, coordinating educational agencies have researched and implemented STEM education, resulting in a publication titled "Science, Technology, Engineering, and Mathematics Education: Overcoming Challenges in Europe." This publication clearly outlines the challenges of STEM education in Europe and compares the STEM skills of students in European countries with those in Asia. It reports that approximately 20% of students in Asia receive STEM education, while Europe achieves only 2% (Kennedy & Odell, 2014). However, to date, STEM education has been widely implemented in European countries and has proven to be highly effective in teaching. Notably, countries such as Finland, Germany, Sweden, the United Kingdom, and Turkey have excelled in their STEM education initiatives (Freeman & Marginson, 2019).

Asia is a continent where countries implemented STEM education relatively early, only a few years after the United States. Research related to STEM education in Asian countries began in China around 2010, focusing on studying STEM education in the U.S. and the methods of implementing STEM education in China (Zhou & Li, 2021). From initial research on STEM education, there has been a significant explosion in the development of STEM education in China within just ten years. The government has issued an action plan for STEM education through 2029, outlining policies to enhance STEM education via collaboration between scientists and businesses. This partnership aims to maximize the investment of resources, manpower, equipment, funding, and projects to promote domestic science and technology (Ma, 2021). The Ministry of Education of China has mandated the incorporation of STEM education into the curriculum (Yan et al., 2020). This mandate has been enthusiastically embraced by schools, which have actively developed and implemented robust STEM education programs (Gao,

2014). In addition to China, Qatar has prioritized STEM education as one of the key areas of focus for its government (Sellami et al., 2017). This focus arises from the fact that Qatar, like many areas in the Arab Gulf countries, faces a shortage of workforce in STEM fields (Sellami et al., 2017), Therefore, incorporating STEM education into teaching is seen as a means to reform education in order to develop a workforce for Qatar's future knowledge-based society (Ali et al., 2021). STEM education is also a significant focus in Malaysia, where the government emphasizes encouraging students to enroll in Science, Technology, Engineering, and Mathematics subjects by integrating STEM education into teaching and learning since 2017 (Bahrum et al., 2017). Malaysia views STEM education as a teaching orientation in the context of the Fourth Industrial Revolution (Edy Hafizan et al., 2017), However, the implementation of STEM education in Malaysia currently faces challenges due to a significant educational disparity between rural and urban areas (Al Salami et al., 2017). STEM education in Vietnam has been implemented since 2010 through initiatives such as STEM Festivals and local STEM clubs (Pham & Tran, 2021).

STEM education has been implemented across four continents, with several African countries also recognizing the value of STEM education in teaching various subjects. They have proposed strategies to promote STEM education in schools. For example, South Africa has established clubs to support STEM education in secondary schools (Tikly et al., 2018). These international STEM developments reveal a shared global trend of integrating engineering design and technological applications into school curricula. However, the adoption of STEM in Vietnam has followed a different trajectory, with implementation beginning later and in a more fragmented manner. This highlights the need for a clearly defined STEM teaching competency framework specifically tailored for Vietnamese general education.

STEM Competencies

Competence is the combination of professional attributes, personal qualities, and behavioral patterns that an individual should possess and apply to successfully achieve specific goals or objectives (Shankar et al., 2020). The clearly defined competencies of teachers can serve as a reference for prospective teachers and as a roadmap for current educators who need to equip themselves with new skills to meet the rapidly changing needs of students and society (Alan & Güven, 2022).

STEM competencies refer to an individual's ability to appropriately apply STEM knowledge, skills, and attitudes in their daily life, workplace, or educational context (Nikolova et al., 2018a). STEM competencies encompass knowledge, skills, attitudes, and values related to various aspects of life (Slater & Burrows, 2015). A citizen with STEM competencies is empowered to enhance their daily life while contributing to the equitable, inclusive, and sustainable development of their nation and the world (Nikolova et al., 2018b). The components of STEM competencies are closely interconnected rather than isolated or separate; they combine in a manner that is contextual, cohesive, and holistic (Song & Zhou, 2021). In STEM education, students need to interact with and explore various elements of technology, skills, and relevant values to 'act' in order to solve problems and make decisions (Sari et al., 2019). Recent research has emphasized the need to systematically identify and structure STEM teacher competencies to support effective instructional practice, often using expert consensus approaches to define core competency domains (Caner & Ogan-Bekiroglu, 2025).

STEM competencies are demonstrated through the application of integrated knowledge in life via the utilization of STEM skills. STEM skills are those that individuals educated in science, technology, engineering, and mathematics at higher educational levels are expected to possess (Siekmann & Korbel, 2016). STEM skills are defined as the ability to generate insights into scientific and mathematical principles; the capacity to systematically and critically evaluate complex problems; and the skill to apply theoretical knowledge of a subject to practical issues. This includes the ability to communicate scientific topics to stakeholders and others, as well as creativity, logical reasoning, and practical intelligence (Carlisle & Weaver, 2018). STEM skills, categorized as technical skills, refer to the ability to apply scientific and mathematical knowledge to design technologies and scientific products or to perform engineering and technology tasks within the fields of science and technology in the STEM sectors (Leung, 2020). Based on the definitions and concepts of competence, STEM competencies can be proposed to include the following components:

(a) STEM Knowledge: This encompasses scientific knowledge and technical knowledge relevant to each STEM field, along with the ways in which ideas, concepts, principles, and theories are interconnected (Bybee, 2010).

(b) Technical Knowledge Related to STEM Careers: This includes knowledge related to the application of skills, attitudes, and values in a specific field, profession, or job within the technical occupations related to STEM fields, including (Siekmann & Korbel, 2016): (1) Technical Knowledge and Technology: Knowledge of the practical applications of engineering science and technology, including the application of principles, techniques, processes, and equipment in the design and production of various products and services, (2) Computers, Electronics, and Programming: Knowledge of electrical circuits, processors, microcontrollers, electronic devices, computer hardware and software, including applications and programming, (3) Design and Technology: Knowledge of design techniques, tools, and principles related to the production of accurate technical plans, drawings, blueprints, and

models, (4) Manufacturing and Processing: Knowledge of materials, production processes, quality control, costs, and other techniques aimed at maximizing efficiency in the production and distribution of goods, (5) Construction and Fabrication: Knowledge of materials, methods, and tools related to the construction or repair of structures (such as houses, buildings, equipment) or other structures (such as highways and roads), (6) Mechanics: Knowledge of machinery and tools, including their design, use, repair, and maintenance, (7) Mathematics: Knowledge of mathematics, algebra, geometry, calculus, statistics, and their applications, (8) Physics: Knowledge of physical principles, laws, relationships between them, and applications to understand forces, materials, the atmosphere, as well as mechanical, electrical, atomic, and subatomic structures and processes, (9) Chemistry: Knowledge of the chemical composition, structure, and properties of substances, as well as the chemical processes and transformations they undergo. This includes the use of chemicals and their interactions, hazard signs, manufacturing techniques, and handling methods, (10) Biology: Knowledge of the anatomy and physiology of plant and animal species, cells, functions, interdependencies, and interactions with each other and the environment, (11) Operation, Monitoring and Control, Troubleshooting and Repair: Controlling the operation of equipment or systems, observing indicators to ensure a machine operates correctly, identifying the causes of operational failures, and deciding on appropriate actions, (12) Maintenance and Repair of Equipment: Performing routine maintenance on equipment and determining when and what type of maintenance is necessary, repairing machinery or systems using necessary tools, (13) System Analysis and Evaluation, Quality Control: Determining how a system operates and how changes in conditions and environments will affect outcomes, identifying measures or indicators of system performance, and necessary actions to improve or rectify performance against system goals.

(c) STEM Skills: These are the essential skills required to perform tasks related to STEM, including cognitive skills, information processing and data analysis skills, problem-solving and engineering thinking skills, scientific reasoning skills, computational thinking and IT skills, design thinking, creativity, and innovation, manipulative and technological skills, as well as collaboration and communication skills (Kan & Murat, 2018) including: (1) Cognitive Skills: These skills involve managing and processing information, including recognizing, collecting, processing, and utilizing relevant data to make decisions, (2) Information Processing and Data Analysis Skills: Information processing skills are essential for searching, synthesizing, organizing, and selecting relevant information for specific tasks to generate, comprehend, interpret, analyze, and reason about experiential data. This includes verifying authenticity, validity, and reliability, as well as effectively displaying results within STEM education, (3) Problem Solving and Engineering Thinking: Problem-solving is a hallmark of STEM research and careers. This skill enables researchers to design, fabricate, and utilize machinery in STEM contexts, (4) Scientific Processing: Teaching STEM involves creating a product or a new solution related to real-life contexts. Scientific processing skills are crucial in systematically finding solutions to problems or making decisions. These skills manifest in observation, classification, measurement, reasoning, prediction, communication, utilizing spatial relationships, interpreting data, identifying activities, controlling variables, formulating hypotheses, and experimentation. Thus, these skills are vital components of STEM competency, (5) Computational Thinking and IT Skills: Effectively utilizing skills and capabilities to connect Information and Communication Technology (ICT) is vital for advancing STEM fields, (6) Design Thinking, Creativity, and Innovation: in STEM education, design thinking provides a structured framework that encourages and fosters learners' abilities to innovate and improve. Design thinking integrates important elements and creative thinking through stages such as information gathering, creative brainstorming, ideation, prototyping, trial and error, reviewing, redesigning, filtering, testing, and implementation, which can be effectively applied to STEM learning and careers, (7) Manipulative and Technological Skills: Manipulative and technological skills refer to psychomotor skills related to the precise and safe use of equipment in STEM education, (8) Collaboration and Communication Skills: Effective collaboration and communication skills do not always occur naturally and must be cultivated, as most tasks are complex and interconnected and cannot be achieved through individual effort alone.

(d) STEM Attitudes and Ethical Values: Engaging in STEM activities requires a combination of STEM knowledge, practical STEM skills, and attitudes and ethical values related to STEM. Ethical values in STEM depend on the comprehensive development of knowledge, skills, attitudes, and a profound awareness of civic responsibility. Participation in authentic real-world situations, challenges, and dilemmas that demand intervention and innovative solutions, such as addressing food or housing shortages, climate change, migration, genetic testing, etc., provides opportunities for students to learn how to develop and guide intervention measures as well as innovative solutions that serve the greatest good with minimal harm. Therefore, ethical decision-making must be an integral part of STEM learning and practice (Joyce et al., 2018).

Although previous literature provides extensive descriptions of STEM knowledge, skills, and attitudes, these competencies have not yet been systematically translated into a teaching competency framework suitable for general education teachers in Vietnam. Therefore, this study addresses a critical gap by synthesizing these competencies and adapting them into a contextually relevant framework.

Teaching Competence

The competence of teachers is formed and developed based on the execution of specific professional activities. Teachers' teaching competence creates a close connection between professional knowledge, the ability to carry out specialized and professional activities, and the process of developing personal qualities and professional values (Hedley, 1997).

Shulman (1987) describes a framework for teacher competence, which can be summarized as follows: (1)Content Knowledge: The knowledge of the subject matter being taught, (2)General Pedagogical Knowledge: This includes principles and strategies for managing and organizing classroom environments, (3)Curriculum Knowledge: Understanding the curriculum and how it is structured, (4)Pedagogical Content Knowledge: The knowledge of how to effectively teach specific content, (5)Knowledge of Learners and Their Characteristics: Understanding the diverse characteristics of students and how they learn, (6)Knowledge of Educational Contexts: This encompasses the characteristics of classrooms, schools, communities, and cultures, (7) Knowledge of Educational Ends, Purposes, and Values: An understanding of the goals and values of education, along with their philosophical and historical foundations (Shulman, 1987).

Teaching Competence consists of several basic component competencies: (1) Preparation Competence: This includes actions such as selecting reference materials to prepare for teaching activities, determining the objectives of the lesson (derived from the subject objectives and educational level objectives), (2) Implementation Competence: This is demonstrated through the teaching and educational practice, encompassing skills such as classroom management, checking previous lessons, introducing new content, skill practice, knowledge development, and assessing and encouraging students, (3) Language Use Competence: This is a crucial competency. When evaluating a teacher's teaching competence, it is essential to consider their expression and presentation skills, (4) Competence in Using Teaching Equipment and Materials: This is an indispensable competency for teachers at any educational level today. Equipment and materials not only serve as effective tools for teaching and learning but also stimulate creative thinking for both teachers and students, (5) Social Activity Competence in and out of School: The focus of communication relationships is between teachers and students. This relationship requires the teacher to mobilize all their abilities to establish effective teaching interactions. Importantly, through the communication process, the teacher can positively influence the learners, (6) Evaluation Competence: The teacher's ability to accurately assess students significantly impacts both the results of self-directed learning and the ethical development of students and the teacher themselves (Caena & Redecker, 2019).

Danielson's Framework for Teaching (2011) simplifies the teaching competencies into four main domains: (1) Preparation and Planning: This involves the teacher's ability to plan lessons effectively, set clear objectives, and select appropriate instructional strategies and materials that align with students' needs, (2) Classroom Environment: This focuses on creating a positive, respectful, and supportive classroom atmosphere that fosters student engagement and promotes a sense of community, (3) Instructional Activities: This domain encompasses the actual teaching practices, including how the teacher delivers content, interacts with students, and uses various teaching methods to facilitate learning, (4) Professional Responsibilities: This involves the teacher's commitment to their professional growth, including reflective practice, collaboration with colleagues, and engagement with the community to enhance student learning (Danielson, 2011). Empirical studies in STEM education have also shown that contextualized STEM integration experiences play a critical role in developing pedagogical competence among pre-service and in-service teachers (Morais et al., 2025).

The teaching competence of teachers depends on pedagogical competence. The pedagogical competence of Koehler & Mishra (2009) (TPACK) includes seven areas: (1) Deep knowledge of the subject matter, (2) Teaching methods, (3) Knowledge of technology in teaching, (4) Structuring/restructuring teaching content to suit specific contexts and specific learners, aligned with teaching objectives, (5) Structuring/restructuring teaching content to create opportunities for technology application, (6) Applying technology, tools/technological means in teaching and assessment, (7) Highly integrated teaching content in both substance and implementation (Koehler & Mishra, 2009). These are presented in **Figure 1.**

The TPACK framework in STEM education is based on the view that if teachers have the "TPACK" - an understanding of pedagogical methods, subject content, and appropriate technologies in STEM education - knowledge and competencies which allow them to design and implement STEM lessons effectively. This enables teachers to integrate various components of STEM into teaching in a clear and systematic manner (Chai et al., 2019; Štuikys & Burbaitė, 2018). When teachers are equipped with sufficient knowledge and competencies under the TPACK framework, they will have a comprehensive understanding of subject content, teaching methods, and appropriate technologies to design STEM lessons in an effectively integrated way. This helps STEM teachers enhance the quality of teaching, foster their students' creative thinking, problem-solving abilities, and application of knowledge to real-life situations. Teacher competencies under the TPACK-STEM model ensure that teachers are adequately prepared to deliver STEM teaching effectively (**Figure 2**).

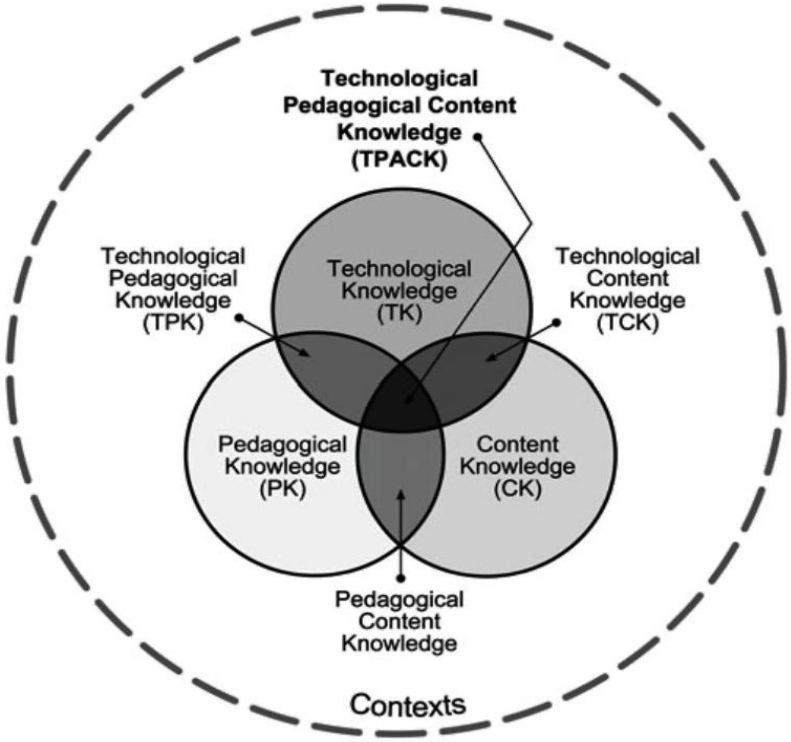

Figure 1. TPACK Model (Koehler & Mishra, 2009)

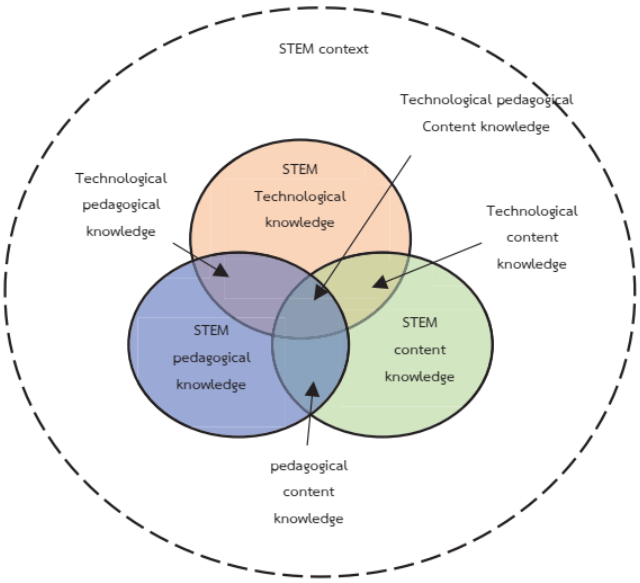

Figure 2. TPACK-STEM (Abdullah & Mahmud, 2024)

These competencies provide the theoretical foundation for constructing the STEM teaching competency framework proposed in this study. They guide the selection of standards, criteria, and indicators, ensuring alignment between international conceptualizations and national educational requirements.

METHODOLOGY

The study employed a mixed-methods approach, combining theoretical research with expert consultation.

Step 1: Analyze existing teaching competency frameworks and STEM competency frameworks to develop a STEM teaching competency framework suitable for secondary school teachers, thereby proposing definitions, concepts, and the STEM teaching competency framework for secondary teachers.

Step 2: Seek expert opinions on the proposed STEM teaching competency framework for secondary school teachers, as presented in Table 1.

Table 1. A sample of experts on the STEM teaching competency framework who are actively involved in STEM education specifically

No	Experts	Number of Expert Opinions in Round 1	Number of Expert Opinions in Round 2
1	General Education Teachers		
2	High School Teachers (Physics, Chemistry, and Biology)	3	6
	Middle School Teachers (Natural Sciences)	3	3
3	University Lecturers in Teacher Education (Physics, Chemistry, Biology)	4	6
Total		10	15

The experts included teachers who had directly participated in STEM teaching, university lecturers engaged in STEM research and teaching, as well as those who supervised pre-service teachers in STEM education.

Expert consultation was conducted in two rounds, as follows:

Round 1: Experts were asked to provide feedback on the STEM teaching competency framework at the level of standards, criteria, and indicators. Based on their feedback, revisions and adjustments were made to the drafted content.

Round 2: Experts were further consulted on the revised theoretical framework to standardize the STEM teaching competency framework for secondary school teachers.

RESULTS AND DISCUSSION

Basis for developing the concept, definition, and STEM teaching competency framework for secondary school teachers

From the literature review, in order to construct a STEM teaching competency framework for secondary school teachers, the study examined several teaching models and STEM teaching competency frameworks (Table 2). One of the most important actors in STEM education is teachers and educators, who have the ability to integrate core knowledge, STEM knowledge, and skills, and teach them successfully in an inspiring manner (Siekmann & Korbel, 2016).

Table 2. Teaching competency frameworks and STEM teaching competency frameworks in STEM education

No	Teaching Model	Content	Description
1	TPACK Model (Koh & Koh, 2016)	Technological Content Knowledge - TCK	Refers to understanding the relationship between technology and content. Disciplinary knowledge is often used to identify and explain the functions of technology in teaching.
		Pedagogical Content Knowledge - PCK	Refers to the organization, adaptation, and adjustment of content so that it can be taught. Teachers demonstrate knowledge of teaching methods, ways of representing content, and how to explain concepts to students.
		Technological Pedagogical Knowledge	Refers to knowledge about how to apply technology in teaching, such as methods, strategies, and technology use to support teaching.
		Technological Pedagogical Content Knowledge - TPACK	Refers to the integration of all three types of knowledge to develop effective teaching plans and instructional practices

Table 2. Continued

2	TPACK-STEM Competency Framework (Niess et al., 2009)	Awareness of the purpose of integrating technology in mathematics teaching	Teachers understand the reasons and benefits of using technology in teaching
		Understanding how students acquire and think about mathematics when using technology	Teachers grasp how technology influences students' learning processes and thinking.
		Knowledge of the curriculum and technology-integrated instructional materials	Teachers know how to select and use technology-integrated instructional materials.
		Teaching strategies and ways of representing mathematical content using technology	Teachers apply effective teaching methods and use technology to illustrate content
3	STEM Teacher Competency Framework (Guzey et al., 2016)	Understanding of STEM content	Possess knowledge of STEM education
		Understanding of STEM instructional approaches	Ability to develop STEM lesson plans and implement STEM teaching
		Technological Competence	Ability to apply information technology in STEM teaching
		STEM Learning Design Competence	Ability to design STEM learning and experiential activities for students
4	TPACK-STEM Competency Framework (Abdullah & Mahmud, 2024)	Content Knowledge	+ In-depth knowledge of each subject within STEM (Mathematics, Science, Technology, Engineering). + Understanding of how to integrate knowledge across different fields.
		Pedagogical Knowledge	+ Ability to organize teaching activities and apply appropriate instructional methods. + Understanding of how students acquire and process STEM knowledge.
		Technology Knowledge	+ Ability to use technology to support STEM teaching. + Understanding of technologies and software related to STEM (e.g., Arduino, 3D printing, digital simulation, etc.).
		Technological Pedagogical Content Knowledge (TPACK)	+ Integrating STEM knowledge with technology to design engaging lessons. + Developing effective STEM-integrated teaching methods.
		Engineering Design Knowledge	+ Applying the engineering design process in STEM teaching. + Creating learning environments for students to carry out design and fabrication projects.
		STEM Assessment Knowledge	+ Developing tools to assess students' STEM competencies. + Assessing learning processes and products with a competency-based approach.

Based on the teaching competence frameworks and the concept of STEM competence, this research constructs the concept and defines STEM teaching competence as follows:

Concept, definition, and STEM teaching competency framework for secondary school teachers

STEM teaching competence is the ability of teachers to design, organize, and implement effective STEM teaching activities. This competence includes an understanding of the fields of Science, Technology, Engineering, and Mathematics, along with pedagogical skills and classroom management skills. In addition to competencies such as managing students and maintaining a positive learning environment, the ability to encourage and develop

critical and creative thinking in students is also essential. The main components of teachers' STEM competencies according to the TPACK model can be seen in **Table 3**.

After constructing the concept and definition of STEM competence for general education teachers, the research organized a seminar with 10 experts in Vietnam in May 2024. The research team held discussions and sought the opinions of experts on the component competencies of STEM teaching competence, with the results presented in **Table 4**.

After obtaining feedback from experts in Round 1, the study has made adjustments based on some of the experts' suggestions and proposed the STEM teaching competence and the framework describing the components of STEM teaching competence in **Figure 3**.

Based on the proposed STEM teaching competence model for secondary school teachers, grounded in the description of component competences from the studied teaching models combined with the concept of the STEM teaching process, the study proposes a theoretical framework for STEM teaching competence for secondary school teachers. This framework consists of four elements: standards, criteria, indicators, and behavioral manifestations, as presented in **Table 5** (Appendix 1).

After designing the framework of STEM teaching competence, detailing each criterion, indicator, and behavioral manifestation for secondary school teachers, the study continued to seek feedback from 15 experts in Vietnam (as described in the sample in the research methodology section). The results of the expert feedback are presented in **Table 6**.

The results of the discussion in **Table 4** show that all 15 experts agree with the standards and criteria of STEM teaching competence, and 13 out of 15 experts (accounting for 86.66%) agree with the indicators and behavioral manifestations described in the STEM teaching competence for secondary school teachers. Therefore, it is possible to finalize the STEM teaching competence framework for secondary school teachers, including 3 standards, 8 criteria, 14 indicators, and 26 behavioral manifestations as presented in **Table 5**, has been finalized based on expert consultation in **Table 6**.

Table 3. STEM Teaching Competencies of Secondary School Teachers

Competency Component	Criteria	Description
Content Knowledge The subject matter knowledge of teachers in STEM teaching is a critical foundation that ensures the effectiveness of teaching subjects in the fields of Science, Technology, Engineering, and Mathematics. Mastery of subject matter knowledge in STEM teaching not only helps teachers feel confident in their instruction but also enables them to create rich and meaningful learning experiences for students	STEM Content Knowledge	• Science: A deep understanding of scientific principles, concepts, and processes in subjects such as Physics, Chemistry, Biology, and Earth Science. • Technology: Knowledge of information technology, software, hardware, and how to use them in learning and teaching. • Engineering: Understanding engineering principles, technical design, and the process of solving engineering problems. • Mathematics: A solid understanding of mathematical concepts, including algebra, geometry, probability, and statistics.
	Interdisciplinary Knowledge	The ability to integrate knowledge from the fields of Science, Technology, Engineering, and Mathematics to solve complex and practical problems.
Pedagogical Skills Pedagogical skills are a key factor that helps teachers effectively implement STEM teaching methods. Teachers need skills in designing and implementing learning activities that are suitable for the STEM model	Organizing/Implementing STEM Teaching	The ability to organize integrated STEM learning activities, facilitating students to develop problem-solving skills, critical thinking, and creativity.
	Assessing Students in STEM Teaching	Utilizing diverse assessment methods and tools to measure and improve student learning outcomes
Technological Skills Knowledge of educational tools and software, understanding how to use them to support the teaching and learning process	Use of information technology tools in teaching and assessment in STEM education.	Understanding and ability to use educational tools and software, with knowledge of how to apply them to support teaching and assessment in STEM education

Table 4. Results of Experts' Discussion on STEM Teaching Competence

STEM teaching competence	Expert Discussion Opinions
The components of competence include: - Subject knowledge - Pedagogical skills - Technology use skills	All 10 experts agree on the three components of STEM teaching competence for secondary school teachers. Three high school teachers suggested, "It is necessary to add the term STEM or STEM teaching to each component name to differentiate STEM teaching from traditional teaching."
Components of competence in subject knowledge	All 10 experts agree with the description of subject knowledge, including agreement on the two components: Knowledge of STEM fields and Interdisciplinary Knowledge. One expert, a Natural Science teacher, commented: "It should be specified that interdisciplinary knowledge belongs to the fields of Science, Technology, Engineering, and Mathematics". Another expert from higher education stated: "It should be specified that interdisciplinary knowledge belongs to the STEM fields and additional content on practical applications in STEM interdisciplinary knowledge should be included".
Content of pedagogical skills	All 10 experts agree with the description of subject knowledge, including agreement on the two components: Knowledge of STEM fields and Interdisciplinary Knowledge. One university lecturer commented: "It is necessary to develop indicators for this component related to the teaching process, including: skills for developing STEM teaching plans, STEM teaching skills, and assessment skills in STEM teaching".
Content on technology use skills	All 10 experts agree with the description of subject knowledge, including agreement on the two components: Knowledge of STEM fields and Interdisciplinary Knowledge. One high school teacher suggested: "An additional component for developing students' technology use skills should be included to demonstrate that STEM teaching impacts all of students' competencies"

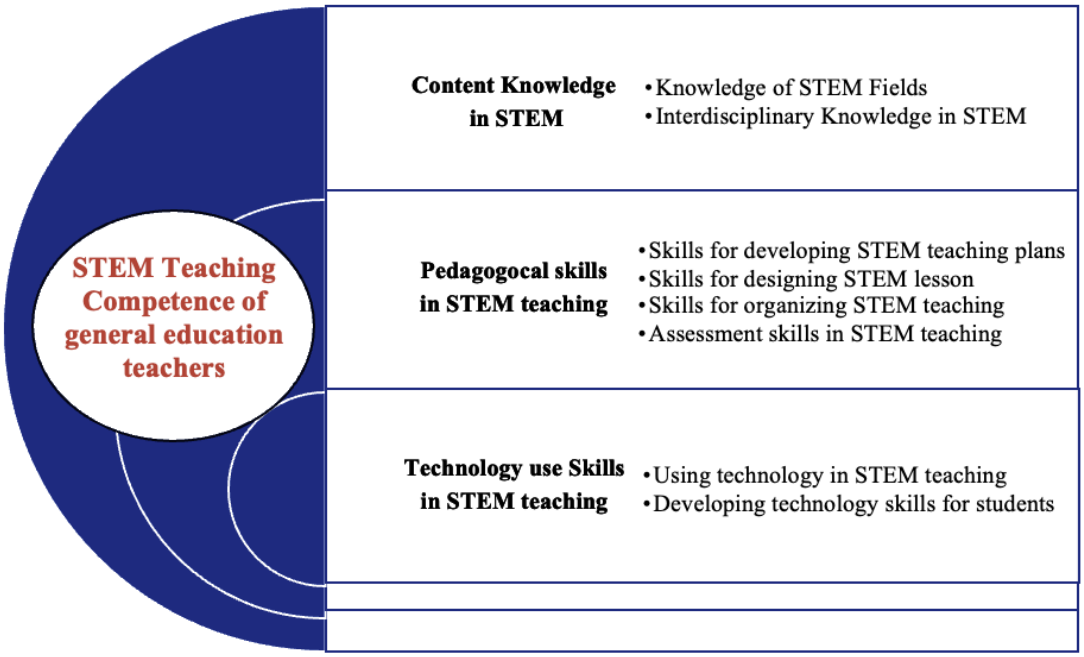

Figure 3. STEM teaching competence model of general education teachers Model (Proposed by the authors)

Table 6. Results of feedback from 15 experts

Experts	Standards	Criteria	Indicators	Behavioral manifestations
1	Agree	Agree	Agree	Agree
2	Agree	Agree	Agree	Agree
3	Agree	Agree	Agree with the criteria, with the suggestion: "move indicator A2.2 to the indicator of criterion B.2"	Agree with the behavioral manifestations, with the suggestion: "move behavioral manifestation A.2.2.1 to the section of behavioral manifestations of criterion B.2".
4	Agree	Agree	Agree with the criteria, Suggestion: "It is necessary to provide a clear description of indicator C2.2"	Agree with the behavioral manifestations, Suggestion: "It is necessary to provide a detailed description of the behavioral manifestations of indicators C2.2.1 and C2.2.2, which are currently presented in the competence framework in a general manner without being described in terms of skills"
5	Agree	Agree	Agree	Agree
6	Agree	Agree	Agree	Agree
7	Agree	Agree	Agree	Agree
8	Agree	Agree	Agree	Agree
9	Agree	Agree	Agree	Agree
10	Agree	Agree	Agree	Agree
11	Agree	Agree	Agree	Agree
12	Agree	Agree	Agree	Agree
13	Agree	Agree	Agree	Agree
14	Agree	Agree	Agree	Agree
15	Agree	Agree	Agree	Agree

CONCLUSION

Building the concept, definition, and framework of STEM teaching competencies helps establish a common understanding within the educational community, thereby facilitating the exchange of information and experiences between teachers and researchers. Establishing a STEM teaching competency framework not only enhances teachers' competencies but also supports the management and improvement of educational quality in schools, meeting the growing needs of society in the era of rapid digital transformation. The study has established the concept, definition, and framework of STEM teaching competencies, comprising three standards (STEM professional knowledge; STEM teaching pedagogical skills; STEM teaching technology skills), eight criteria, 14 indicators, and 26 behavioral manifestations, derived from these three standards for general teachers. The proposal of a STEM teaching competency framework for general education teachers is meaningful for training and fostering teachers to perform well in STEM teaching, thereby improving teaching effectiveness in general schools.

The study used expert interviews in 2 rounds (round 1 with 10 experts and round 2 with 15 experts) and initially standardized the STEM teaching competency framework for secondary school teachers. A minor limitation of this study is that it did not seek expert opinions on a large scale and has not yet evaluated the teaching competency of secondary school teachers in the classroom. However, based on the expert opinion form, the STEM teaching competency framework is appropriate. It provides a clear set of standards that help teachers understand the requirements for effective STEM teaching. Teachers can rely on this competency framework to evaluate and improve their teaching skills, thereby enhancing their professional qualifications and their ability to meet students' learning needs. The competency framework helps teachers become more aware of integrating different subjects in STEM teaching, thereby helping students develop critical thinking and problem-solving skills. The STEM teaching competency framework is also essential for educational managers, providing a basis for developing and adjusting teacher training programs and helping ensure that training content aligns with practical requirements. The competency framework can be used to evaluate teachers' teaching quality, thereby enabling appropriate support and improvement measures, promoting innovation in teaching methods, creating a creative learning environment, and encouraging students to explore new knowledge.

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Ethical Statement

This research did not involve clinical or experimental studies with human participants and was based solely on expert interviews. The study design and interview procedures were ethically approved by the National Foundation for Science and Technology Development (NAFOSTED) under Project code 503.01-2021.06. All expert information was treated confidentially, and data were handled in accordance with ethical standards for privacy and participant protection.

Competing Interests

The authors declare that they have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors jointly contributed to the conception and design of the study, data collection and analysis, manuscript preparation, critical revision, and final approval. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Artificial Intelligence (AI) Disclosure

ChatGPT (OpenAI, 2025) was used solely to assist with language-related tasks, including paraphrasing, grammar, wording, and clarity during the revision process. The AI did not contribute to the research design, data analysis, interpretation of results, or conclusions. All content was reviewed and finalized by the author, who assumes full responsibility for the manuscript.

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Appendix 1

Table 5. Framework of STEM Teaching Competence of general education teachers (proposed by the authors)

Standards	Criteria	Indicators	Behavioral manifestations
A. Content Knowledge in STEM	A.1. Knowledge of STEM Fields	A1.1. Comprehensive Understanding of the Fields of Science, Technology, Engineering, and Mathematics and Interdisciplinary Knowledge, Integration of Knowledge for Real-World Problem Solving	A.1.1.1. Understanding of Scientific Principles, Concepts, and Processes in Physics, Chemistry, Biology, and Earth and Space Science. A.1.1.2. Knowledge of Engineering Principles, Design Processes, and Techniques for Solving Engineering Problems. A.1.1.3. Strong Grasp of Mathematical Concepts, Including Algebra, Geometry, Probability, and Statistics.
		A1.2. Ability to Integrate Knowledge from the Fields of Science, Technology, Engineering, and Mathematics to Solve Complex, Real-World Problems.	A.1.2.1. Applying Interdisciplinary Knowledge to Real-World Situations and Learning Projects. A.1.2.2. Understanding of Industrial and Career Fields Related to STEM at National and Local Levels.
	A2. Pedagogical Knowledge in STEM	A2.1. Integrating Elements of Science, Technology, Engineering, and Mathematics into STEM Topics.	A.2.2.1. Ability to Design STEM Integrated Topics that Align with the National Curriculum.
		A2.2. Mastery of Modern and Effective Teaching Methods in STEM Education.	A.2.2.2. Designing STEM Integrated Learning Activities that Facilitate Students' Development of Problem-Solving, Critical Thinking, and Creativity Skills Through Projects Incorporating Science, Technology, Engineering, and Mathematics.
B. Pedagogical Skills in STEM teaching	B.1. Skills for developing STEM teaching plans	B1.1. Familiarity with National and International STEM Standards and Curriculum Frameworks.q	B1.1.1. Clearly Defining Learning Objectives and Program Outcomes, Ensuring Alignment with Educational Standards and Student Needs.
		B1.2. Developing Integrated STEM Themes that Combine Theory and Practice, Creating Real-World Projects and Learning Activities.	B1.2.1. Collaborating with Other Teachers, School Staff, and External Experts to Develop and Implement STEM Programs.
	B.2. Skills for designing STEM lessons	B.2.1. Ability to Design Lessons that Integrate the Fields of Science, Technology, Engineering, and Mathematics to Foster Students' Thinking Skills	B2.1.1. Designing Project-Based Lessons Where Students Can Apply Knowledge to Solve Real-World Problems Through Projects (Project-Based Learning) and Inquiry (Inquiry-Based Learning). B2.1.2. Designing Learning Activities that Include Scientific Experiments, Programming,

			Engineering Design, and Real-World Application Problems Based on Questions, Encouraging Students to Investigate, Explore, and Research Independently.
	B3. Skills for organizing STEM teaching	B.3.1. Guiding Students to Approach and Solve Complex Problems by Applying STEM Knowledge and Skills.	B3.1.1. Guiding Students in Planning Their Learning, Managing Time, and Self-Assessing Their Progress.
		B.3.2. Using Active Teaching Techniques to Encourage Students' Active Participation, Such as Group Discussions, Experiments, and Project-Based Activities	B.3.2.1. Ensure that necessary resources (equipment, materials, space, and time) are appropriately allocated to support STEM activities. B.3.2.2. Employ effective behavior management strategies to maintain and foster an optimal learning environment for students.
		B.3.3. Building and Maintaining a Positive Learning Environment that Encourages Student Engagement and Collaboration.	B3.3.1. Effectively Managing Time to Ensure All Activities Are Completed on Schedule and Meet Quality Standards. B3.3.2. Ability to Handle Emerging Situations in the Classroom Flexibly and Effectively.
	B4. Assessment skills in STEM teaching	B4.1. Use appropriate assessment methods and tools to evaluate students' competencies in STEM education.	B4.1.1. Using Project-Based and Real-World Problem Assessments to Evaluate Students' Ability to Apply Knowledge. B4.1.2. Providing Continuous and Constructive Feedback to Help Students Understand Their Strengths and Areas for Improvement. B4.1.3. Encouraging Students to Self-Assess and Peer Assess to Develop Critical Thinking and Creativity Skills.
C. Technology use skills in STEM teaching	C.1. Application of technology in STEM teaching	C1.1. Using Modern Tools and Technology to Support Teaching and Learning.	C1.1.1. Proficiency in Using Educational Tools and Software to Support Teaching and Learning, Such as Simulations and Engineering Design Applications. C1.1.2. Using Online Learning Platforms and Communication Tools Such as Email, Forums, and Messaging Apps to Communicate with Students and Parents. Providing Detailed and Personalized Feedback for Each Student. C1.1.3. Using Technology Tools to Manage the Classroom More Effectively, from Lesson Planning to Tracking Student Progress and Communicating with Parents.

	C.2. Developing technology skills for students	C.2.1. Guiding Students on How to Use Technology Effectively and Safely in Learning and Daily Life. C.2.2. Educating Students on Ethical Issues and Copyright Related to Cultural and Legal Technology Use.	C2.1.1. Guiding Students to Use Technology to Effectively Collect, Manage, and Analyze Information to Solve Problems and Make Decisions. C2.1.2. Guiding Students to Use Technology to Create Innovative, Engaging, and High-Quality Products, as Well as to Solve Problems Creatively. C2.2.1. Guiding Students to Access, Evaluate, and Manage Information and Data Safely and Effectively. C2.2.2. Guiding Students to Use Technology While Ensuring Ethical and Safe Practices, Protecting Personal Data, and Engaging in Safe Online Interactions.