STEM Education

STEM Education, 6(5): 908–926
DOI: 10.3934/steme.2026036
Received: 09 March 2026
Revised: 09 July 2026
Accepted: 16 July 2026
Published: 19 August 2026

https://www.aimspress.com/journal/steme

Research article

Development and validation of a STEM teaching capacity measurement tool for primary school teachers in Vietnam

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Academic Editor: Jun Shen

Abstract: The digital transformation era underscores the pivotal role of globalized STEM education in fostering a workforce capable of navigating contemporary and prospective societal challenges. In Vietnam, STEM education is oriented as a core strategy and is in the early stages of development. Concurrently, the instructional proficiency of educators in STEM disciplines emerges as a critical determinant for optimizing educational outcomes in this field. The lack of a reliable measurement tool for teachers' STEM teaching capacity is an important issue affecting the development of STEM teaching capacity and the effectiveness of STEM initiatives. Through a rigorous, reliable process of building and validating a scale, we developed a measurement tool to measure STEM teaching capacity among primary school teachers in Vietnam. This measurement tool ensures reliability and validity; it includes 37 items, representing 6 dimensions of STEM teaching capacity (teachers' knowledge of STEM education, STEM lesson design capacity, STEM teaching implementation capacity, STEM lesson assessment capacity, digital technology capacity, and teachers' attitudes toward STEM education). With these findings, we expect that this tool will help to make the assessment of STEM teaching capacity more comprehensive and realistic. At the same time, this could also be helpful in building strategies to develop STEM teaching capacity for teachers; it not only focuses on knowledge and teaching skills as before, but also needs to pay attention to digital technology competence and promote positive attitudes toward STEM teaching of teachers.

Keywords: scale validation, scale development, STEM teaching capacity, STEM education, confirmatory factor analysis, educational measurement, digital competence

1. Introduction

In each country's development strategies, educational development is considered the key to enhancing national capacity, especially in the digital, collaborative, and globalized era [1]. In today's context, the era of science, engineering, and technology is at the core; to meet society's human resource needs, STEM education (science, engineering, technology, mathematics) plays a very important role [2]. Early exposure to STEM curricula facilitates the simultaneous cultivation of mathematical reasoning, foundational scientific literacy, and linguistic proficiency, all of which constitute the bedrock for lifelong scientific fluency [3]. Such educational approaches serve as a robust catalyst for fostering creative thinking, complex problem-solving abilities, and innovative mindsets [4]. Nevertheless, integrating STEM at the primary level presents significant pedagogical hurdles for educators striving to equip learners with essential STEM literacy [5,6].

Teachers' STEM teaching capacity includes awareness, knowledge, and skills to effectively carry out STEM teaching activities [7,8]. Teachers' STEM teaching capacity can be measured through component capacities such as general cognitive capacity of STEM integrated teaching, capacity to design STEM integrated topics, capacity to organize teaching of STEM integrated topics, and capacity to test and evaluate [9]. Many studies have confirmed that the effectiveness brought to students through STEM education programs depends largely on teachers' STEM capacity [10,11]. In addition, the rapid development of technology and information requires teachers to have additional digital competencies to be able to integrate and take advantage of the benefits of technology in educational activities [12]. According to Arikan et al. [13], STEM teaching capacity should be systematically evaluated and supervised to enhance the overall quality of STEM education, and having a set of reliable assessment tools is essential for better STEM education. In addition, Baek et al. [14] argued that competency scales must align with the swift advancements in both education and technology.

In Vietnam, STEM education has been affirmed by the education sector as one of the focuses of the country's education, and it is in the beginning stages of application to primary school students (implementation began in 2023). Along with that, the current source of teachers teaching STEM to primary school students is mainly homeroom teachers, who do not have knowledge and skills in teaching STEM; as such, developing their capacity to teach STEM is considered a significant strategic challenge. Issues related to capacity and criteria for measuring and evaluating the STEM teaching capacity of teachers in general and primary school teachers in particular are still quite new topics, not yet reaching consensus. Previous measurements and assessments have been mainly based on the teaching capacity framework for teachers in general, so they lacked comprehensiveness and were not close to reality, especially in the context of the current strong development of digital technology. Therefore, building a set of tools to measure teachers' STEM teaching capacity to ensure reliability and validity, and to be consistent with the current development trend of digital technology, is very important. We conducted this study with the aim of developing and validating a toolkit to measure primary school teachers' STEM teaching capacity, thereby providing measurement standards to assess teachers' STEM teaching capacity in a more comprehensive and reliable manner. At the same time, it could also serve as a solid basis for developing strategies to further teachers' STEM teaching capacity, thereby improving the effectiveness of STEM education.

2. Literature review

2.1. STEM teaching capacity

STEM education represents an instructional approach encompassing the concurrent teaching of science, technology, engineering, and mathematics [15], an educational system that creates connections between science, technology, engineering, and mathematics subjects and implements them using application-oriented methods [2]. Integrated subjects in STEM combined with real-life contexts help students better understand STEM, thereby fostering a greater interest in STEM-related career paths [16]. In addition, to be able to implement STEM education, teachers and instructors need to have appropriate competencies [9]. STEM teaching competencies are considered a set of cognitive and non-cognitive competencies associated with STEM careers [17]. Teachers' STEM teaching capacity can also include problem-solving ability, the ability to perceive STEM issues, and social skills for teaching [2]. Alternatively, it can also be seen as a set of knowledge and skills in the STEM field, as well as social knowledge and skills to meet the requirements of STEM teaching [8]. Based on the above views, although different authors all have their own views on STEM teaching capacity, this still presents some consistency: STEM teaching capacity can be simply understood as teachers using specialized knowledge related to STEM subjects together with pedagogical and social skills to organize STEM teaching activities for students for high-efficiency teaching.

In this study, we developed a STEM teaching competency framework for primary school teachers based on the theoretical foundation of the Knowledge–Skills–Attitudes (KSA) model. This is a comprehensive competency assessment framework representing the knowledge, skills, and attitudes necessary for an individual to perform a job effectively. Accordingly, the KSA components in the STEM teaching competency framework for primary school teachers include: (K) STEM knowledge, which is understanding the nature of STEM, interdisciplinary knowledge, and related scientific knowledge; (S) Skills, including pedagogical skills (designing STEM topics, organizing activities, and assessing competencies) and technological skills (integrating digital technology and modern technology into teaching); and (A) Attitudes, representing the necessary qualities of a teacher. Furthermore, the theoretical framework Technology Pedagogical Content Knowledge (TPACK) by Mishra & Koehler [18] provides the necessary theoretical foundation for teachers in integrating technology into STEM teaching. Accordingly, to teach STEM effectively, teachers need content knowledge (CK) (extensive knowledge of the field and subject to be taught), technology knowledge (TK) (knowledge of information technology, tools, and technological resources serving teaching), and pedagogical knowledge (PK) (emphasizing that teachers need to understand the dynamic interaction between technology, pedagogical methods, and subject content to make correct decisions on technology integration in the specific teaching context). Another theory, the Pedagogical Content Knowledge (PCK) model (also known as the PCK Consensus Model), was developed by 22 international science education researchers at the 2012 PCK Summit [19]. According to Gess-Newsome [20], the PCK model anatomically analyzes the practical competence of teachers into independent pieces such as subject matter knowledge (subject matter knowledge, pedagogical methods, understanding of students and the environment), personalization integration, PCK in teaching practice, and outcomes. The PCK model is considered a particularly important construct for science teachers that contributes to predicting effective teaching [21]. According to Chan et al. [22], separating the PCK into distinct, independent components helps to accurately identify teachers' strengths and weaknesses, facilitating the development of accurate assessment criteria and appropriate professional development programs.

2.2. The structure of STEM teaching capacity

Determining the structure and criteria for measuring STEM teaching capacity is a topic that has attracted much attention from scholars. The structure of STEM teaching competencies can be different, depending on the approach. According to the practical work approach to STEM, the structure of STEM teaching competencies can include problem-solving skills, people skills, organizational skills, technology skills, and resource skills [7,17]. STEM teaching capacity can also include STEM knowledge, STEM skills, digital skills, research skills, and soft skills [8]. Meanwhile, some other studies have built a STEM teaching capacity structure based on the STEM teaching organization process. For example, Chien [23] and An [24] stated that the STEM teaching capacity structure includes the capacity to develop STEM topics, the capacity to design and organize STEM teaching activities, and the capacity to test and evaluate STEM lessons. The STEM teaching capacity of teachers can also include the knowledge of integrated STEM teaching, the capacity to design integrated STEM topics, the capacity to organize integrated STEM teaching and testing, and evaluation capacity [9,25]. In addition, Pham [26] stated that teachers' STEM teaching capacity, in addition to knowledge and skills, should include professional qualities and ethics.

Another important issue in STEM teaching capacity is digital technology capacity. Maharani et al. [27], based on the DigCompEdu framework (European Framework for the Digital Competence of Educators), proposed six contents related to digital capacity for STEM teachers: using digital technology for interorganizational communication and professional collaboration; modifying and sharing digital resources; deploying and managing digital technology in teaching and self-learning; using digital tools to evaluate, develop, and improve assessment processes; empowering learners; and facilitating the development of learners' digital competence. Wang [28] contended that the digital proficiency of educators represents a primary determinant in attaining STEM educational objectives. Furthermore, the expertise of STEM teachers in utilizing diverse technological instruments, such as simulation platforms, programming software, and virtual laboratories, will enable them to creatively design instructional activities that promote deeper, more authentic learning experiences [11]. In addition, research by Kalogiannakis & Papadakis [29] and Kalogiannakis et al. [30] also suggests that for STEM education activities to be effective, teachers need a foundation of knowledge and skills, as well as the ability to effectively utilize digital technology tools in teaching activities.

In Vietnam, the current STEM teaching competency framework for primary school teachers includes (1) general cognitive competency in STEM teaching, (2) design competency, (3) teaching organization competency, and (4) assessment competency [31]. At the same time, in this competency framework, skills related to digital technology are limited to the ability to use teaching aids. Meanwhile, in Singapore (same region as Vietnam), the STEM teaching competency framework emphasizes that teachers need to have the ability to use digital tools and modern technology in designing themes and teaching [32]. This once again raises the issue that Vietnam needs a STEM teaching competency framework that is more suitable for the current situation.

3. Methods and data

To attain the specified objectives, we executed the construction, refinement, and validation phases in alignment with the systematic procedures illustrated in Figure 1. The steps in the diagram below were assessed by Boateng et al. [33] as suitable and effective for developing and validating the self-assessment scale.

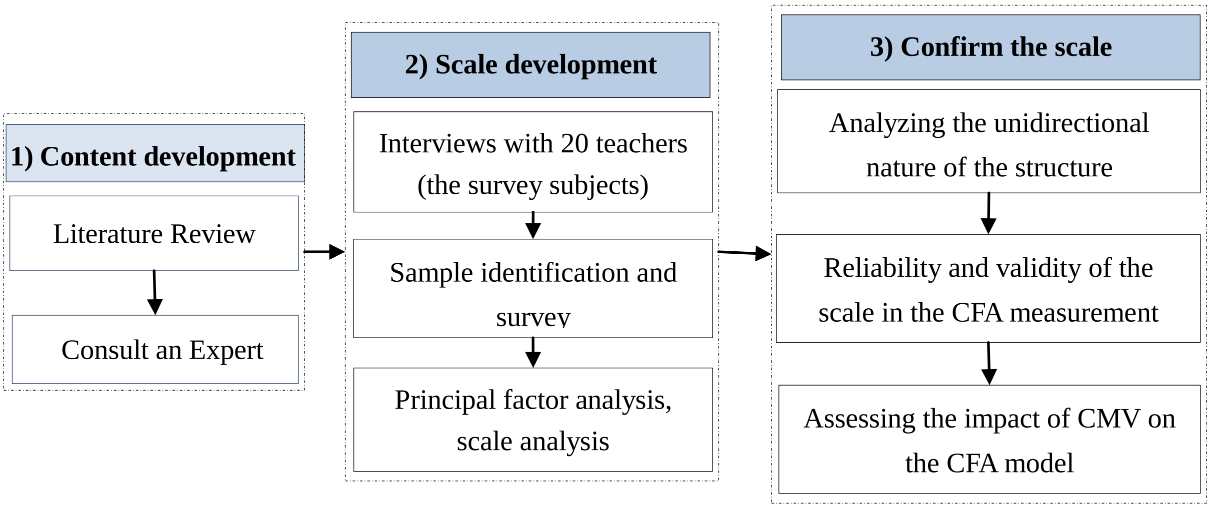


Figure 1. Scale validation diagram.

Phase 1: Building the content to measure the STEM teaching capacity of primary school teachers through a literature review. At the same time, the validity of these contents is considered through consultation with experts, to assess whether the contents (items) obtained from the literature review are suitable for reality or not, and whether any adjustments or additions are needed. The consultation results will be discussed in groups, adjusted to build a preliminary toolkit.

Phase 2: In this phase, we conduct semi-structured interviews with 20 teachers on the measurement contents in the preliminary survey to check whether the questions are unambiguous, confusing, and whether the survey subjects fully understand the content [34]. After that, we conduct a group discussion to make final adjustments before conducting the survey to collect data. To ensure the reliability of the results in the scale analysis, the minimum sample size is determined at a ratio of 10:1 [35], which means the minimum sample size is equal to the number of observed variables times 10. At the same time, the stratified random sampling method is applied to ensure representativeness for the whole population. After that, the survey questionnaire is designed through Google Forms and sent to candidates via email and social networks such as Zalo and Facebook to collect data [36]. To ensure the quality of collected data, the study applies the reverse question method; at the same time, Harman's single-factor analysis method is also applied to evaluate common method variance (using one data collection method for many subjects).

Phase 3: The scale validation process is carried out through assessing the unidimensionality of the constructs, measuring reliability and validity using the measurement model in confirmatory factor analysis (CFA). According to Hair et al. [35], except for the case where the errors of the observed variables are linked together, the model's fit to the market data provides the necessary and sufficient conditions for the set of observed variables to achieve unidimensionality. At the same time, its measurement indexes must satisfy the following conditions: Chi-square value adjusted by degrees of freedom (CMIN/df) <3; Goodness of Fit Index (GFI) >0.9; Comparative Fit Index (CFI) >0.9; Tucker & Lewis Index (TLI) >0.9; root mean square error approximation (RMSEA) <0.08. However, GFI depends significantly on the number of observed variables, the number of group structures, and sample size, so GFI is not recommended to be used [37].

The reliability of a scale is assessed through composite reliability (CR), which is the reliability of a set of observed variables measuring a concept; the CR standard is >0.7. The validity of a scale is measured through convergence and discrimination. Convergence measures the concentration of observed variables in a concept; the scale achieves convergence value when the average variance extracted (AVE) is >0.5 [35]. Discriminant validity represents the level of discrimination of measurement concepts. The standard for scales achieving discrimination is when maximum shared variance (MSV) <AVE, and the square root of average variance extracted (SRTAVE) > inter-construct correlation [35]. In addition, in this study, the Heterotrait-Monotrait (HTMT) index measuring the discrimination efficiency is also considered (HTMT standard <0.85) [38]. In addition, we also use Common Latent Factor Analysis (CLF) to assess whether common method variance affects CFA results by examining the differences between the model without CLF and the model with CLF.

The analysis support tools are SPSS version 26 and Amos version 25 software from IBM.

4. Research results

4.1. Results of content creation

Studies related to STEM teaching capacity were analyzed, combined with consultation with five experts in the field of STEM education, to supplement and adjust the content to suit the reality of primary school teachers and the curriculum in Vietnam. After conducting group discussions and adjustments, we built a content framework to measure STEM teaching capacity for primary school teachers with 44 criteria representing 6 main components: knowledge of STEM education [9,25], STEM lesson design capacity [23,24,26], STEM teaching implementation capacity [9,23,25,26]; STEM lesson assessment competencies [9,23,24], digital technology competencies [6,27], and attitudes toward STEM education [8,26]. The criteria for measuring the components of STEM teaching capacity of primary school teachers are shown in detail in Table 1, in which knowledge of STEM education includes 7 criteria from C1 to C7, STEM lesson design capacity includes 9 criteria from C8 to C16, STEM teaching implementation capacity includes 9 criteria from C17 to C25, assessment capacity includes 5 criteria from C26 to C30, digital technology capacity includes 6 criteria from C31 to C36, and teacher attitude includes 8 criteria from C37 to C44.

Table 1. Framework for measuring STEM teaching capacity for primary school teachers.

No	Content	Source
C1	Knowledge of STEM subjects	[9,25]
C2	Interdisciplinary and integrated teaching knowledge	
C3	Knowledge of STEM education methods	
C4	Knowledge of the national education program	
C5	Knowledge of organizing STEM experiential and extracurricular activities	
C6	Ability to develop integrated content according to the textbook program	
C7	Knowledge of primary school student psychology	
C8	Ability to design lively and engaging lessons	[23,25,26]
C9	Ability to design practical problems related to students' level	
C10	Ability to design integrated STEM lesson plans	
C11	Ability to integrate interdisciplinary knowledge in lessons	
C12	Ability to determine criteria for evaluating designs and products	

C13	Ability to develop STEM teaching content	
C14	Ability to use learning materials to support STEM education activities	
C15	Ability to design STEM lessons in the direction of developing students' qualities and abilities	
C16	Ability to design school activities related to STEM themes	
C17	Ability to implement lively and engaging STEM lessons	[9,25,26]
C18	Ability to use design and products to guide STEM learning activities	
C19	Ability to support students' difficulties in STEM teaching	
C20	Ability to create a positive and cooperative learning environment for students	
C21	Ability to guide experimental and technical practice	
C22	Ability to use technology in STEM teaching	
C23	Ability to organize reporting and discussion activities for students	
C24	Ability to manage the classroom in STEM teaching activities.	
C25	Ability to coordinate with other teachers to organize STEM activities	
C26	Ability to select appropriate methods for lesson assessment	[9,23]
C27	Ability to develop assessment tools	
C28	Ability to conduct an assessment of student STEM learning outcomes	
C29	Ability to adjust STEM lessons after assessment needs to be changed	
C30	Ability to summarize experiences from previous results	
C31	Awareness of the importance of technology in teaching	[6,27]
C32	Ability to use technology for self-study and research	
C33	Ability to use technology in building STEM topics and lessons	
C34	Ability to use technology in connecting and sharing	
C35	Ability to support students in accessing technology	
C36	Stimulate students' passion for technology	
C37	Passion and dedication to STEM education	[8,26]
C38	Creative thinking and willingness to innovate	
C39	Proactive in self-study and self-improvement	
C40	Cooperation and sharing of expertise within the STEM teacher community	
C41	Adaptation to local and school conditions	
C42	Responsibility and professional demeanor	
C43	Desire to contribute to educational innovation	
C44	Participate in research activities and scientific initiatives	

4.2. Results of scale development

With the above-determined content, we have built a structured survey of answers in the form of multiple-choice questions. The criteria are measured according to the Likert scale of 5 levels, from completely disagree to completely agree, corresponding to the level of competence from "very low" to "very high". Before sending the survey to candidates to collect data, the research team conducted semi-structured interviews with 20 candidates in the survey target group to check and adjust the official survey. Based on the minimum sample size calculation formula above, the study determined the minimum sample size to be 440 (10 × 44). To collect data for the study, we sent the survey to all teachers of 15 primary schools (inner city 8, outer city 7) in Ho Chi Minh City, Vietnam. As a result, we obtained 497 responses. After eliminating unqualified samples based on the reverse question, the study had 478 valid responses; candidate characteristics are shown in Table 2.

Table 2. Characteristics of the survey subjects (N = 478).

No	Characteristics		Quantity	Percent
1	Gender	Female	423	88.7%
		Male	54	11.3%
2	Experience	Less than 5 years	78	16.4%
		5 to 10 years	118	24.7%
		Over 10 years	281	58.9%
3	Education	College	5	1.0%
		University	461	96.6%
		Masters, PhD	11	2.3%

To check whether the collected research data were inflated or biased due to the common method, we used Harman's single-factor analysis method. All 44 observed variables were put into the analysis to create a single factor. The analysis results (Table 3) show that the total variance extracted for a single factor is 27.686% (<50%), so the collected data is reliable [39].

Table 3. Results of single-factor analysis (N = 478).

KMO value	0.932
Bartlett's test (P-value)	<0.001
Number of observed variables included in the analysis	44
Number of factors forming	1
Total variance extracted	27.686%

4.3. Item reduction to extract the main factor

Using principal factor analysis to extract the main factors and remove observed variables that do not ensure a loading factor >0.5, the analysis results (Table 4) (KMO = 0.932, P-value (Bartlett's) < 0.001) show that, with 44 observed variables included in the analysis, the study extracted 6 main factors. These six factors have an extracted variance value of 1.103 > 1 and represent 61.94% of the variance of the observed variables.

Table 4. Results of principal factor analysis (N = 478).

No	Content		Value
1	KMO value		0.932
2	Bartlett's test	Chi-Square	16969.69
		df	964
		P-value	<0.001
3	Total variance explained	Number of extracted factors	6
		Extracted variance value	1.103
		Total % of extracted variance	61.94

In addition, measuring the loading factors of the factors (Table 5) shows that the observed variables C7, C17, C18, C25, C30, C37, and C38 have loading factors <0.05, so these variables are removed from the scale list. The exclusion of these items from the study's scales can be explained as follows: Statistically, Hair et al. [35] argued that variables with factor loading coefficients <0.5 are observed variables that contribute too little information compared to other observed variables within the same principal factor (latent concept formed), and therefore should be excluded. In practical terms, we find that the content of the excluded item may have already been represented in other observations within the group (e.g., passion and dedication (C37) are related to teachers actively learning to improve their skills (C39), responsibility in teaching (C42), and desire to contribute (C43). Alternatively, the content may not be entirely consistent with the remaining items (e.g., C38 (creative thinking and readiness for innovation) belongs to higher-order thinking skills or innovation skills, while the remaining items relate to attitudes). At the same time, the six main extracted factors represent the six components of STEM teaching capacity: design capacity (9 items, C8–C16); teachers' attitudes toward STEM (6 items, C39–C44); implementation capacity (6 items, C19–C24); digital technology capacity (6 items, C31–C36); teachers' knowledge of STEM education (6 items, C1–C6); and lesson assessment capacity (4 items, C26–C29)

Table 5. Rotated matrix of factors.

	NLTK	TDGV	NLTH	NLCN	KTGV	NLDG
C13	0.932					
C16	0.896					
C12	0.885					
C15	0.878					
C10	0.874					
C14	0.871					
C11	0.833					
C9	0.816					
C8	0.761					
C18						
C41		0.920				
C44		0.917				
C43		0.913				
C42		0.894				
C40		0.821				
C39		0.792				
C38						
C21			0.909			
C20			0.871			
C19			0.821			
C24			0.817			
C22			0.815			
C23			0.788			
C17						
C33				0.877		
C34				0.854		
C31				0.788		

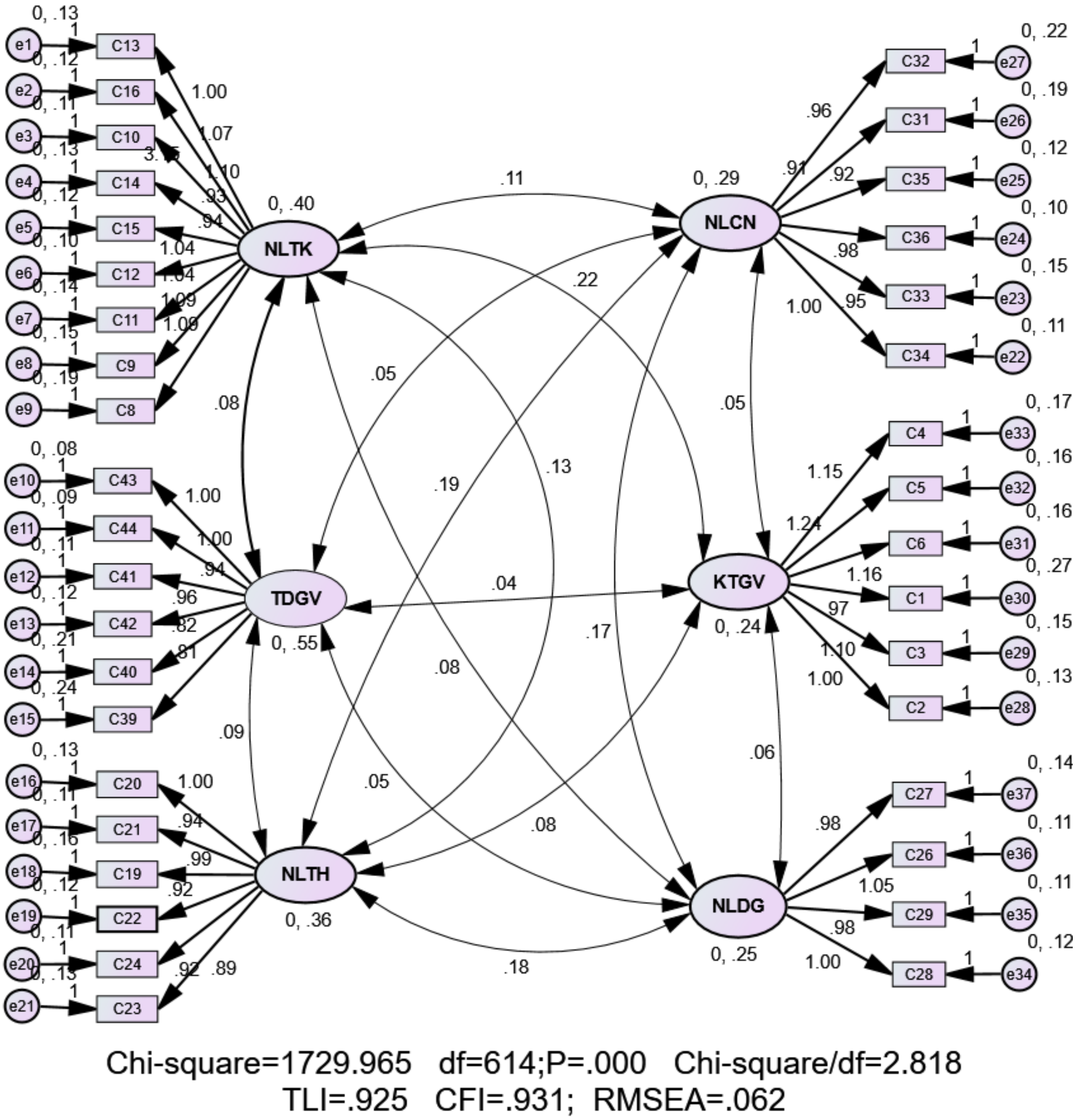
	NLTK	TDGV	NLTH	NLCN	KTGV	NLDG
C32				0.781		
C36				0.724		
C35				0.715		
C2					0.852	
C3					0.834	
C1					0.768	
C6					0.703	
C5					0.684	
C4					0.670	
C7						
C28						0.870
C29						0.825
C26						0.792
C27						0.744
C30						
C37						
C25						

Note: *Extraction: principal axis factoring; Rotation: Promax; Cells with factor loading <0.5 are hidden. NLTK is STEM lesson design capacity, KTGV is teachers' knowledge of STEM education; NLCN is digital technology capacity; TDGV is teachers' attitudes toward STEM teaching; NLTH is STEM teaching implementation capacity; NLDG is STEM lesson assessment capacity.*

4.4. Scale validation analysis results

4.4.1. Unidirectionality measurement results of structures

To measure the unidimensionality of the constructs in STEM teaching capacity, the study used the critical model in confirmatory factor analysis (CFA) (view Figure 2). The results of the unidimensionality assessment (Figure 2) are P-value (chi2) < 0.001; CMIN/df = 2.818 < 3; TLI = 0.925 > 0.9, CFI = 0.931 > 0.9; and RMSEA = 0.062 < 0.08. Thus, all indicators measuring the model's suitability are positive.



Note: *NLTK is STEM lesson design capacity; KTGV is teachers' knowledge of STEM education; NLCN is digital technology capacity; TDGV is teachers' attitudes toward STEM teaching; NLTH is STEM teaching implementation capacity; NLDG is STEM lesson assessment capacity.*

Figure 2. CFA critical model.

4.4.2. Measuring the reliability and validity of the scales

The reliability of the scales is assessed through the CR coefficient. The measurement model results (Table 6) show that the CR values of all scales are >0.7, so the reliability of these scales is guaranteed. Along with it, the convergence of the scales calculated by AVE has the lowest value of 0.626 (KTGV) and >0.5, so the scales in the study ensure convergence. Besides, the discriminant value calculated by MSV of all scales is <AVE, and the discriminant value calculated by SRTAVE is greater than the inter-construct correlation.

Table 6. Measurement model results.

	CR	AVE	MSV	MaxR(H	NLTK	TDGV	NLTH	NLCN	KTGV	NLDG
NLTK	0.967	0.765	0.522	0.968	**0.874†**					
TDGV	0.952	0.767	0.045	0.962	0.178***	**0.876†**				
NLTH	0.939	0.720	0.373	0.940	0.350***	0.213***	**0.848†**			
NLCN	0.914	0.639	0.426	0.919	0.314***	0.139**	0.591***	**0.799†**		
KTGV	0.909	0.626	0.522	0.914	0.722***	0.098*	0.264***	).187***	**0.791†**	
NLDG	0.892	0.675	0.426	0.893	0.267	0.130	0.611	0.652	0.228	**0.821†**

Note: *NLTK is STEM lesson design capacity; KTGV is teachers' knowledge of STEM education; NLCN is digital technology capacity; TDGV is teachers' attitudes toward STEM teaching; NLTH is STEM teaching implementation capacity; NLDG is STEM lesson assessment capacity; ***, **, * represent the significance level at p < 0.001, 0.01, and 0.05; † is SRTAVE.*

In addition, the study also used the HTMT index to measure discriminant validity. According to Henseler et al. [38], discriminant validity is achieved when HTMT < 0.85. The analysis results shown in Table 7 show that all measurement values are <0.85, so the scales in this study ensure discriminant validity.

Table 7. HTMT analysis results.

	NLTK	TDGV	NLTH	NLCN	KTGV	NLDG
NLTK						
TDGV	0.181					
NLTH	0.352	0.208				
NLCN	0.315	0.124	0.589			
KTGV	0.713	0.084	0.255	0.181		
NLDG	0.265	0.114	0.609	0.657	0.225	

Note: *NLTK is STEM lesson design capacity; KTGV is teachers' knowledge of STEM education; NLCN is digital technology capacity; TDGV is teachers' attitudes toward STEM teaching; NLTH is STEM teaching implementation capacity; NLDG is STEM lesson assessment capacity.*

Through the above analysis results, we have confirmed the set of criteria for measuring STEM teaching capacity of primary school teachers with 37 items measuring 6 main components in the capacity structure, as follows: (1) Teachers' knowledge includes 6 items, measuring their knowledge of STEM subjects, understanding of STEM teaching, and their understanding of the national education program; (2) Design capacity includes 9 items, measuring teachers' capacity in designing STEM lesson contents and STEM topics; (3) Capacity to implement STEM lessons included 6 items, measuring the capacity to organize teaching activities effectively, manage the classroom, and handle arising situations; (4) Assessment capacity includes 4 items, measuring teachers' capacity to develop assessment tools and methods and conducting assessments, and the ability to adjust STEM lessons;

(5) Digital capacity includes 6 items, measuring teachers' knowledge and skills in digital technology as well as their ability to apply it to teach STEM and engage students; and (6) Teacher attitudes includes 6 items, measuring teachers' attitudes toward STEM education activities as well as their proactive spirit in improving their own capacity.

In this study, to assess whether the common method variance distorts the measurement results of the CFA model, the common latent factor (CLF) was used. The comparison results between standardized parameters of the model with CLF and the model without CLF were <0.02; therefore, CLF does not distort the results [40]. Similarly, the comparison of the differences in χ^2 and df between the model without CLF (1294.965; 613) and the model with CLF (1294.965; 614) showed no statistically significant difference ($P > 0.05$); therefore, CLF does not distort the results [41]. Thus, the issue of common method variance does not affect the research results.

5. Discussion

Our research results have confirmed that teachers' capacity in STEM teaching activities is a set of many different capacities; it is not simply knowledge about STEM teaching activities, capacities in designing, implementing, and evaluating STEM lessons, as some previous studies mentioned [9,23,25,26], but also includes digital technology capacity and a positive attitude of teachers. Our research results have confirmed more components of STEM teaching capacity than previous studies. For example, the studies of Pham [26], Trang [25], and Thuy et al. [9] did not mention the digital capacity of STEM teachers; they only mentioned the skills of using digital media to support teaching. Meanwhile, the criteria for measuring digital competence in our study not only include the ability to use digital technologies to design lessons and support teaching activities but also the ability to support students in using them and stimulate their interest in digital technology. Therefore, it requires teachers not only to be able to use but also to master the technology, which is consistent with the content of "empowering and developing learners' digital competence" of the DigCompEdu framework. Many studies have also confirmed that digital capacity is an important competency for teachers, helping them effectively use digital technologies to improve all areas of their professional activities [6,27]. Therefore, confirming digital capacity as a dimension in teachers' STEM teaching capacity can help measure such capacity more comprehensively and effectively.

Another finding in this study is that teachers' knowledge should be separated into an independent component from design competence. This result is consistent with the separation of teacher competence components according to the PCK model [20]. Specifically, the teachers' knowledge mentioned in the study (knowledge of STEM subjects, knowledge of teaching methods, teaching context) is located in the *professional knowledge* component of the PCK model, while the ability to design STEM lessons belongs to *personalized integration* (the ability of a teacher to integrate professional knowledge and plan before teaching). Furthermore, according to [42], separating the PCK model into independent components helps researchers build accurate evaluation criteria. It can be said that teacher knowledge and STEM lesson design competence are two separate components belonging to different parts of the PCK, which is meaningful in terms of measuring teacher capacity; however, in practical teaching, they are closely related.

In addition, in our study, the structure of teachers' STEM teaching capacity also includes teachers' attitudes. This finding will contribute to filling gaps in the structure of STEM teaching capacity that some previous studies have not mentioned. We believe that teachers' attitudes play an important role in forming their knowledge and skills. Teachers' positive attitudes toward STEM education not only motivate them to improve their own teaching capacity but also stimulate students' interest in STEM subjects, thereby improving the effectiveness of STEM education. In addition, attitude is always considered an important component in the ASK (Attitude–Skills–Knowledge) personal capacity model, which has also been applied to measure teachers' capacity [8,43].

Despite the aforementioned contributions, this study still has limitations. This tool is based on self-reported responses and was validated using samples from primary schools in Ho Chi Minh City, which may limit the ability to generalize to other areas. Using only data from teachers' self-reports may lead to methodological shortcomings such as biased responses, extreme tendencies, or cognitive issues, which may lead to biased results. Therefore, future studies should conduct cross-validation with various independent methods, such as a combination of self-assessment and observation of the teaching process, or assessment through competency tests. At the same time, studies also need to test the invariance of the measurement across important subgroups (e.g., gender, teaching experience, and region).

6. Conclusions and recommendations

STEM education is considered the key to developing human resources to meet the needs of current and future society. Meanwhile, teachers' STEM teaching capacity is a particularly important factor in improving the effectiveness of STEM education; as such, having a reliable toolkit to measure STEM teaching capacity will be important in assessing capacity and developing appropriate development strategies. Through the process of building and validating a measurement model with many rigorous assessment steps, we have built a toolkit to measure STEM teaching capacity for primary school teachers with 37 items, representing 6 components of the capacity structure: STEM knowledge, STEM lesson design capacity, STEM teaching capacity, STEM lesson assessment capacity, digital technology capacity, and teachers' attitudes toward STEM.

We expect that this toolkit will help to make the assessment of STEM teaching capacity more comprehensive and realistic. Furthermore, we recommend that when developing a STEM teaching competency framework, education administrators in Vietnam consider integrating digital technology competencies and teacher attitudes into the framework, instead of focusing solely on pedagogical competencies, as is currently the case. This would not only contribute to improving the effectiveness of STEM education but also align with Vietnam's digital transformation direction in education. Along with that, to improve STEM teaching capacity in particular and teaching capacity in general, teachers not only need to improve their knowledge and teaching skills but also need to improve their digital technology capacity, as well as promote a positive attitude toward the subject. In addition, in the context of a constantly developing society and rapid changes in human resource needs, the criteria for measuring teachers' capacity also need to be changed and updated continuously to be closer to reality. The results of this study will become a premise and could play an important role in measuring STEM teaching capacity, from which it is possible to develop strategies as well as conduct studies to evaluate the effectiveness of developing STEM teaching capacity for primary school teachers.

Furthermore, in the context of a constantly evolving society and the ever-changing workforce competency requirements, the criteria for measuring teacher competency also need to be modified and updated to suit reality. Simultaneously, similar studies should be conducted in various locations and compared before establishing a standard competency framework. This will help reduce errors related to self-assessment and ensure representativeness of the overall population.

Author contributions

Le Thi Xinh: Conceptualization, methodology, investigation, formal analysis, writing - original draft. Dang Ngoc Trung: Literature review, instrument refinement, data curation, visualization, writing - review and editing. Bui Van Hong: Supervision, methodological guidance, validation, writing - review and editing, final approval. All authors contributed to the article and approved the submitted version.

Use of Generative-AI tools declaration

The authors confirm that all research design, data collection, statistical analysis, interpretation, and manuscript writing were performed exclusively by the authors. Generative AI (Gemini) was used solely for minor tasks such as technical formatting and guidance on journal requirements. Grammarly was utilized strictly for correcting minor English grammar and phrasing. The authors reviewed, approved, and assumed full responsibility for the final content of the manuscript.

Acknowledgments

The authors wish to thank the participating primary schools and teachers for their cooperation and support throughout the study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics declaration

This study was approved by Ho Chi Minh City University of Technology and Engineering (HCM-UTE) in accordance with its ethical procedures for educational research. Permission for data collection was also obtained from the participating primary schools. All participants were informed about the study purpose, the voluntary nature of participation, and the confidentiality of their responses, and they provided informed consent prior to completing the survey. No personally identifiable information was collected, and the dataset was analyzed in anonymized form.

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