

Original Article

Integrated STEM Education Competence Framework for University Lecturers

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Abstract

The rapid advancement of science, engineering, and technology, driven by the Fourth Industrial Revolution, has heightened the demand for a highly skilled workforce in science, technology, engineering, and mathematics (STEM) fields. Integrated STEM education has emerged as a key driver of educational innovation in Vietnam, spanning both general and higher education. The competence of university lecturers in delivering integrated STEM education, a newly recognized pedagogical and professional skill set, is crucial to the success of STEM education at the tertiary level. As with general pedagogical competence, the development of an integrated STEM education competence framework is essential for enhancing this capability among university lecturers. However, there remains a lack of theoretical foundation and best practices tailored to the Vietnamese higher education context. This study aims to develop a framework for integrated STEM education competence specifically for university lecturers through document analysis and survey research. Multivariate statistical techniques, including exploratory factor analysis (EFA), Cronbach's alpha, and Pearson correlation, were applied to analyze data collected from 205 lecturers across nine public universities in Vietnam. The integrated STEM education competence framework for Vietnamese university lecturers consists of three component competencies and 23 items: designing and implementing integrated STEM education (15 items), assessing integrated STEM learning outcomes (4 items), and demonstrating positive attitudes toward integrated STEM education (4 items). The framework was found to be both reliable and valid, with strong positive correlations among the three component competencies. This study also outlines limitations and provides recommendations for future research.

Keywords: Integrated STEM Education, integrated STEM Education Competence, University Lecturers, STEM, STEM Education.

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) refers to the disciplines of science, technology, engineering, and mathematics. STEM education extends its interdisciplinary nature through variations such as science, technology, engineering, arts, and mathematics (STEAM), which incorporates the arts, and science, technology, reading, engineering, arts, and mathematics (STREAM), which includes reading and writing. Instead of teaching these subjects as separate, isolated disciplines, integrated STEM education combines them into a cohesive learning approach that focuses on real-world applications. This model aims to develop learners' competencies in mathematics, science, technology, and engineering by engaging them in interdisciplinary learning experiences directly tied to practical, everyday situations.

Integrated STEM education equips students with both the knowledge and skills in STEM fields through an approach that encourages the application of these disciplines in solving meaningful, real-world problems. As students engage in this problem-solving process, they not only gain content-specific knowledge but also develop crucial 21st-century skills, including problem-solving, collaboration, critical thinking, and creativity. The benefits of integrated STEM education extend beyond the classroom, addressing the growing demand for skilled workers in various STEM-related careers, such as biology, agriculture, environmental science, computing, physical and mathematical sciences, health care (e.g., physicians, nurses, home health aides), manufacturing (e.g., production assistants, welders, maintenance technicians), and engineering (Rosenzweig & Chen, 2023). As a result, integrated STEM education has been a cornerstone of educational reform in Vietnam since the 2006–2007 academic year, playing a pivotal role in the modernization of general education.

At the higher education level, programs in natural sciences, engineering, and technology

often incorporate elements of STEM disciplines, although these integrations tend to occur within specific fields rather than across them. However, STEM education in Vietnam is primarily found in extracurricular activities, with limited systematic integration into the formal curriculum (Phuong, 2024). To address this issue and meet the growing demand for a highly skilled STEM workforce, Vietnamese universities have begun restructuring their curricula to emphasize the interdisciplinary nature of STEM education. Central to the success of these efforts is the development of integrated STEM education competence among university lecturers.

The creation of an integrated STEM teaching competence framework for university lecturers is critical to improving the quality and effectiveness of STEM education at Vietnamese higher education institutions. This competence framework provides a structured approach to developing the pedagogical and professional skills required for effective integrated STEM instruction. Nevertheless, the majority of research on integrated STEM teaching competence has concentrated on delineating component competencies and their respective items (Bui, 2019; Chien, 2019; Duong, 2022; T. T. T. Nguyen et al., 2020; Song, 2017). Verifying the validity and reliability of component competencies and their items using multivariate statistics remains a research gap. Consequently, existing research has not adequately tackled the necessity of establishing a comprehensive integrated STEM education competence framework for university lecturers. This framework's validity and reliability must be ensured, thereby guiding training activities to improve this competence for university lecturers.

This article seeks to fill this gap by addressing two key questions:

What are the component competencies and associated indicators included in an integrated STEM education competence framework for university lecturers?

How can the validity and reliability of an integrated STEM education competence framework be assessed?

LITERATURE REVIEW

STEM, STEM Education, and Integrated STEM Education

STEM refers to a curriculum that focuses on the disciplines of science, technology, engineering, and mathematics (Hallinen, 2024). Initially, the U.S. National Science Foundation (NSF) used the acronym SMET (Science, Mathematics, Engineering, and Technology) in the 1990s to denote these fields or a curriculum that integrated knowledge and skills from these areas (Hallinen, 2024; Sanders, 2009). The acronym was restructured to STEM by Judith Ramaley, an American biologist and assistant director of education and human resources at NSF, in 2001 (Hallinen, 2024; Wong et al., 2016). Compared to STEM, SMET was considered quite difficult to put together (Catterall, 2017) or “sounded too much like smut” (Sanders, 2009, p. 20). Beyond the core fields of mathematics, natural sciences, engineering, and computer science, the NSF now broadly includes disciplines such as psychology, economics, sociology, and political science within the STEM domain (Green, 2007). The STEM initiative from the NSF equips students with critical thinking and problem-solving skills to prepare them for the rapidly evolving workforce of the future (H. T. T. Nguyen et al., 2021; White, 2014).

STEM has been conceptualized in various ways, including: (a) as a discipline, instruction, field, and pictured career (Hasanah, 2020), or as a field, package, and approach (Ministry of Education Malaysia (MOE), as cited in Aspin et al., 2021, p. 127); (b) as a meta-discipline, which involves integrating knowledge from different STEM disciplines into a new, cohesive whole (Morrison, 2006); (c) as the combination of one, two, three, or all four STEM fields (Breiner et al., 2012; Siekmann, 2016; White, 2014).

STEM, when viewed as a cohesive field or career, can either refer to (a) the accumulation of knowledge in science, technology, engineering, and mathematics as distinct but related areas (Ogan-Bekiroglu & Caner, 2018); or (b) the integration of these disciplines in both workforce preparation and daily life (Pimthong & Williams, 2020).

From an instructional perspective, STEM involves (a) an interdisciplinary approach to learning that combines rigorous academic concepts with real-world lessons in contexts that connect school, community, work, and the global enterprise (Tsupros et al., 2008); (b) a shift from traditional teaching and teacher-centered learning to active, student-centered learning (Hasanah, 2020).

STEM serves as a vital educational framework that blends content from science, technology, engineering, and mathematics into meaningful school activities. STEM activities offer students the opportunity to acquire both domain-specific and 21st-century skills, preparing them to become high-quality professionals capable of adapting to the demands of the Fourth Industrial Revolution. In this sense, STEM education goes beyond the acronym itself - representing a broad, dynamic, and interdisciplinary field with deep roots in science education.

STEM education is a multifaceted concept with varied interpretations based on the perspectives and objectives of those involved (Hoang, 2021). Initially, the U.S. Department of Education (2007) and Tsupros et al. (2008) introduced STEM education in the late 2000s. It has been defined as either programs that promote STEM disciplines (U.S. Department of Education, 2007) or as an integrated teaching and learning approach across science, technology, engineering, and mathematics (Gonzalez & Kuenzi, 2012; Sungur Gul et al., 2023; Tsupros et al., 2008). The integrated approach to STEM education emphasizes multidisciplinary, interdisciplinary, and transdisciplinary learning, combining rigorous academic knowledge with real-world applications. STEM education facilitates the integration of classroom learning with community, professional, and global contexts, enhancing STEM literacy and preparing students for success in the emerging economy. It encompasses both formal and informal education, spanning from early childhood to postdoctoral levels (Gonzalez & Kuenzi, 2012).

This study outlines three key aspects of STEM education, drawing from the aforementioned perspectives. First, STEM education refers to an interdisciplinary science education program in the four disciplines of science, technology, engineering, and mathematics. STEM education also emphasizes the student-centered approach. Last but not least, STEM education highlights the development of STEM literacy and core 21st-century skills to prepare learners for the demanding future workforce. Thus, STEM education refers to the design, implementation, and assessment of interdisciplinary science education curricula in four disciplines: science, technology, engineering, and mathematics, through student-centered methods, enabling students to develop STEM literacy and core 21st-century skills for adapting to the future's increasingly challenging workforce.

To reduce ambiguity around the term "STEM education," Sanders (2009) suggests using the term "integrated STEM education" for programs that emphasize interdisciplinary approaches. Sanders defines integrated STEM education as approaches that explore teaching and learning across two or more STEM subjects, or between STEM and other school disciplines. Building on this, Stohlmann et al. (2012) advocate the inclusion of all four STEM areas in a classroom, lesson, or unit while emphasizing the connection between STEM subjects and real-world issues. Moore and Smith (2014) further reinforce this by asserting that integrated STEM education aims to integrate the four disciplines of science, technology, engineering, and mathematics into a single class, unit, or lesson, drawing connections between these disciplines and real-world issues. Additionally, integrated STEM education is not merely an approach to teaching STEM content in two or more STEM disciplines but also underscores the significance of engaging in STEM practices within authentic contexts to improve student learning (Kelley & Knowles, 2016). Integrated STEM education enhances the problem-solving and logical thinking abilities of students (Mustafa et al., 2016).

In brief, the transition from discrete discipline education to integrated discipline education to meet the demand for high-quality human resources in science, technology, engineering, and mathematics is an inevitable and objective tendency in the 4.0 education context. "STEM education" and "Integrated STEM education" are both terms for interdisciplinary science education programs that combine the four disciplines of science, technology, engineering, and mathematics. However, while "STEM education" could be defined as "the teaching of the four separate and distinct fields of science, technology, engineering, and mathematics" (Bui, 2019, p. 919), "integrated STEM education" emphasizes integrated teaching and learning between or among any two or more of the four disciplines with real-life problems using the student-centered approach. Furthermore, "integrated STEM education" increases student engagement in learning STEM-related real-world problems and enables them to develop core 21st-century skills such as problem-solving, critical thinking, creative thinking, and collaboration (Huang et al., 2022; Nazifah & Asrizal, 2022; Stehle & Peters-Burton, 2019; Tytler et al., 2023). Drawing on the different views of "integrated STEM education," this article proposes the following working definition: Integrated STEM education refers to the design, implementation, and assessment of interdisciplinary science education that integrates real-world issues into four disciplines: science, technology, engineering, and mathematics through student-centered methods, enabling students to develop STEM literacy and core 21st-century skills for adapting to the future's increasingly challenging workforce.

Integrated STEM Education Competence

The term "Integrated STEM education competence" stems from "Integrated STEM education" and aims to differentiate it from "STEM education competence," which typically denotes the ability to teach each STEM discipline separately. Nadelson and Seifert (2017) highlight two significant challenges in implementing an integrated STEM curriculum: (a) the structural overhaul required within an educational system that is long accustomed to segregating STEM disciplines, and (b) the

limitations in teachers' STEM knowledge and professional development. To address these challenges, educators must not only restructure separate discipline curricula into a unified STEM framework but also adapt their instructional methods and assessment strategies. Moreover, teachers need to possess a solid foundation in STEM knowledge and foster a mindset of lifelong learning. Although Nadelson and Seifert do not explicitly study integrated STEM education competence, their insights provide a foundation for identifying the necessary competencies educators must develop to implement integrated STEM curricula effectively. These include proficiency in STEM knowledge, integrated curriculum development, teaching methodologies, and assessment.

Several studies have identified similar components in their discussions of integrated STEM education competence (Bui, 2019; Chien, 2019; Duong, 2022; T. T. T. Nguyen et al., 2020; Song, 2017). The common point of the aforementioned studies on integrated STEM education competence is to identify components and their items; nevertheless, their validity and reliability have not been verified through multivariate statistical analysis. For instance, Song (2017) proposes a competence framework for teachers in integrated STEM education, which includes cognitive, instructional, and affective domains. Cognitive competencies involve integrating STEM concepts, combining disciplines, and identifying practical challenges and relevant technologies. Instructional skills encompass project-based learning, student-centered activities, and the application of knowledge to real-world contexts, as well as guidance in career-related fields of science and technology. Affective traits refer to a teacher's commitment to incorporating STEM disciplines, fostering STEM-related learning environments, and maintaining confidence in students' achievements. While Song's (2017) framework covers essential competencies related to knowledge, teaching skills, and attitudes, it does not address assessment, which is a key component of integrated STEM education.

Bui (2019) offers a comprehensive framework for integrated STEM instruction that includes five key components: learning outcomes, content, instructional strategies, assessment, and required conditions. Bui's framework provides a solid scientific foundation for structuring the competencies required for integrated STEM education. However, the validity of the framework has not been determined due to a lack of empirical evidence.

T. T. T. Nguyen et al. (2020) propose a structural model of integrated STEM education competence for secondary and high school teachers in Vietnam, with the goal of identifying the behavioral skills needed for more effective integrated STEM instruction. According to Nguyen et al., there are four components of integrated STEM education competence: cognition in integrated STEM teaching, STEM teaching plan creation, STEM teaching plan implementation, and STEM teaching plan assessment and adjustment. It is not difficult to identify that, except for "cognition in integrated STEM teaching," the other component competencies reflect the core of "STEM teaching" more clearly than "integrated STEM education."

Duong (2022) outlines four components of integrated STEM teaching competence for university lecturers: understanding integrated STEM education, designing STEM-integrated lessons, implementing them, and assessing learning outcomes. These components align closely with the processes of designing, executing, and evaluating integrated STEM education. Duong's study lacks detailed descriptions of each component of university lecturers' integrated STEM education competence and any empirical evidence to support the validity of the proposal.

In brief, while there are variations in how different studies conceptualize integrated STEM education competence, the literature consistently highlights three core components: (a) knowledge, skills, and attitudes related to the four STEM disciplines; (b) the ability to develop interdisciplinary curricula; and (c) implement the student-centered approach and the competence-based assessment. Based on the review, this study proposes the following definition: Integrated STEM education competence is the ability to apply knowledge, skills, and attitudes related to four STEM disciplines and their real-world issues, as well as interdisciplinary science education curricula, student-centered methods, and assessment strategies to design and implement integrated STEM education lessons or topics and assess integrated STEM learning outcomes successfully.

Proposing an Integrated STEM Education Framework for University Lecturers

An integrated STEM education competence framework for university lecturers outlines the essential competencies required for the effective implementation of integrated STEM education. This competence encompasses the ability to apply knowledge, skills, and attitudes from the four STEM disciplines and their real-world issues, as well as interdisciplinary curricula, student-centered methods, and assessment strategies to design and implement integrated STEM education lessons or topics and assess learning outcomes successfully. Competence in task or activity performance requires not only technical expertise (knowledge and skills) but also positive attitudes. These positive

attitudes are integral throughout the STEM education process, influencing the design and implementation of lessons and the assessment of learning outcomes.

This study proposes an integrated STEM education competence framework for university lecturers, drawing from the aforementioned literature review on STEM, STEM education, integrated STEM education, and integrated STEM education competence. The definition of integrated STEM education competence is determined based on the literature review, which provides a scientific foundation for identifying component competencies and their items. Therefore, the proposed integrated STEM education competence framework for university lecturers includes the following main components: STEM knowledge, curriculum development, student-centered approach, learning outcomes assessment, and positive attitudes towards integrated STEM education.

STEM literacy refers to the mastery of foundational or specialized knowledge and skills in science, technology, engineering, and mathematics. It also involves the ability to identify and solve STEM-related real-world problems, apply STEM knowledge in professional contexts, and effectively communicate these concepts to various stakeholders, including colleagues, students, the community, and industry partners.

University lecturers take critical steps in developing integrated STEM education curricula. This process involves several key steps, including designing learning outcomes, compiling relevant content and instructional materials, selecting appropriate student-centered teaching strategies, and developing valid and reliable assessment methods that align with the intended learning outcomes of the integrated STEM education course, lesson, or topic.

The implementation of the student-centered approach in integrated STEM education necessitates the creative and effective use of active and experiential learning methods. In integrated STEM settings, lecturers foster a collaborative learning environment where students engage in hands-on, inquiry-based activities. They employ ICT tools, utilize appropriate facilities and equipment, and guide students through processes that encourage exploration, experimentation, and practical application of STEM concepts, often following technical design procedures.

Assessing integrated STEM learning outcomes requires the development of valid and reliable tasks and assessment tools using competence-based assessment methods that align with defined learning outcomes. It also involves providing timely, constructive feedback, analyzing students' academic performance, and adjusting teaching strategies as necessary to enhance learning. This process ensures that assessment reflects students' progress in mastering integrated STEM topics.

The proposed integrated STEM education competence framework (see Table 1) includes both tangible and intangible components. Tangible components, such as STEM knowledge, curriculum design, program implementation, and outcome assessment, form the technical core of the framework. Intangible components, such as attitudes towards STEM education, represent personal psychological attributes, yet these attitudes can manifest as tangible behaviors. Enthusiasm, creativity in lesson design and delivery, collaboration with stakeholders, openness to integrating additional disciplines (such as the arts, health, and artificial intelligence [AI]), and the sharing of research findings and best practices with the broader community demonstrate a lecturer's positive attitude towards STEM education.

Table 1. Proposed Integrated STEM Education Competence Framework for University Lecturers

Component Competence	Original Code	Item/Item Description
Having Literacy (SL)	STEMSL1	Master fundamental knowledge and skills in the four disciplines: science, technology, engineering, and mathematics.
	SL2	Explain scientific and mathematical principles, technical design processes, and scientific research methodologies.
	SL3	Analyze systems, design engineering and technology solutions, program, and select appropriate equipment for STEM-related real-world problems and careers.
	SL4	Apply STEM knowledge and skills to identify and solve real-world STEM-related challenges and career-related issues.
	SL5	Effectively communicate STEM knowledge and skills to various stakeholders, including colleagues, students, communities, and businesses.

Developing Integrated STEM Education Curricula (DS)	DS1	Differentiate between STEM education programs that focus on a single discipline and those that integrate two or more disciplines.
	DS2	Design learning outcomes for integrated STEM education courses, lessons, and topics.
	DS3	Develop content for integrated STEM education (lessons and topics) that align with the learning outcomes.
	DS4	Select appropriate teaching methods that correspond with the learning outcomes of integrated STEM education courses, lessons, and topics.
	DS5	Choose assessment methods and design valid, reliable tasks and tools that align with the learning outcomes of integrated STEM education.
Implementing the Student-Centered Approach in Integrated Education (IS)	IS1	Foster a collaborative, active learning environment when organizing integrated STEM learning activities for students.
	IS2	Apply the student-centered approach in integrated STEM lessons and topics, including case studies, project-based learning, inquiry-based learning, flexible learning, and service learning.
	IS3	Encourage students to engage in discussion, discovery, experimentation, application, and practice of integrated STEM topics.
	IS4	Use ICT tools, simple technical devices, and equipment to organize integrated STEM learning activities effectively.
	IS5	Facilitate student presentations on integrated STEM lessons and topics and encourage peer feedback and assessment.
Assessing Integrated Learning Outcomes (AS)	AS1	Assess students' performance in integrated STEM lessons and topics using valid, reliable tools and methods.
	AS2	Apply assessment methods that align with the learning outcomes of integrated STEM lessons and topics.
	AS3	Provide constructive and timely feedback on students' academic performance using reliable assessment tools.
	AS4	Analyze students' learning outcomes in integrated STEM lessons and topics to inform future teaching and learning strategies.

Table 1. Continued

Component Competence	Original Code	Item/Item Description
Demonstrate Positive Attitudes Towards Integrated STEM Education (DA)	DA1	Exhibit enthusiasm and creativity when designing and delivering integrated STEM lessons and topics.
	DA2	Collaborate with colleagues, students, communities, and businesses to develop and implement integrated STEM curricula and lessons.
	DA3	Be open to incorporating other fields, such as the arts, health, and AI, into integrated STEM education, and adopting innovative pedagogical approaches.
	DA4	Share research findings and best practices in integrated STEM education with colleagues, students, and other interested stakeholders.

The proposed integrated STEM education competence framework for university lecturers will be able to provide a solid scientific foundation for developing the integrated STEM education competence for university lecturers, contingent upon its validation and reliability. This framework will serve the following purposes: (a) building integrated STEM education competence training programs for lecturers and teacher students; (b) developing guidance tools for university lecturers and teacher

students to practice integrated STEM education competence; and (c) creating a valid and reliable integrated STEM education competence scale for university lecturers.

METHODOLOGY

Research Design

We employed two main research steps to develop an integrated STEM education competence framework for university lecturers. First, the literature review on STEM, STEM education, integrated STEM education, and integrated STEM education competence was taken into account with the aim of proposing the integrated STEM education competence framework for university lecturers. Second, an exploratory factor analysis (EFA) and Cronbach's alpha coefficient analysis were conducted to verify if the proposed integrated STEM education competence framework for university lecturers is valid and reliable.

Sample and Data Collection

This study follows the general rule of having a minimum of five times as many observations as the number of variables to analyze to achieve a reliable sample size for EFA, with a 10:1 ratio considered more acceptable (Hair et al., 2018). The proposed integrated STEM education competence framework for university lecturers includes 23 variables (see Table 1), so the minimum sample size is 23 (variables) x 5 (times) = 115 (observations). This study selects 205 observations for 23 variables, satisfying the general rule for determining the sample size for EFA.

We selected the convenience sampling method for this study based on the research context (integrated STEM education in Vietnamese higher education), participant characteristics (university lecturers), and theoretical underpinnings of integrated STEM education and integrated STEM education competence. The convenience sampling method is a process of collecting data from a population that is close and accessible to the researcher (Rahi, 2017). The criteria for convenience sampling include (a) university lecturers in Vietnam, (b) university lecturers who have already implemented integrated STEM education, and (c) university lecturers who intend to implement integrated STEM education shortly. A total of 205 university lecturers from 9 public universities in both Northern and Southern Vietnam participated in the study. Of these, 174 lecturers had already implemented integrated STEM education, while 31 expressed their willingness to implement it shortly. Table 1 presents the demographic characteristics of the participants.

Table 2. Demographic Characteristics of the Participants

No	Demographic Characteristics	Total	%
	Higher Education Institutions	205	100
	Hanoi University of Science and Technology	4	2.0
	Bac Lieu University	51	24.9
	Binh Duong University	80	39.0
1.	University of Information Technology - Vietnam National University Ho Chi Minh City	8	3.9
	Sai Gon University	2	1.0
	Hung Yen University of Technology and Education	26	12.7
	Ho Chi Minh City University of Technology and Education	22	10.7
	Ho Chi Minh City University of Education	3	1.5
	Thu Dau Mot University	9	4.4

Table 2. Continued

No	Demographic Characteristics	Total	%
	Working Experience With Integrated STEM Education	205	100.0
2.	Implemented integrated STEM education	174	84.9
	Intend to implement integrated STEM education shortly.	31	15.1

The data collection occurred from February to August 2024, utilizing a questionnaire survey. The questionnaire was distributed to lecturers from nine public universities in Vietnam. Participants received a link to the survey, hosted on Google Forms, via email. A total of 329 responses were initially collected. After excluding 124 invalid responses, 205 valid responses were retained for analysis.

Instrument

A structured questionnaire was developed to assess the validity and reliability of the proposed integrated STEM education competence framework for university lecturers. The questionnaire consisted of two main sections. The first section included two questions focused on collecting demographic information and details about the lecturers' experience with integrated STEM education.

The second section aimed to evaluate lecturers' responses to five key competency components (factors) and 23 associated items (variables) that define integrated STEM education competence for university lecturers. These components are as follows: (a) STEM literacy (SL, 5 observed variables); (b) developing integrated STEM education curricula (DS, 5 observed variables); (c) implementing the student-centered approach in integrated STEM education (IS, 5 observed variables); (d) assessing integrated STEM learning outcomes (AS, 4 observed variables); and (e) demonstrating positive attitudes towards integrated STEM education (DA, 4 observed variables).

Each of the five competency components was measured using a 5-point Likert scale, with response options ranging from "strongly disagree" to "strongly agree." The questions' design closely aligned with the proposed integrated STEM education competence framework, ensuring that each competency area was thoroughly addressed.

Analyzing of Data

The quantitative data were analyzed using frequency analysis and multivariate analysis, conducted with the Statistical Package for Social Sciences (SPSS), version 22. Descriptive statistics were applied to summarize the demographic characteristics of the respondents. Additionally, exploratory factor analysis (EFA) was employed to examine the university lecturers' responses to the five component competencies and their 23 associated variables related to integrated STEM education competence.

EFA was chosen as a method to reduce and clarify the conceptual understanding of a set of observed variables, identifying the number and nature of common factors required to account for the pattern of correlations among these variables (Fabrigar et al., 1999). This analysis also served to assess the construct validity of the competence scale (Williams et al., 2010). The fit of the EFA model was evaluated using the Chi-square difference test, comparing the fit of the proposed solution with that of a parallel analysis, adjusted by reducing the number of suggested factors by one. To conduct the EFA, principal axis factoring was applied, along with Promax rotation, to optimize the factor structure. After identifying the factor groups, a correlation analysis was performed to explore the relationships between these groups.

For consistency in data interpretation, a 5-point Likert scale was used, with the value for each point calculated using the formula: (maximum value - minimum value) / number of points = (5 - 1) / 5 = 0.8.

Table 3. Scale Values for Response Meanings

Scale	Meaning	Mean
1.	Strongly disagree	1.0 < M ≤ 1.8
2.	Disagree	1.8 < M ≤ 2.6
3.	Neutral	2.6 < M ≤ 3.4
4.	Agree	3.4 < M ≤ 4.2
5.	Strongly agree	4.2 < M ≤ 5.0

FINDINGS/RESULTS

Cronbach's Alpha Analysis before Exploratory Factor Analysis

Cronbach's alpha analysis was used for each factor to assess the internal consistency of the 23-item scale, providing an estimate of the scale's reliability. The overall Cronbach's alpha coefficient for the five factors was .926, which exceeds the acceptable threshold of .70. The alpha values for each factor were as follows: LS = .931, DS = .950, IS = .938, AS = .925, and DF = .913. These results indicate that all factors demonstrated strong internal consistency, with alpha coefficients surpassing the .70 criterion.

All 23 items in the scale showed corrected item-total correlations above .30. Additionally, none of the items had a Cronbach's alpha value for item deletion that exceeded the overall alpha value, confirming that no items needed to be removed. As a result, the entire 23-item scale was retained, demonstrating that all items were of high quality.

Table 4. Cronbach's Alpha Coefficients of 23 Items and Five Factors and All of the Items With

Corrected Item-to-Total Correlations of the Integrated STEM Education Competence Framework for University Lecturers

Factor	Cronbach's Alpha	N Items	of Original Item Code	Corrected Total Correlation	Item-Cronbach's Alpha if Item Deleted
Having STEM Literacy (SL)	.931	5	SL1	.809	.918
			SL2	.820	.915
			SL3	.824	.915
			SL4	.834	.913
			SL5	.807	.918
Developing Integrated STEM Education Curricula (DS)	.950	5	DS1	.801	.949
			DS2	.884	.935
			DS3	.870	.938
			DS4	.896	.933
			DS5	.865	.938
Implementing the Student-Centered Approach in Integrated STEM Education (IS)	.938	5	IS1	.845	.921
			IS2	.824	.925
			IS3	.867	.917
			IS4	.845	.921
			IS5	.781	.932
Assessing Integrated STEM Learning Outcomes (AS)	.925	4	AS1	.797	.912
			AS2 AS3	.815 .871	.907 .888
			AS4	.822	.904
			DA1	.764	.900
Demonstrate Positive Attitudes Towards Integrated STEM Education (DA)	.913	4	DA2	.772	.898
			DA3	.859	.867
			DA4	.814	.883
			SL	.838	.903
Integrated STEM Education Competence (ISEC)	.926	5	DS	.850	.900
			IS	.848	.900
			AS	.683	.932
			DA	.813	.907

In short, Table 4 presents Cronbach's alpha coefficients for each factor, along with the corrected item-total correlations and Cronbach's alpha if any items were deleted. All factors demonstrated strong internal consistency, with alpha values above the commonly accepted threshold of .70, confirming the reliability of the integrated STEM education competence scale. Each item within the factors exhibited appropriate item-total correlations, and no items were identified for removal, further supporting the scale's robustness for assessing university lecturers' competence in integrated STEM education.

Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) is a multivariate statistical method used to (a) reduce a large number of variables into smaller factors, (b) identify underlying dimensions between measured variables and latent constructs, thus facilitating theory generation and refinement, and (c) provide

evidence of construct validity for self-report scales. Since there were no predetermined hypotheses regarding the structural nature of the integrated STEM education competency framework for university lecturers, EFA was employed to explore the five proposed factors, eliminate items that loaded on multiple factors, and assess the convergent and discriminant validity of the factors.

Before performing EFA, the suitability of the data was evaluated. An inspection of the correlation matrix revealed 23 variables with correlation values of .55 or higher. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .947, surpassing the recommended threshold of 0.80, indicating the appropriateness of the data for factor analysis. Bartlett's Test of Sphericity (Chi-Square = 5059.462, df = 253, $p < .001$) was statistically significant, confirming that the variables were sufficiently correlated for factor analysis.

The factor extraction process was conducted to determine the underlying structure of the relationships between the 23 variables and the five proposed factors of the integrated STEM education competence framework. This process involved selecting the factor extraction method (common factor analysis versus principal component analysis) and the number of factors to represent the structure. Common factor analysis (specifically principal axis factoring in SPSS) was used along with Promax rotation (non-orthogonal rotation), with an absolute factor loading cut-off of .40. Factor extraction was guided by criteria such as communalities, eigenvalues, cumulative percentage of variance, and factor loadings.

The item communalities in this study were greater than .60 (SL1, SL2, SL3, SL4, SL5, DS1, IS2, IS5, DA2, DA4), $\geq .70$ (DS2, DS3, DS4, DS5, IS1, IS3, IS4, AS1, AS2, AS4, DA1, DA3), and greater than .80 (AS3). The item community values ranged from .614 to .840, so 23 variables were retained in the integrated STEM education competence framework for university lecturers.

Three factors with eigenvalues greater than 1 were extracted, with the last factor having an eigenvalue of 1.001. The cumulative percentage of variance explained by the first three factors was 61.616%, 67.608%, and 70.740%, respectively, meeting the requirement for explaining a substantial proportion of the variance. Factor loadings ranged from 0.55 to 0.938, indicating the appropriateness of the factor solution.

With KMO = .947 and a significant Bartlett's test of sphericity with $p < .000$, the EFA results stopped at the third-factor rotation, indicating a correlation between the observed variables and the total number of observations. The EFA results extracted 3 factors with 23 observed variables, equal to the items presented in the theoretical model (see Table 5). The total eigenvalue (%) of the last factor was 1.001, and the cumulative total variance explained was 70.740%. This means that at the stopping point of 1.001, these 3 factors explained 70.740% of the variation in the data. Thus, the factors and observed variables of the integrated STEM education competence framework for university lecturers satisfied the requirements of convergent and discriminant validity.

These findings suggest that the proposed integrated STEM education competence framework for university lecturers is valid. Out of the original 23 items, all items related to AS and DA were retained in their respective factors. While no items from the original SL, DS, or IS factors were eliminated, the factors were combined to form a more streamlined framework. As a result, the original five-factor structure (SL, DS, IS, AS, and DA) was reduced to three factors, with the number of observed variables remaining unchanged. The new factors were (a) designing and implementing integrated STEM education (DIS), which encompassed SL, DS, and IS; (b) assessing integrated STEM learning outcomes (AS); and (c) demonstrating positive attitudes toward integrated STEM education (DA).

Following the EFA, the internal consistency of the three-factor model was assessed. The overall Cronbach's alpha for the three factors was .874. The alpha values for each factor were DIS (15 items) = .969, AS (4 items) = .925, and DA (4 items) = .913. All 23 items had corrected item-total correlations above .30, and none of them had a Cronbach's alpha that was greater than the total Cronbach's alpha. This showed that the three factors and the 23 observed variables were reliable.

Table 5. Findings of Exploratory Factor Analysis by Extraction Method: Principal Axis Factoring and Cronbach's Alpha of the Integrated STEM Education Competence Framework for University Lecturers

Factor	Original Item Code	Item	Communalities	1	2	3	Corrected Item-Total Correlation	Cronbach's Alpha If Item Deleted
Designing and Implementing Integrated Education	DIS1	DIS11	.731	.938			.787	.968
	DS3	DIS8	.754	.908			.781	.968
	STEMIS2	DIS12	.691	.898			.796	.968
	DS2	DIS7	.707	.813			.809	.967

(DIS)	IS4	DIS14	.700	.812		.808	.967
	DS4	DIS9	.790	.797		.795	.968
	IS3	DIS13	.700	.769		.822	.967
	DS5	DIS10	.704	.638		.841	.967
	IS5	DIS15	.692	.620		.873	.966
	SL1	DIS1	.646	.620		.820	.967
	SL3	DIS3	.656	.613		.803	.967
	SL5	DIS5	.681	.605		.787	.968

Table 5. Continued

Factor	Original Item Code	Item	Communalities	1	2	3	Corrected Item-Total Correlation	Cronbach's Alpha If Item Deleted
	SL2	DIS2	.614	.580			.814	.967
	DS1	DIS6	.670	.573			.814	.967
	SL4	DIS4	.687	.550			.813	.967
Demonstrating Positive Attitudes Towards Integrated STEM Education (DA)	DA3	DA3	.751		.861		.764	.900
	DA1	DA1	.733		.833		.772	.898
	DA4	DA4	.694		.634		.859	.867
	DA2	DA2	.643		.558		.814	.883
Assessing Integrated Learning Outcomes (AS)	AS3	AS3	.840			.911	.797	.912
	STEMAS4	AS4	.758			.811	.815	.907
	AS2	AS2	.724			.784	.871	.888
	AS1	AS1	.706			.779	.822	.904
Kaiser-Meyer-Olkin Measure of Adequacy.				.947				
Bartlett's Test of Sphericity				Approx. Chi-Square				
				5059.4				
				62				
				253				
				.000				
Initial Eigenvalues.				14.465	1.629	1.001		
Cumulative percentage of variance.				61.616	67.60	70.74		
				%	8%	0%		
Cronbach's Alpha coefficient				.969	.925	.913	.874	
Extraction Method: Principal Axis Factoring.								
Rotation Method: Promax with Kaiser Normalization.								
a. Rotation converged in 6 iterations.								

Correlation between Variables

Pearson correlation analysis was conducted to examine the strength of linear relationships between the dependent variable (ISEC) and the independent variables (DIS, AS, and DA). Table 5 presents the correlation coefficient matrix, showing the relationships between the three independent variables and the dependent variable. Below each correlation coefficient, the corresponding significance value and sample size (N) are provided. Each variable is perfectly correlated with itself, with $r = 1$ along the diagonal of the matrix. Overall, ISEC is positively related to DIS, AS, and DA, with Pearson correlation coefficients approaching 1 and the p-value of the t-test indicating that these correlations are statistically significant ($p < .001$).

A positive relationship exists between DIS and AS, with a Pearson correlation coefficient of $r = .661$ ($p < .001$). This indicates a significant association between designing and implementing integrated STEM education and assessing integrated STEM learning outcomes. As proficiency in designing and organizing integrated STEM education activities increases, so does the capacity to assess STEM education outcomes.

DIS is also positively related to DA, with a Pearson correlation coefficient of $r = .798$ ($p <$

.001). The correlation coefficient between DIS and DA is higher than that between DIS and AS, indicating a stronger association. This suggests that improved competency in designing and organizing integrated STEM education leads to a more positive attitude towards integrated STEM education.

The Pearson correlation coefficient ($r = .977$) and the analytical significance value ($p < .001$) indicate a strong positive relationship between DIS and ISEC. The correlation coefficient (r) of DIS in relation to ISEC is close to 1, which encourages us to believe that the relationship between DIS and ISEC is extremely tight. This implies that increased proficiency in designing and implementing integrated STEM education directly correlates with the university lecturers' integrated STEM education competence.

AS is positively correlated with ISEC ($r = .778$, $p < .001$), indicating that improved abilities in assessing STEM learning outcomes are strongly associated with better integrated STEM education competence.

DA also shows a strong positive correlation with ISEC ($r = .875$, $p < .001$). This suggests that as lecturers demonstrate more positive attitudes towards integrated STEM education, their overall competence in integrated STEM education increases.

In short, these findings suggest that enhanced abilities in designing and implementing integrated STEM education, assessing STEM learning outcomes, and demonstrating positive attitudes are strongly associated with higher levels of integrated STEM education competence among university lecturers.

Table 6. Correlation Between Variables

		DIS	AS	DA	ISEC
DIS	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	205			
AS	Pearson Correlation	.661**	1		
	Sig. (2-tailed)	.000			
	N	205	205		
DA	Pearson Correlation	.798**	.641**	1	
	Sig. (2-tailed)	.000	.000		
	N	205	205	205	
ISEC	Pearson Correlation	.977**	.778**	.875**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	205	205	205	205

**Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

This study employed a literature review, a questionnaire, and multivariate data analysis techniques—including exploratory factor analysis (EFA), Cronbach's alpha, and Pearson correlation analysis—to develop an integrated STEM education competence framework for Vietnamese university lecturers. Data were gathered from 205 lecturers across nine public universities in Vietnam, focusing on the factors and observed variables within the proposed framework. The findings indicate that the proposed competence framework meets the criteria for EFA and Cronbach's alpha. Furthermore, Pearson correlation analysis reveals positive relationships between the dependent variable and independent variables within the framework. These results will be discussed in greater detail, comparing them with previous research in the next section.

First, this study employs the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity to investigate the possibility of finding factors in the data set or the sample's adequacy. The KMO considers the variance ratio among all observed variables, which ranges from 0 to 1, to demonstrate the adequacy of each observed variable and the entire model. Meanwhile, Bartlett's sphericity test compares the observed correlation matrix with the identity matrix to determine the correlation between the observed variables. If the Bartlett's sphericity test is not statistically significant, it is not appropriate to use the observed variables for factor analysis. If the KMO value exceeds .70, factor analysis is appropriate (Liu, 2023), and the level of common variance is excellent when the MKO value is between 0.90 and 1.00 (as cited in Beavers et al., 2013). The larger the approximate Chi-square value of Bartlett's Test of Sphericity, the smaller the significance value, which is less than .001, and

vice versa (Liu, 2023). Because the KMO value exceeded .70 and was greater than .90, the data are adequate and suitable for factor analysis, as recommended by Beavers et al. (2013) and Liu (2023). The Bartlett's Test of Sphericity value is statistically significant, so the variables exhibit correlation and meet the requirements for factor analysis.

Communality is the amount of variance in a variable explained by its loadings on factors (Hair et al., 2018), which ranges from 0–1, with values closer to 1 indicating greater variance (Ha & Moreira, 2021). Hair et al. (2018) define communality as a measure of variable retention and help determine the strength of factors in explaining each variable. The accepted cutoff value for item communality is .40 or greater (Nishantha De Silva et al., 2019). Item communality between .40 and .70 is low to moderate, and item communality is less than 0.40 when items are unrelated to each other (Taherdoost et al., 2022). Item communities of .70, .80, or greater are regarded as ideal (Beavers et al., 2013) and high (Zaman et al., 2020), respectively. The item community findings fulfill both the cutoff value requirements established by Nishantha De Silva et al. (2019) and the ideal and high standards indicated by Beavers et al. (2013) and Zaman et al. (2020).

The present study examines the cumulative percentage of variance to ensure that the generated components explain at least a certain level of variance (Hair et al., 2018). All fields, including the natural and social sciences, do not have an absolute cutoff for extracting cumulative variance (Hair et al., 2010, 2018; Taherdoost et al., 2022). However, in the social sciences, factors that account for 60% of the total variance are enough, and in some cases even less (Hair et al., 2010, 2018). For multidimensional data sets, Cattell (1966, as cited in Shaharudin & Ahmad, 2017) recommends using a cumulative variance percentage of 70% as a preliminary guideline for pruning the number of principal components. The cumulative variance extracted identified in this study meets the cutoff value for cumulative variance extraction when explaining at least a specific amount of variance, as stated by Cattell (1966, as cited in Shaharudin & Ahmad, 2017, p. 217), Taherdoost et al. (2022), and Hair et al. (2010, 2018).

Apart from determining the number of factors in a set of variables, this study also investigated the degree to which each variable reflects each developing factor by means of loading values. The factor loadings, which represent the correlation between individual variables and their respective factors, further validated the framework. Hair et al. (2018) suggest that loadings of $\pm.50$ or higher are practically significant, while loadings of $\pm.70$ or higher indicate a well-defined structure. Furthermore, Howard (2016) recommends loading variables into their primary factor with a cutoff above .40. The factor loadings in this study do not only exceed the recommended cutoff as proposed by Howard (2016) but also demonstrate a well-defined structure, as suggested by Hair et al. (2018).

Second, Cronbach's alpha is a statistical measure that quantifies the internal consistency of a factor. It indicates that the different variables measured on a scale must exhibit a strong positive correlation, therefore elucidating the same theoretical construct. A scale that has a strong positive correlation among the observed variables will demonstrate greater consistency, resulting in a higher Cronbach's alpha coefficient. The Cronbach's alpha coefficient value ranges from 0 to 1. Level 0 denotes a negligible connection among the observed variables in the group, whereas level 1 signifies a complete correlation among the observed variables. A good scale should have a Cronbach's alpha of .70 or greater (Nunnally, 1978). George and Mallery (2003) provide a comprehensive guideline for interpreting Cronbach's alpha results in the following: A score of .90 or above is considered excellent, a score of .80 or above is good, a score of .70 or above is acceptable, a score of .60 or above is questionable, a score of .50 or above is poor, and a score of less than .50 is unacceptable. Hair et al. (2010, 2018) also believe that a scale is considered to be one-dimensional and reliable if Cronbach's alpha is greater than the threshold of .70. This implies that the higher the Cronbach's alpha coefficient, the higher the scale's reliability. Additionally, when testing the scale's reliability, it is important to consider the value representing the correlation between each observed variable and the remaining variables in the scale, known as the corrected item or total correlation, while testing the reliability of the scale. If the observed variable has a stronger positive correlation with the other variables in the scale, the higher the corrected item-total correlation value, the better the observed variable. According to Marianti et al. (2023), the item-total correlation cut-off value of 0.30 is commonly used to determine how well an item correlates with the total score. This value reveals how well each item distinguishes between different responses and which items may need to be updated or removed. The Cronbach's alpha coefficient findings for all three factors and each component factor in this study fully meet the Cronbach's alpha requirements, as recommended by George and Mallery (2003), Hair et al. (2010, 2018), and Marianti et al.

Third, the integrated STEM education competence framework for university lecturers is

established from 3 newly emerged components (DIS, AS, and DA) and their corresponding 23 items, as determined by EFA. The Pearson correlation coefficients reveal that there are strong, positive relationships among DIS, AS, and DA (independent variables) and ISEC (dependent variable). This suggests that university lecturers who are capable of DIS, AS, and DA will have a high level of integrated STEM education competence (ISEC).

This modification of LS, DS, and IS into DIS is consistent with the logic of the teaching process in general (Duong, 2022) and the integrated STEM education process (Trung, 2022) in particular. The current study exhibits both similarities and differences when compared to prior studies on the three components of the integrated STEM education competence framework. The current study is consistent with the suggestions put forward by T. T. T. Nguyen et al. (2020) and Duong (2022) for all LS, DS, and IS. It also supports the recommendations made by Song (2017) for LS and IS and unifies the IS with the work of Bui (2019). However, unlike prior studies, this research consolidates LS, DS, and IS into a unified competence, providing a more cohesive framework for integrated STEM education.

Assessment of learning outcomes plays an important role in every teaching process. The assessment of integrated STEM learning outcomes is deeply embedded in the entire process of implementing integrated STEM education lessons or topics. Therefore, the presence of AS in the integrated STEM education competence framework for Vietnamese university lecturers aligns with previous studies (Bui, 2019; Duong, 2022; T. T. T. Nguyen et al., 2020).

Teachers' attitudes towards STEM education are a determining factor in the success of its integration into modern curricula (Vaiopoulou et al., 2024). This study not only agrees with Vaiopoulou et al. (2024) on the role of teachers' attitudes toward integrated STEM education but also resembles the affective trait component in Song's (2017) study.

CONCLUSION

Integrated STEM education has emerged as a crucial driver of innovation within Vietnamese higher education institutions, supporting the preparation of STEM professionals for the Fourth Industrial Revolution. However, university lecturers must improve the integrated STEM education competence to effectively design, implement, and assess integrated STEM lessons or topics. A valid and reliable integrated STEM education competency framework for university lecturers provides them with a scientific foundation to develop this competence.

This study successfully proposed an integrated STEM education competence framework for university lecturers with five main component competencies and 23 items, drawing from the literature review. Furthermore, this study used multivariate analysis to test the validity and reliability of the proposed framework, which was based on data collected from 205 lecturers at nine public universities across Vietnam through the questionnaire survey. As a result, this study confirmed the validity and reliability of the framework, which includes three main component competencies and 23 items. The valid and reliable component competencies and their items within this framework will be used to develop in-service training programs on integrated STEM education and integrated STEM education practice guides.

RECOMMENDATIONS

Future Research Should Focus on the Following Key Issues:

First, develop an integrated STEM education competence scale for university lecturers. Practitioners (lecturers, educators, researchers) should evaluate the integrated STEM education competence of university lecturers through three component competencies and 23 items (as verified to be valid and reliable in the above section). The evaluation of these component competencies and items should be conducted at five levels: unacceptable, meets minimum expectations, good, and excellent. Using this scale enables practitioners to identify the component competencies and items of the integrated STEM education competence that require improvement, thereby enhancing its effectiveness in the classroom.

Second, examine the impact of in-service training programs in STEM-integrated education on improving the integrated STEM education competence of university lecturers. Practitioners design and implement in-service training programs in integrated STEM education for university lecturers, based on the integrated STEM education competence framework. Examining the impact of in-service training programs in STEM-integrated education helps educators confirm the effectiveness of these programs on the professional development of integrated STEM education for faculty.

Third, investigate the integrated STEM education competence of university lecturers in a broader context. Practitioners (educators, researchers, or administrators) look into how well university

lecturers teach STEM subjects across a range of majors and university types, such as public and private ones, in order to come up with comprehensive plans for how to support lecturers' professional development through curriculum, policy, and institutional supports.

Fourth, compare the integrated STEM education competence of novice and experienced university lecturers. Practitioners (educators, researchers, or administrators) compare the integrated STEM education competence of university lecturers with just one year of experience to those with three, five, and ten years or more to build in-service training programs in integrated STEM education that are compatible with novice and experienced university lecturers.

Last but not least, compare the integrated STEM education competence of Vietnamese university lecturers with those in other Southeast Asian countries. Researchers should focus on comparing the levels of competence (inacceptable, meeting minimum expectations, good, and excellent) among university lecturers from similar types of universities and majors, as well as their experiences with integrated STEM education.

LIMITATIONS

This study has certain limitations. First, as all participants were from public universities, the findings may not fully represent the diversity of universities in Vietnam, including private and international institutions. Second, while the sample size was adequate for the observed variables, the distribution of participants across the nine public universities was uneven. Third, the present study did not do confirmatory factor analysis (CFA) to verify if the number of factors (or structures) and the loadings of the observed variables (indicators) on them aligned with the anticipated values of the integrated STEM education competence framework for university lecturers, as suggested by document analysis.

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