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Determination of Integrated STEM Teacher Competencies: A Modified Delphi Method

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ABSTRACT

Determination of integrated STEM teacher competencies for the effective use of STEM education is important in terms of managing the learning process and performing STEM integration effectively. More studies are needed to identify and describe STEM teacher competencies as a result of comprehensive research. The purpose of this research was to constitute integrated STEM teacher competencies for secondary education by taking the opinions of the STEM experts. The research was carried out via three-round modified Delphi method and validation stage. The following four competency areas were defined within the scope of integrated STEM teacher conceptual framework: Cognitive Characteristics in STEM Teaching, STEM Teaching Skills, Affective-Motivational Characteristics in STEM Teaching, and Collaboration and Engagement Skills. Under these competency areas, 14 competencies and 58 competence indicators were determined. This study would be a guiding framework for the development of STEM teacher education programs at the undergraduate or graduate levels.

Keywords: STEM teacher, integrated STEM teacher competencies, modified Delphi method

INTRODUCTION

In the 21st century, students must be able to apply the knowledge they acquire in the classroom to real-world situations and challenges they encounter in daily life (Wagner, 2010). The concept of "21st-century skills" encompasses critical thinking, problem-solving, information literacy, systems thinking, interpersonal collaboration, leadership, entrepreneurship, adaptability, effective communication, and creativity—competencies essential for success in both life and career (OECD, 2017).

STEM (Science, Technology, Engineering, and Mathematics) education has been introduced as a means to bridge the gaps between these disciplines, integrating them into a cohesive framework that fosters the development of 21st-century skills (National Research Council, 2014). Research suggests that STEM education plays a crucial role in equipping students with these competencies and achieving the desired educational outcomes (Kelley and Knowles, 2016) as learning by doing is characteristic in STEM acquisition (Cedere et al., 2022). Specifically, an integrated STEM curriculum that incorporates engineering design and practices has been shown to enhance students' scientific understanding and learning outcomes (Anwar et al., 2022). Moore et al. (2014) has defined integrated STEM education as "an effort by educators to have students participate in engineering design as a means to develop technologies that require meaningful learning and application of mathematics and/or science" (p. 38). This definition underscores the role of engineering as a bridge between science and mathematics, facilitating deeper learning through technology development (Ring, 2017). The inclusion of engineering and an awareness of the intimate relationship among STEM disciplines signifies a shift towards more application-oriented settings of science that provide relevant contexts inspired by real-world problems and an emphasis on developing 21st century skills (Dare et al., 2021). The categories of instructional designs for STEM education include design-based learning, inquiry-based learning, project-based learning, and problem-based learning (Halawa et al., 2024). Integrating this experiential and hands-on learning in education has the potential to increase students' interest and motivation in learning STEM concepts as well as practices and has a role in enhancing students' abilities to integrate and apply STEM knowledge to solve authentic real-world problems (Azizan and Abu Shamsi, 2022; Dare et al., 2021; Lavado-Anguera et al., 2024; Lestari, 2021; Lin et al., 2021; Yuksel, 2025).

Effective implementation of integrated STEM requires teachers to have a strong foundation in STEM content as well as specialized pedagogical knowledge to effectively deliver instruction (Thibaut et al., 2018). However, due to the variety of STEM education models, teachers are often left to interpret and define key aspects of STEM instruction, including

(a) the overall approach to STEM education,
(b) the nature and extent of disciplinary integration, and
(c) the role of engineering, technology, and potentially other non-STEM disciplines in the K-12 system (El Nagdi et al, 2018).

STEM educators, who typically specialize in individual disciplines, must collaborate to develop and implement interdisciplinary STEM curricula (Herschbach, 2011; Sanders, 2009). Given the critical role of teachers in STEM education, it is essential to assess their knowledge, skills, attitudes, values, and experiences (Jang, 2016). Therefore, the purpose of this study was to identify and define the teacher competencies required for effective integrated STEM teaching.

STEM Teacher Education

Although STEM teacher preparation is widely recognized as a crucial factor in the successful implementation of integrated STEM education, uncertainty remains regarding how teachers integrate STEM disciplines into their teaching practices (Hsu and Fang, 2019). To address this challenge, professional development programs are essential to equip science teachers with the necessary skills to effectively integrate science, technology, engineering, and mathematics into their instruction (National Research Council, 2012). Research on STEM teacher competencies highlights the specific skills required for implementing integrated STEM programs. For instance, Sandall et al. (2018) identified ten core competencies essential for effective STEM instruction based on STEM educators' perspectives. These competencies include integration, project-based learning, design-based training, STEM content creation, and teacher collaboration through professional development programs.

Despite growing recognition of teachers' central role in STEM education and the necessity of fostering STEM-specific pedagogical thinking (Reeve, 2015; Radloff and Guzey, 2016), professional development programs for STEM teachers remain inadequately defined and underexplored. Rinke et al. (2016) examined the impact of a STEM teacher education model built on the principles of integrated STEM education, which combined science and mathematics courses. Their findings indicate that pre-service teachers who participated in the STEM-specific training benefited significantly more than those in traditional teacher education programs. The study particularly emphasized that this model enhanced pre-service teachers' ability to develop lesson plans, integrate engineering, design, and art into STEM curricula, and improve STEM literacy.

Furthermore, Shernoff et al. (2017) identified critical professional development needs among STEM teachers, revealing that they require additional time for planning and collaboration, access to STEM-specific training opportunities, adequate STEM resources, reinforcement of a STEM-oriented school culture, inter-group cooperation, and more instructional time. Teachers also reported challenges in classroom management during STEM integration, aligning STEM content with educational standards, and accessing sufficient technological tools and resources. Similarly, Dare et al. (2018) have argued that despite the increasing emphasis on integrated STEM education in K-12 settings, opportunities for teachers to engage in professional development specific to STEM integration remain limited. Existing curricula are not structured to support interdisciplinary teaching, further complicating teachers' efforts to incorporate STEM principles effectively. Moreover, many teacher educators themselves lack training in interdisciplinary instruction, as traditional teacher preparation programs often do not emphasize cross-disciplinary integration (Brown and Bogiages, 2019). As a result, teachers may enter the profession without firsthand experience in integrated STEM education, making it difficult for them to model and implement interdisciplinary learning strategies effectively.

A review of the literature underscores the urgent need to establish a clear and well-defined set of STEM teacher competencies to guide the development and implementation of professional development programs. By identifying these competencies, educators and policymakers can create more structured and effective training opportunities, ensuring that STEM teachers are adequately prepared to integrate multiple disciplines, foster innovative thinking, and improve student learning outcomes. Thus, this study aims to develop an Integrated STEM Teacher Competency Framework that can serve as a foundational guide for STEM teacher preparation and ongoing professional development.

STEM Teacher Competencies

Teaching STEM disciplines, such as science and engineering, requires an integrated approach, making it essential for science teachers to possess not only subject-specific content knowledge but also the pedagogical skills necessary to implement STEM integration effectively (Wang, 2012). To successfully teach in an integrated STEM environment, teachers must demonstrate both competence and confidence (Thomas, 2014). Competence, in this context, refers to the knowledge, skills, attitudes, and motivational factors that enable individuals to master specific professional tasks (Epstein and Hundert, 2002). In teacher education, competence encompasses the essential knowledge, skills, and values required to effectively complete a teacher preparation program (Houston, 1987). Teachers' competencies influence their pedagogical approaches, communication styles, professional values, and instructional decision-making, all of which contribute to their professional development and curriculum implementation (Selvi, 2010). Consequently, identifying the key competencies that facilitate effective integrated STEM teaching is crucial (Song, 2020).

Despite the growing recognition of STEM education's importance, research on STEM teacher education and professional competencies remains limited (Milner-Bolotin, 2018a). One of the earliest attempts to define a STEM education framework, developed by Honey et al. (2014), provided guidance on STEM integration in K-12 education but failed to include specific competencies for STEM teachers. Similarly, Thibaut et al.'s (2018) Integrated STEM Education Framework did not address STEM teacher competencies, leaving a significant gap in the literature. Moreover, existing STEM education models offer little guidance for teachers on defining STEM as an instructional approach, integrating it into the learning environment, and effectively linking engineering and technology with STEM disciplines (El Nagdi et al., 2018).

Another critical limitation in the existing research is the emphasis on STEM teacher identity rather than competencies (Dou and Cian, 2021; El Nagdi et al., 2018; El Nagdi and Roehrig, 2020; Weinberg et al., 2021). While understanding STEM teacher identity is valuable, it does not provide a clear framework for the knowledge, skills, and attitudes required for effective STEM teaching. Moreover, studies that have attempted to define STEM teacher competencies are either incomplete or lack a comprehensive theoretical basis. For instance, Milner-Bolotin (2018b) proposed a set of three broad competencies:

1. Cognitive abilities, including professional knowledge and Technological Pedagogical Content Knowledge (TPACK).
2. Zone of proximal development, referring to opportunities for professional growth in TPACK through collaboration.
3. Affective characteristics, such as beliefs, attitudes, and predispositions toward STEM teaching.

However, while these competencies were identified, their content and specific applications were not detailed. Similarly, Song (2020) proposed three primary STEM teacher competency domains—cognitive characteristics, instructional skills, and affective characteristics—and, through an exploratory sequential mixed-methods approach, developed a 19-item framework. These items were categorized into five overarching competencies: Intellectual competency, creative competency, instructional competency, integrative competency, and professional development competency.

Although Song (2020) provided a structured competency framework, the study was limited to teachers' self-perceptions, neglecting perspectives from STEM education experts or literature-based validation. More recently, the research by Hurley et al. (2023) outlined four essential competencies for STEM teachers: core competencies like collaboration, problem-solving, and critical thinking; ability to foster these competencies in students; knowledge of STEM careers and workplace diversity; and understanding of industrial processes and real-world applications. Their framework emphasizes the importance of teachers having broad STEM knowledge rather than narrow specialization, aiming to improve the implementation of STEM education in secondary schools. However, their study also had limitations, as it did not establish a comprehensive competency model applicable to various educational contexts.

Purpose of the Study

The existing literature lacks a comprehensive and well-defined framework for integrated STEM teacher competencies (Milner-Bolotin, 2018a). Identifying these competencies is essential for effective STEM instruction, as they guide teachers in managing the learning process, implementing STEM integration strategies, and developing interdisciplinary connections. A competency-based STEM education framework would contribute to the improvement of teacher education programs and professional development initiatives (Arikan et al., 2022). By

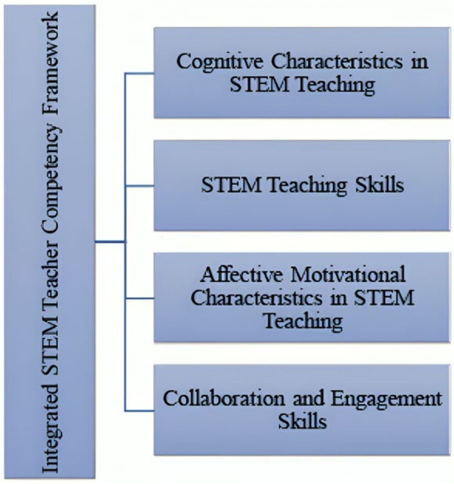

Figure 1. Integrated STEM teacher competency framework

defining STEM teacher competencies, this study aims to support the planning, implementation, and evaluation of STEM teacher education programs, ensuring that teachers are adequately prepared to engage students in integrated STEM learning. Additionally, a competency-based framework would provide clear guidelines for teacher professional development, instructional planning, and curriculum design.

This study aimed to establish a consensus on integrated STEM teacher competencies for secondary education by incorporating insights from both STEM education experts and practicing teachers. By addressing this research gap, it would contribute to the development of a standardized competency framework used for STEM teacher preparation and ongoing professional growth. To achieve this goal, the study addressed the following research question: What are the integrated STEM teacher competencies for secondary education?

Conceptual Framework for Integrated STEM Teacher Competencies

Teacher competencies encompass personal characteristics, knowledge, skills, and attitudes required for effective teaching in various educational contexts (Blömeke et al., 2015; Tigelaar et al., 2004). Blömeke et al. (2015) expanded upon Koeppen et al.'s (2008) definition of competencies as "domain-specific cognitive dispositions" proposing that competencies should be viewed as multidimensional constructs that include both cognitive and affective-motivational characteristics. According to this perspective, competencies exist along a continuum, beginning with underlying traits that shape perception, interpretation, and decision-making, which then translate into observable behaviors in real-world teaching scenarios.

The integration of STEM disciplines has been recognized as a promising approach to addressing real-world challenges, particularly in the engineering design process through the application of technological knowledge, scientific inquiry, and mathematical reasoning (Moore et al., 2015). Given this context, Blömeke et al.'s (2015) competence model and Moore et al.'s (2014) vision for integrated STEM education provide the foundation for the current study's conceptual framework. Defining STEM Teacher Competencies Blömeke and Delaney (2012) have categorized teacher competencies into two broad domains:

1. Cognitive Abilities (Professional Knowledge):
   a. Content Knowledge (CK)
   b. General Pedagogical Knowledge (GPK)
   c. Pedagogical Content Knowledge (PCK)
2. Affective-Motivational Characteristics:
   a. Beliefs about the discipline (e.g., mathematics, science)
   b. Perceptions of teaching and learning within the discipline
   c. Professional motivation and self-regulation

Since STEM education demands both subject-matter expertise and interdisciplinary teaching strategies, defining STEM teacher competencies requires an approach that integrates these cognitive and affective dimensions. Therefore, this study synthesizes and expands upon existing competency frameworks from Blömeke and Delaney (2012), Milner-Bolotin (2018b) and Song (2020) to develop a comprehensive model for integrated STEM teacher competencies.

Proposed Integrated STEM Teacher Competency Framework

The proposed framework presented in **Figure 1** comprises four major competency domains, each derived from previous research:

1. Cognitive Characteristics in STEM Teaching (CCST)
    a. Derived from Blömeke and Delaney (2012), Milner-Bolotin (2018b), and Song (2020).
    b. Includes content knowledge in STEM disciplines and the ability to integrate them effectively.
2. STEM Teaching Skills (STS)
    a. Based on Song (2020).
    b. Encompasses competencies related to STEM lesson planning and implementation, including the use of active learning strategies and interdisciplinary instruction.
3. Affective-Motivational Characteristics in STEM Teaching (AMCST)
    a. Adapted from Blömeke and Delaney (2012), Milner-Bolotin (2018b), and Song (2020).
    b. Includes STEM teachers' beliefs, attitudes, and predispositions toward their discipline and professional motivation.
4. Collaboration and Engagement Skills (CES)
    a. Inspired by Milner-Bolotin (2018b).
    b. Supports teachers' professional growth through peer collaboration, feedback, and engagement in learning communities.

The cognitive characteristics domain ensures that STEM teachers have strong foundational knowledge across STEM disciplines, allowing them to make meaningful interdisciplinary connections. The STEM teaching skills domain focuses on teachers' ability to design, implement, and refine integrated STEM lessons. The affective-motivational characteristics domain highlights teachers' attitudes, beliefs, and motivation toward STEM education. Finally, the collaboration and engagement skills domain emphasizes the importance of peer learning, professional networks, and collective problem-solving in STEM education. Given that teacher learning is complex, multidimensional, and often unconscious (Korthagen, 2017), fostering collaborative STEM learning communities is essential. In such communities, teachers share experiences, provide feedback, and develop innovative teaching strategies, reducing professional anxiety while enhancing intrinsic motivation. These professional networks support continuous growth, allowing teachers to refine their practices in response to evolving STEM education demands.

The lack of a comprehensive, well-defined competency framework for STEM teachers underscores the necessity of this study. By integrating multiple research perspectives, this framework provides a structured approach to identifying, assessing, and developing STEM teacher competencies. It serves as a foundation for teacher education programs, professional development initiatives, and STEM curriculum design, ensuring that teachers are well-equipped to deliver high-quality, interdisciplinary STEM education.

METHODOLOGY

The Delphi Method attempts to draw on a wide reservoir of knowledge, experience and expertise in a systematic manner, allows a group of experts to deal with a complex problem systematically and should be used when the primary source of information sought is informed judgment (Ziglio, 1996). The Delphi Method is suitable for generating ideas and making changes in educational purposes in order to develop curriculum and determine teacher competencies (Helmer, 1966). The modified Delphi technique is similar to the Delphi method in terms of procedure and intent but the major modification consists of beginning the process with a set of carefully selected items drawn from various sources including synthesized reviews of the literature and interviews with selected content experts (Custer et al., 1999). Modified Delphi method was used for this study to determine integrated STEM teacher competencies and reach consensus among STEM education experts because the inclusion of initial focus group interviews containing questions based on the literature was a competency of the modified procedure (Custer et al., 1999; McKenna, 1994). Another reason for using modified Delphi method was that a modification involved the fact that participants were not anonymous during the discussion process (Leake et al., 2019) to encourage expert interaction but key decisions leading to consensus were still conducted anonymously using an online survey (Keegan et al., 2019).

Participants

Scheele (2002) has suggested that experts who are directly affected by the study and have experience in the study should be included in order to create a successful group in the selection of participants. In addition, it was aimed that the competencies generated in this research would be useful for and adaptable to various STEM teacher education contexts in different countries. For these reasons, the participants of this study were divided into following three groups: Group-1(Focus Group of 5 STEM Experts): International professors working abroad in the STEM fields; Group-2 (Group of 20 STEM Experts): National professors working in the STEM fields; and Group-3 (Group of 20 STEM Teachers): National teachers who received STEM training and implemented various STEM activities into their teaching practices.

Table 1. Data collection process

	First Delphi round	**Second Delphi round**	**Third Delphi round**	**Final process**
Participants	5 Inter. STEM Experts (Group-1)	5 Inter. STEM Experts (Group-1)	5 Inter. STEM Experts (Group-1)	20 Nation. STEM Experts (Group-2) 20 STEM Teachers (Group-3)
Response rate	%100	%100	%100	%100
Data collection tool	Focus group interview Protocol (15 open-ended questions)	Questionnaire (15 competencies and 132 competence indicators)	Questionnaire (14 competencies and 74 competence indicators)	Survey (14 competencies and 74 competence indicators)
Purpose	Determination of competencies and competence indicators.	Verification of the specified competencies and competence indicators.	Final consensus for each identified competence and indicator.	Validation of STEM teacher competencies and competence indicators.

Expertise in STEM disciplines, experience in STEM field, writing cited articles about STEM education in the indexed journals, directing at least one project in STEM education, and willingness to be participant of this research were the basic criteria in selecting the experts of Group-1 and Group-2. Group-1 consisted of five STEM international professors to build competencies with a focus group from the global perspective. These participants had bachelor's and graduate degrees in biology education, chemistry education, physics engineering, mathematics education, and information and communications technology (ICT) education and were working at the Schools and Colleges of Education. Three of the professors were female. There was one more criterion for this group: They should have earned their master's and doctorate degrees abroad and have been working abroad, so that they had knowledge about teacher education context as well as had experience with pedagogical approaches for integrated STEM teaching in different countries. Group-2 and Group-3 were constructed for quantitative and statistical aggregation of the items obtained from the first group. Group-2 included 20 STEM professors working in the same country that the researchers live in and hence, they were more reachable to work with. They were also working at the Schools and Colleges of Education in different universities. While 65% of the group came from a science education background, 20% of them had bachelor's degrees in mathematics education, and 15% of them had bachelor's degrees in ICT education. Half of the members of the Group-2 was female. Group-3 composed of 20 STEM teachers having a major from one of the STEM disciplines (science, physics, chemistry, biology, mathematics, and ICT), receiving STEM training, having STEM implementation experience, and willingness to involve in the study were the criteria used to constitute this group. While 60% of the teachers in Group-3 had one of science majors, 25% of them were mathematics teachers and 15% of them were ICT teachers. Consequently, Group-2 and Group 3 were the experts having basic information about the problem situation and sufficient knowledge, and acting objectively as well as rationally as Tersine and Riggs (1976) suggested.

Data Collection and Data Analysis

This research included modified Delphi method and validation of the results by using both qualitative and quantitative data collection and analysis processes. The participants' views and opinions were gathered and analyzed, and competencies and competence indicators were obtained. **Table 1** summarizes the data collection process. In the first Delphi round, the focus group interviews were conducted with Group-1. In the second and third Delphi rounds, two different questionnaires were applied to Group-1. The survey was conducted with Group-2 and Group 3 in the final process.

The purpose of the first Delphi round was determination of competencies and competence indicators while the aim of the second round was to verify the specified them. Final consensus for each identified competencies and competence indicators was made in the third Delphi round. One more process was added into the research to attain validation of STEM teacher competencies. Semi-structured interview protocol consisting of 16 open-ended questions were developed based on the STEM competency areas presented in **Figure 1**. Attention was paid to ensure that the questions were suitable for the purpose of the research and had content validity. The questions were pilot tested with two STEM education experts and the protocol was finalized as a result of the feedback given by them. There were four questions in the cognitive characteristics in STEM Teaching (CCST) area, eight questions in the STEM teaching skills (STS) area, two questions in the affective-motivational characteristics in STEM teaching (AMCST) area, and two questions in the collaboration and engagement skills (CES) area. The focus group interviews were conducted online with the participants twice and lasted 160 minutes in total. The questions are provided in **Appendix A**.

Table 2. Questions, responses and codes

Questions about STEM teaching skills competency area	Experts' response	Codes produced from the experts' quotes
In terms of preparing a STEM lesson plan, what competencies should a STEM teacher have?	"Being aware of the goal is not just enough to complete the activity, the teacher needs to prepare a student-centered STEM lesson plan and calculate its duration. She needs to get to know her students, take their individual differences into consideration and reflect this in her lesson plan. She ensures that other STEM teachers contribute to the activities and also includes discourse and critical thinking in her plan" (E2).	* Creates a student-centered STEM lesson plan (E2). * Takes the students' individual differences into account while planning the STEM lesson (E2). * Includes discourse and critical thinking in her STEM lesson plan (E2). * Collaborate with other STEM teachers to prepare STEM activities (E2).
What competencies should a STEM teacher have in order to implement scientific inquiry into his/her teaching?	"She uses critical thinking, decision-making, and questioning to support design with data, math, and science" (E1). "She provides valid content for students to generate questions. She also provides students with experiences that enrich asking questions." (E2). "She allows reasoning by asking questions, do activities that require reasoning, and makes inquiries to determine a STEM project topic." (E3). "She enables students to ask questions in order to reason and poses problems that will arouse students' curiosity. She examines what students performed with the discourse and reflection sections." (E4). "She designs a course where students can ask questions and provides an environment where students can reason and present how they solved their problems. She also has metacognitive knowledge and moderates this in her lessons" (E5).	* Uses critical thinking, decision-making, and questioning to support design with data, math, and science (from E1). * Provides valid content for students to generate questions (from E2). * Provides students with experiences that enrich asking questions (from E2). * Allows reasoning by asking questions (from E3). * Performs reasoning-oriented activities (from E3). * Makes inquiry in determining the STEM project topic (from E3). * Enables students to generate questions (from E4). * Poses problems that will arouse students' curiosity (from E4). * Examines what students do with the discourse and reflection sections (from E4). * Designs a lesson where students can ask questions (from E5). * Provides an environment where students can make reasoning and present how they solved the problems (from E5). * Has metacognitive knowledge and moderates this in her lessons (from E5).

Note: E: STEM education expert.

Content analysis was performed in the first Delphi round because it was aimed to examine the collected data in detail for creating codes and sub-themes (Downe-Wamboldt, 1992). Focus group interviews were transcribed by the first author. Then, she examined the responses for each question under the relevant competency area. She performed this analysis for each expert separately. That is, after she analyzed the first expert's responses to four questions regarding the CCST competency area, she started to analyze the second expert's responses for the same four questions. After completing data analysis for the first competency area, she moved to the second competency area named STS and analyzed the data gathered from eight questions for each expert. Codes were created based on the experts' excerpts and written as competence indicators. It was aimed at constitute a competence pool. Some questions about STEM teaching skills competency area, the experts' responses for the questions and generated codes can be seen in **Table 2**. The relevant codes were brought together and the sub-themes that would best cover the codes were determined (Miles and Huberman, 1994). Names of the sub-themes were given by taking the content of the related questions into account. This way of coding and naming ensured keeping the conceptual structure. For example, in order to cover all the codes generated from the question "What competencies should a STEM teacher have in order to implement scientific inquiry into his/her teaching?", the name of the sub-theme was identified as "Inquiry-Based STEM Teaching" under the STEM teaching skills theme. Codes were written as competence indicators, sub-themes were stated as competencies, and themes were renamed as competency areas. In qualitative research, it is important to present data with code and theme in data analysis in order to reduce bias and make comparisons between themes, sub-themes and codes (Merriam and Grenier, 2019).

In order to assess the reliability of coding, the second author independently coded Expert 1's responses for the questions of CCST competency area, Expert 2's responses for the questions of STS competency area, Expert 3's responses for the questions of AMCST competency area, and responses of Expert 4 and Expert 5 for the questions of CES competency area. After two researchers compared their coding, they reached 92% agreement and the reliability measured by Cohen's ϰ was found as 0.80. Since Kappa values over 0.75 seem excellent (Fleiss, 1981), coding of the competence indicators had high reliability. The researchers revised the responses and finalized coding. The second author also named the sub-themes independently. The two found 96% agreement between them and the reliability measured by Cohen's ϰ was calculated as 0.89. A total of four competency areas, 15 competencies and 132 competence indicators were reached in the first Delphi round. These competencies and competence indicators were asked to the Group-1 again through the second Delphi round to examine whether they approved the identified competencies and competence indicators. In the second round, the competence indicators obtained from each expert were sent to that expert for verification. For example, E4 reviewed the competence indicators only generated from his responses during the focus group interviews. However, the experts had also opportunities to add new competence indicators under the relevant competency and to see the competencies obtained from the other participants. The instruction in the forms sent to the experts was as follows: "In the attached form, I have inferences about teacher competencies and competence indicators obtained from the statements of the participants during the focus group interviews. As you can see in the rest of the form, each competency area is explained and each competency area consists of competencies. Under the competencies, there are STEM teacher competence indicators derived from your statements. The absence of a competence indicator under a competency indicates that no inference has been made regarding that competency. Please indicate whether you approve the relevant competence indicator by checking the box next to it. If you think that indicator should not be included in the relevant competency, do not check the box. The stated competence indicators are based solely on your statements. If you would like to add a new one under the relevant competency, please write. If you want to benefit from the competencies obtained from the other participants, you can use the list I will send you by e-mail". The expert group removed and added some indicators and the number of competence indicators was changed to 123 during the second round.

After the second Delphi round, similar data were brought together within the framework of certain codes and sub-themes, and editing and interpretation were made during the content analysis by the two researchers over the discussion. Repetitive competence indicators with the same scope were combined and sub-themes were revised. This process was done after the second round because the researchers tried to adhere to the experts' statements in order to reflect their meanings to the codes after the first round. This time reliability of analysis was examined with a PhD student, who had master's degree in STEM education and ten years of teaching experience. There was 90 % agreement between the coders and the reliability measured by Cohen's ϰ was 0.80. The researchers and the PhD student revised codes and sub-themes and as a result, 15 competencies were reduced to 14 and 123 competence indicators were decreased to 74. In the third Delphi round, Group-1 was asked to evaluate the competencies and to provide explanation if they did not approve any competency. The experts also indicated whether they approve the competence indicators or not by checking the relevant box and had opportunity to change or revise them. There were different opinions on the determination of the consensus criterion in the modified Delphi method (Diamond et al., 2014). All competence indicators were approved by the Group-1 with 80 % or 100 % agreement and therefore, final consensus for 14 competencies and 74 competence indicators was achieved.

Competencies and competence indicators were turned into a survey items with 5-point Likert-type scale (Absolutely Unnecessary, Unnecessary, Partially Necessary, Necessary, Absolutely Necessary) and the survey was completed by the Group-2 and Group-3 in order to take their opinions about the STEM teacher competencies. Quantitative data analyses were performed and mean, median and interquartile range values were calculated for each item. The Kendall coefficient was checked for this process and the coefficient of agreement was calculated as 0.152 (Kendall's W:0.152, $p > 0.05$). It was considered that there needs to be a consensus on the items with both a median value of 5.00 and an interquartile range (IQR-Inter Quantile Range) value of 1.00 and below 1.00. Items with a median value of less than 5.00 were eliminated. Loughlin and Moore (1979) suggested that the acceptable percentage of agreement among participants should be 51% in order to progress further. After the last process, the number of competence indicators was decreased to 58 and the final version of the integrated STEM teacher competencies was formed by taking three different perspectives into account.

RESULTS

As a result of the modified Delphi research findings and validation process, four competency areas, 14 competencies and 58 competence indicators were identified as the integrated STEM teacher competencies for secondary education. These competencies are described below with regard to their competency areas.

Cognitive Characteristics in STEM Teaching Competency Area

The results for the CCST competency area are given in more detail including appendixes to reflect all the steps and processes in the modified Delphi rounds and validation process comprehensively. After the first Delphi round, "STEM Content Knowledge", "Making Interdisciplinary Connections", and "Curriculum Knowledge" competencies and 44 competence indicators under these competencies were identified (see **Appendix B**). There were 36 indicators, seven indicators, and one indicator under the competencies respectively. STEM content knowledge competency focuses on meaningful learning of science, mathematics and other disciplines accompanied by the engineering design process. The orientation towards STEM teaching and the focus on students' understanding of STEM also stand out for this competency. On the other hand, the competency of making interdisciplinary connections can be considered as ensuring harmony between STEM disciplines. The curriculum knowledge competency emphasizes that STEM is related to every subject and STEM activities can be prepared for every subject. The experts had common views on STEM curricula. They stated that the expression "STEM curriculum" leaded to stereotyping the content, which was contrary to the STEM philosophy. They especially thought that the freedom of the STEM approach would be taken away with the curriculum. The competence indicators removed during the second Delphi round based on the Group-1's suggestions are listed in **Appendix B**. E4 wrote about STEM Content knowledge competency that "I would not keep students' awareness of their interests in this competency. I think learning walks should not be in this competency either. Learning walks can be considered in the competency of assessment. Knowing one's own discipline in detail can be considered in this competency". As a result, "applies learning walks" competence indicator was moved to the assessment competency under the STS competency area. Regarding competency of making interdisciplinary connections, E4 stated that ""follows publications (articles, books, documentaries, etc.) related to disciplines other than his/her" and "gains knowledge about professions" should be included". Based on his advice the mentioned competence indicators were added.

After the second round, the name of the competency, i.e. "Making Interdisciplinary Connections", was changed to "STEM Interdisciplinary Connection Knowledge", the name of the competency, i.e. "Curriculum Knowledge", was changed to "STEM Curriculum Knowledge", and a new competency, i.e. "Technology Literacy", was added to the CCST competency area. According to the International Technology and Engineering Educators Association (2020), technological literacy is the ability to use, manage, assess, and understand technology. The number of competence indicators was reduced to 24 after the second round and they were all approved with either 80 % or 100 % during the third Delphi round (see **Appendix C**). These 24 competence indicators under the CCST competency area were converted into a 5-point Likert type survey and conducted to the Group-2 and the Group-3. As a result of the analyses of the data obtained in the final process, the median values of seven out of 24 competence indicators were below 5.00 and these indicators were eliminated (see **Appendix D**). The remaining 17 competence indicators were re-evaluated according to the interquartile range value and checked if it was 1.00 or less than 1.00. No item was found whose interquartile range value was above 1.00. Finally, in order to determine the importance of these competence indicators, the percentage of experts and teachers who gave 5 (Absolutely Necessary) to these indicators on the Likert scale was calculated and ranked. None of the competence indicators had below 51 % agreement (see **Appendix E**).

As can be seen in **Table 3**, STEM Content Knowledge competency included nine indicators, STEM Interdisciplinary Connection Knowledge competency comprised four indicators, STEM Curriculum Knowledge competency contained two indicators, and Technology Literacy competency consisted of two indicators distributed under the CCST competency area.

STEM Teaching Skills Competency Area

After the first modified Delphi round, 60 competence indicators and seven competencies were obtained under the Teaching Skills competency area. There were three indicators under the "Preparation of Teaching Strategies", 18 indicators under the "Preparation of a STEM Lesson Plan", five indicators under the "Preparation of a STEM Guideline", 11 indicators under the "Inquiry-Based Teaching", five indicators under the "Technology Literacy", five indicators under the "Consideration of Student Differences" and 13 indicators under the "Measurement and Evaluation" competencies. During the second round, the following three competence indicators were not approved by the Group-1, so that the researchers removed them: "Ensures that teachers from other disciplines contribute to the lesson plan", "Includes discourse, argumentation and critical thinking in the lesson plan", and "Is aware of the fact that the goal is not just enough to complete the activity". Some experts in the Group-1 made extra comments about the indicators. For instance, E2 wrote that "the teacher should be aware of students' interests and needs and makes some changes based on them". However, no addition was made because the feedback received from the experts overlapped with the identified competencies.

Table 3. Cognitive characteristics in STEM teaching competency area and its competencies and competence indicators

	Mean	Median	IQR
STEM content knowledge			
1. Has STEM content and context knowledge.	4.73	5.00	1.00
2. Knows STEM content that will appeal to students of different levels.	4.35	5.00	1.00
3. Has content knowledge about other disciplines at the level of awareness.	4.58	5.00	1.00
4. Knows how to adapt engineering design to different contexts.	4.35	5.00	1.00
5. Has problem solving skills in engineering design process.	4.70	5.00	0.75
6. Knows and internalizes the engineering design process steps.	4.65	5.00	0.75
7. Can assess students' prior knowledge who are new to design.	4.40	5.00	1.00
8. Encourages students to think systematically and establish cause-effect relationships during the STEM activity.	4.68	5.00	0.75
9. Supports students' learning by assessing their science and/or math knowledge using engineering language and giving feedback to them.	4.45	5.00	1.00
STEM interdisciplinary connection knowledge			
10. Makes preliminary preparations for interdisciplinary connections.	4.63	5.00	1.00
11. Plans interdisciplinary connections and establishes necessary relationships.	4.60	5.00	1.00
12. Places knowledge in STEM context and adapts it to daily life problems.	4.75	5.00	0.00
13. Identifies instructional strategies to establish interdisciplinary connections.	4.68	5.00	1.00
STEM curriculum knowledge			
14. Knows how to implement the curriculum related to his/her discipline.	4.85	5.00	0.00
15. Defines the goals related to its own discipline from the curriculum goals related to other disciplines.	4.55	5.00	1.00
Technology literacy			
16. Knows educational technologies to use for his/her instructional purposes.	4.45	5.00	1.00
17. Decides how to use educational technologies as a motivating attention-gathering and focusing resource in STEM activities.	4.38	5.00	1.00

After the second round, a few changes were made and the number of competence indicators was decreased to 31, which were under the six competencies. Some of the competencies' names were altered from "Inquiry-Based Teaching" to "Implementation of Inquiry-Based STEM Teaching" and from "Measurement and Evaluation" to "Assessment of STEM Teaching and Learning". In addition, the competency of "Technology Literacy" was taken from this area and replaced in the CCST competency area because the competencies were about knowing and deciding. Due to the fact that all competencies in the STS competency area were approved with either 80 % or 100 % in the third Delphi round, they were converted into a 5-point Likert type items and administered to the Group-2 and Group-3.

Quantitative data analysis indicated that the median values of three out of 31 competence indicators were below 5.00. These indicators were "makes differentiated instruction after creating the draft of the lesson plan.", "transforms and adapts a general STEM lesson plan to the student level." and "has metacognitive knowledge and adapts it to her lesson". The remaining 28 competence indicators were re-evaluated according to another consensus criterion and no item was found with an interquartile range value above 1.00. Moreover, the percentage of teachers scoring 5 (Absolutely Necessary) for all indicators was more than 51%. Therefore, as shown in **Table 4**, STEM education experts and teachers determined six competencies and 28 competence indicators for the STS competency area.

Affective-Motivational Characteristics in STEM Teaching Competency Area

Results emerged from the content analysis after the first Delphi round revealed eight competence indicators under the "Being a Lifelong Learner" competency and two competence indicators under the "Giving Importance to Professional Development" competency. During the second round, one expert advised two more competence indicators for the professional development competency; thus, "follows developments in other disciplines" and "participates in professional development related to her discipline" were added. After the second round, the competency indicator "identifies students' daily life problems" was detached and two indicators, i.e. "is enthusiastic and highly motivated" and "having high internal motivation to be sustainable", were combined and turned into one competency indicator as "is enthusiastic and has high internal motivation". The competency of being a lifelong learner was deleted and a new competency "Supporting of STEM Career Planning" was generated. Two competence indicators, i.e. "is knowledgeable about STEM professions" and "renews her discipline and pedagogical knowledge", were replaced in the professional development competency.

Table 4. STEM teaching skills competency area and its competencies and competence indicators

	Mean	Median	IQR
Preparation of STEM lesson plan			
18. Determines learning and performance goals for students in the lesson plan.	4.75	5.00	0.00
19. Processes acquisitions that are suitable for real word problems.	4.75	5.00	0.00
20. Prepares students step by step to reach their learning goals by taking classroom context and daily life problems into account	4.63	5.00	1.00
21. Prepares a lesson plan by considering students' differences.	4.53	5.00	1.00
22. Incorporates science and mathematics subjects into the STEM activity together with the engineering design process.	4.70	5.00	0.00
23. Follows up whether students have achieved the determined goals or not.	4.70	5.00	1.00
24. Evaluates the lesson plan after its implementation and revises it if there is necessary.	4.75	5.00	0.75
25. Sees the lesson plan as a working process rather than a lesson summary.	4.43	5.00	1.00
Preparation of STEM teaching strategy			
26. Determines which questions to ask and which strategies to use during the STEM course design and implementation process.	4.68	5.00	1.00
27. Prepares resources and materials for the course content in accordance with students' level and culture.	4.63	5.00	1.00
Preparation of STEM guideline			
28. Prepares directions for students that include the engineering design process where students record their activities analyze data and draw their designs.	4.58	5.00	1.00
29. Guides students with directions that give purpose of the STEM activity and enable students to continue their processes.	4.60	5.00	1.00
Implementation of inquiry-based STEM teaching			
30. Uses critical thinking. decision making and questioning to support design with data math and science.	4.60	5.00	1.00
31. Provides reasoning-oriented content for students to generate questions.	4.68	5.00	1.00
32. Sets up daily life problems that will arouse curiosity.	4.80	5.00	0.00
33. Examines what students understand by using discourse and reflection strategies.	4.48	5.00	1.00
34. Provides students with experiences that enable them to produce questions and enrich their questions.	4.65	5.00	1.00
35. Provides an environment where students can reason make examples and solve problems.	4.68	5.00	1.00
Consideration of student differences in STEM teaching			
36. Considers context of the subject when choosing STEM activities.	4.78	5.00	0.00
37. Has awareness of students' STEM interests and needs.	4.48	5.00	1.00
38. Considers differences in students places these differences in lesson of the course.	4.50	5.00	1.00
Assessment of STEM teaching and learning			
39. Compares students' prior knowledge with their knowledge at the end of the teaching process.	4.58	5.00	1.00
40. Compares students' end product with their first product	4.35	5.00	1.00
41. Applies various methods and uses different approaches for classroom assessment.	4.70	5.00	1.00
42. Makes formative assessment.	4.78	5.00	0.00
43. Follows students' interaction with other students.	4.63	5.00	1.00
44. Makes summative assessment of achievement in long-term STEM projects.	4.45	5.00	1.00
45. Measures student instructions/engineering notebook through alternative measurement tools.	4.30	5.00	1.00

The name of the competency, i.e. "Giving Importance to Professional Development", was changed to "Emphasizing STEM Professional Development". These adjustments resulted in having four competence indicators under the "Supporting of STEM Career Planning" competency and seven competence indicators under the "Emphasizing STEM Professional Development" competency. All the 11 competence indicators in the questionnaire were approved with either 80 % or 100 % by the Group-1 during the third round. Consequently, they were turned into Likert scale item survey. Findings appeared from the analyzing of the data gathered from the Group-2 and Group-3 exposed that the median values of three competence indicators were below 5.00. After elimination of the indicators, i.e. "follows developments in other disciplines", "provides resources and guidance to students about STEM careers" and "STEM brings together good examples of career planning with students in the classroom environment", the remaining eight competence indicators were re-evaluated according to interquartile range values and the percentage of experts and teachers scoring 5 (Absolutely Necessary) to the competence indicators. Finally, the competency area of AMCST was formed as two competencies and eight competence indicators (see **Table 5**).

Table 5. Affective-motivational characteristics in STEM teaching competency area and its competencies and competence indicators

	Mean	Median	IQR
Emphasizing STEM professional development			
46. Sees and realizes the aspects that need improvement.	4.75	5.00	0.00
47. Is enthusiastic and has a high internal motivation.	4.58	5.00	1.00
48. Renews his/her content and pedagogical knowledge by following the developments.	4.73	5.00	0.75
49. Is open for learning and applies to what s/he has learned.	4.80	5.00	0.00
50. Gives students self-confidence and autonomy (ability to manage himself /herself) so that they can question.	4.70	5.00	1.00
51. Participates in professional development programs related to his/her discipline.	4.65	5.00	1.00
Supporting of STEM career planning			
52. Is aware of students' STEM interests.	4.48	5.00	1.00
53. Has knowledge about STEM professions.	4.60	5.00	1.00

Table 6. Collaboration and engagement for STEM competency area and its competencies and competence indicators

	Mean	Median	IQR
Collaboration with colleagues and stakeholders			
54. Receives ideas from different disciplines and fields.	4.68	5.00	1.00
55. Exchanges ideas with teachers of other disciplines.	4.80	5.00	0.00
56. Collaborates with teachers of other disciplines and receives support.	4.73	5.00	0.00
57. Makes plans by integrating disciplines together with teachers of other disciplines.	4.58	5.00	1.00
Engagement in STEM learning communities			
58. Takes part in a STEM learning community and benefits from the experiences of other teachers.	4.35	5.00	1.00

Collaboration and Engagement Skills Competency Area

As a result of the focus group interviews, there were 12 competence indicators under the "Collaboration with Colleagues-Parents-Stakeholders" competency, one competence indicator under the "Being in Learning Communities" competency, and five competence indicators under the "Providing Support in Career Planning" competency. However, after the second round some modifications were made and the number of competency was reduced to two and the number of competence indicators was decreased to eight. The providing support in career planning competency and the relevant items were diminished because the AMCST competency area had the competency of supporting STEM career planning. All the competence indicators related to parents were combined in the competence indicator of "collaborates with parents to increase students' motivation and includes them in the learning process". Moreover, the name of the competency, i.e. "Being in Learning Communities", was changed to "Engagement in STEM Learning Communities" and the competence indicator, i.e., "participates in a STEM learning community and benefits from the experiences of other teachers", was added to this competency. In addition, some repetitive competence indicators, i.e. "Collaborates with teachers to gain new information about both the student and the learning environment planning" and "Applies for cooperation and receives support", were deleted from the collaboration with colleagues-parents-stakeholders competency.

All eight competence indicators passed the third round and they were included in the survey. However, three competence indicators, i.e. "collaborates with parents to increase students' motivation and includes them in the learning process", "participates in national studies with teachers from other disciplines" and "cooperates and works internationally", were eliminated based on their median vales during the validation process. As presented in **Table 6**, the results of the consensus left four competence indicators under the collaboration with colleagues and stakeholders competency and one competence indicator in the engagement in STEM learning communities competency.

DISCUSSION

This study utilized a modified Delphi method to identify and validate the competencies required for integrated STEM teaching at the secondary level. The modified Delphi method, known for being a more cooperative and structured approach than the traditional Delphi method, allowed for the systematic refinement of competency indicators through multiple expert reviews (Graefe and Armstrong, 2011). The study's findings revealed four key competency areas, 14 competencies, and 58 validated competence indicators, which provide a comprehensive framework for integrated STEM teacher competencies. The discussion below explores these competency areas in relation to existing literature and the implications for STEM education.

Cognitive Characteristics in STEM Teaching

The Cognitive Characteristics in STEM Teaching competency area underscores the essential knowledge and reasoning skills required for effective STEM instruction. Teachers must possess strong pedagogical content knowledge (PCK) to facilitate deep learning experiences in STEM disciplines (Shulman, 1987). Within the STEM context, PCK extends beyond individual subject knowledge to include interdisciplinary STEM content knowledge, curriculum knowledge, and knowledge of integration strategies.

The study identified four key competencies under the Cognitive Characteristics in STEM Teaching competency area:

1. STEM Content Knowledge – Teachers must demonstrate expertise in STEM subjects, particularly the engineering design process, which plays a central role in STEM instruction. This aligns with prior research highlighting the importance of integrating engineering principles into STEM education (Saxton et al., 2014).
2. STEM Interdisciplinary Connection Knowledge – Teachers need to effectively plan and establish meaningful connections between STEM disciplines, a factor that significantly influences the level of STEM integration in classrooms (Dare et al., 2018).
3. STEM Curriculum Knowledge – Findings emphasize that STEM should not be restricted to a predefined curriculum; rather, STEM principles should be embedded into various subjects, an idea supported by Herschbach (2011).
4. Technology Literacy – Teachers must be proficient in using and integrating technology into STEM instruction, as engineering and technology are inherently connected (Barak, 2014).

This study's competency indicators reflect prior recommendations on 21st-century STEM education, particularly in fostering systematic thinking, problem-solving, and cause-effect reasoning (Song, 2020; Srikoom et al., 2018). However, a unique contribution of this study is the emphasis on engineering design as a fundamental STEM knowledge area, reinforcing the idea that effective STEM instruction extends beyond subject-matter knowledge to application-based learning.

STEM Teaching Skills

The STEM Teaching Skills competency area focuses on the practical implementation of STEM instruction, incorporating competencies related to lesson planning, inquiry-based learning, student differentiation, and assessment. Research suggests that effective STEM instruction requires flexible pedagogical content knowledge and the ability to adapt teaching strategies based on real-world problem-solving approaches (Johnson et al., 2015).

Six competencies emerged under the STEM Teaching Skills competency area

1. Preparation of STEM Lesson Plans – Teachers must be able to develop structured lesson plans that integrate STEM disciplines.
2. Preparation of STEM Teaching Strategies – Teachers should be skilled in selecting and adapting instructional strategies based on STEM principles.
3. Preparation of STEM Guidelines – Competencies in this area ensure teachers guide students effectively during STEM activities.
4. Implementation of Inquiry-Based STEM Teaching – STEM instruction should be discovery-driven and inquiry-based, allowing students to explore concepts actively (Jolly, 2017).
5. Consideration of Student Differences in STEM Teaching – Teachers must address student diversity and varying learning needs to maximize engagement.
6. Assessment of STEM Teaching and Learning – Teachers need well-defined assessment strategies to evaluate student progress before, during, and after instruction.

These competencies align with Hsu and Fang's (2019) STEM content framework, which recommends designing STEM instruction based on real-world contexts, inquiry-based engagement, and measurable learning outcomes. The study's findings reinforce the importance of reflective teaching practices, as STEM instruction is inherently dynamic and requires teachers to continuously adapt their strategies.

Affective-Motivational Characteristics in STEM Teaching

The Affective-Motivational Characteristics in STEM Teaching competency area highlights the attitudes, values, and motivations necessary for successful STEM instruction. Research suggests that teachers who actively engage in professional development and maintain a positive attitude toward STEM disciplines are more effective in fostering student interest in STEM careers (Srikoom et al., 2018).

Two primary competencies emerged under the Affective-Motivational Characteristics in STEM Teaching competency area:

1. Emphasizing STEM Professional Development – Teachers must continuously engage in professional development to stay informed about advancements in STEM education.
2. Supporting STEM Career Planning – Teachers play a crucial role in guiding students toward STEM careers by fostering awareness of STEM professions and providing mentorship.

This study's findings align with prior research on STEM teacher identity and motivation, which emphasizes the need for self-confidence, enthusiasm, and a proactive approach to professional learning (Dou and Cian, 2021; Srikoom et al., 2018). A novel insight from this study is the recognition that STEM teachers must not only develop their own expertise but also actively support students' career aspirations, reinforcing STEM's role in workforce development.

Collaboration and Engagement Skills

The Collaboration and Engagement Skills competency area emphasizes the importance of professional collaboration and engagement in STEM learning communities. According to Warford (2011), teacher zone of proximal development is enhanced through peer collaboration and professional networking, allowing educators to exchange best practices and overcome teaching challenges.

Two competencies were identified under the Collaboration and Engagement Skills competency area:

1. Collaboration with Colleagues and Stakeholders – Teachers should actively engage with colleagues, parents, and community partners to enrich STEM learning opportunities.
2. Engagement in STEM Learning Communities – Participation in STEM-focused learning communities allows teachers to benefit from peer support, feedback, and shared resources (Tam, 2015).

These findings support Milner-Bolotin's (2018b) recommendation that collaboration is a key factor in teacher development, reinforcing the idea that STEM teaching is most effective when it is a shared endeavor rather than an isolated effort. While this study provides a comprehensive framework for integrated STEM teacher competencies, some limitations must be acknowledged. First, the identified competencies were derived primarily from STEM education experts' perspectives. While their insights provide valuable guidance, teacher practitioners' perspectives and classroom realities should also be considered. Future research should incorporate feedback from pre-service and in-service STEM teachers to ensure that the competencies reflect practical teaching experiences. Second, this study focused exclusively on secondary STEM education. However, STEM education is equally important in elementary and post-secondary levels. Future studies should explore STEM teacher competencies for different educational stages, considering age-specific pedagogical approaches. Last, although the Delphi method provided rigorous validation, competencies and indicators may need further refinement as STEM education evolves. Additional longitudinal studies are necessary to examine how these competencies influence classroom implementation and student learning outcomes.

CONCLUSIONS, IMPLICATIONS AND SUGGESTIONS

Integrated STEM education emphasizes the interdisciplinary integration of science, technology, engineering, and mathematics, mirroring the real-world practices of STEM professionals to better prepare students for future STEM careers (Breiner et al., 2012). Competence, as conceptualized by Blömeke et al. (2015), exists along a continuum, encompassing perception, interpretation, and decision-making, which collectively shape observable teaching behaviors. Given the increasing demand for STEM proficiency, STEM teacher education must incorporate content integration and innovative instructional approaches (Rinke et al., 2016).

The results confirm that integrated STEM teaching requires a multifaceted skill set, encompassing cognitive knowledge, teaching skills, affective characteristics, and collaborative engagement. Merely possessing subject-specific knowledge is insufficient; teachers must also be adept in interdisciplinary integration, inquiry-based instruction, professional motivation, and collaborative learning communities. By establishing a structured framework, this study provides a foundation for STEM teacher education programs, professional development initiatives, and curriculum design. Therefore, this study fills a critical gap in STEM teacher education by systematically identifying and validating four competency areas essential for integrated STEM teaching. Unlike previous studies, this research holistically synthesizes all required STEM teacher competencies into a single framework, providing practical applications for teacher education, professional development, and policy-making. As STEM education continues to gain prominence, effective teacher preparation will remain a key factor in improving student learning outcomes and workforce readiness. By establishing a clear set of STEM teacher competencies, this study contributes to the ongoing advancement of STEM education and serves as a foundational resource for future research and policy development.

The detailed STEM teacher competency framework presented in this study offers several practical implications for teacher education programs, in-service training, and future research: The competency framework can be used as a guideline to design STEM-focused teacher education curricula. Course objectives can be aligned with integrated STEM teacher competencies, ensuring a structured learning pathway for pre-service teachers. The identified competencies can serve as a basis for professional development programs, addressing STEM pedagogy, interdisciplinary integration, and technology literacy. Training programs can be developed for teachers from diverse disciplinary backgrounds, fostering collaborative STEM teaching approaches. The framework also highlights the importance of collaboration, suggesting that teachers should engage in STEM learning communities to exchange best practices. Emphasis on inquiry-based learning and differentiation strategies ensures that STEM instruction is student-centered and adaptable to diverse learning needs. Education policymakers can use the framework to establish competency standards for STEM teachers, ensuring consistent and high-quality STEM instruction across schools. Considering the increasing importance of STEM education in workforce development, determining and reinforcing STEM teacher competencies is essential for improving teaching quality and student outcomes.

Given the dynamic and evolving nature of STEM education, further research is needed to expand and refine integrated STEM teacher competencies. Therefore, future studies may consider expanding the framework to other educational levels, exploring STEM teacher competencies in different contexts, assessing the impact of STEM teacher competencies on student outcomes, and incorporating pre-service STEM teacher perspectives. By addressing these areas, future research can further strengthen STEM teacher education and ensure that teachers are equipped with the necessary competencies to prepare students for 21st-century skills.

REFERENCES

Anwar, S., Menekse, M., Guzey, S. S. and Bryan, L. A. (2022). The effectiveness of an integrated STEM curriculum unit on middle school students' life science learning. *Journal of Research in Science Teaching*, 59(7), 1204–1234. https://doi.org/10.1002/tea.21756

Arikan, S., Erktin, E. and Pesen, M. (2022). Development and validation of a STEM competencies assessment framework. *International Journal of Science and Mathematics Education*, 20, 1–24. https://doi.org/10.1007/s10763-020-10132-3

Azizan, S. A. and Abu Shamsi, N. (2022). Design-based learning as a pedagogical approach in an online learning environment for science undergraduate students. *Frontiers in Education*, 7. https://doi.org/10.3389/feduc.2022.860097

Barak, M. (2014). Closing the gap between attitudes and perceptions about ICT-enhanced learning among pre-service STEM teachers. *Journal of Science Education and Technology*, 23(1), 1–14. https://doi.org/10.1007/s10956-013-9446-8

Blömeke, S. and Delaney, S. (2012). Assessment of teacher knowledge across countries: A review of the state of research. *ZDM Mathematics Education*, 44(3), 223–247. https://doi.org/10.1007/s11858-012-0429-7

Blömeke, S., Gustafsson, J. E. and Shavelson, R. J. (2015). Beyond dichotomies. *Zeitschrift für Psychologie*, 223(1), 3–13. https://doi.org/10.1027/2151-2604/a000194

Breiner, J. M., Harkness, S. S., Johnson, C. C. and Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, 112(1), 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Brown, R. E. and Bogiages, C. A. (2019). Professional development through STEM integration: How early career math and science teachers respond to experiencing integrated STEM tasks. *International Journal of Science and Mathematics Education*, 17(1), 111–128. https://doi.org/10.1007/s10763-017-9863-x

Cedere, D., Jurgena, I., Birzina, R. and Kalnina, S. (2022). Prospective pre-school teachers' views on STEM learning in grade 9: The principle of continuity in education. *Problems of Education in the 21st Century*, 80(1), 69–81. https://doi.org/10.33225/pec/22.80.69

Custer, R. L., Scarcella, J. A. and Stewart, B. R. (1999). The modified Delphi technique: A rotational modification. *Journal of Vocational and Technical Education*, 15(2). https://doi.org/10.21061/jcte.v15i2.702

Dare, E. A., Ellis, J. A. and Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education*, 5, 4. https://doi.org/10.1186/s40594-018-0101-z

Dare, E. A., Keratithamkul, K., Hiwatig, B. M. and Li, F. (2021). Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education. *Education Sciences*, 11(11), 737. https://doi.org/10.3390/educsci11110737

Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M. and Wales, P. W. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology*, 67(4), 401–409. https://doi.org/10.1016/j.jclinepi.2013.12.002

Dou, R. and Cian, H. (2021). Constructing STEM identity: An expanded structural model for STEM identity research. *Journal of Research in Science Teaching*, 59(3), 458–490. https://doi.org/10.1002/tea.21734

Downe-Wamboldt, B. (1992). Content analysis: Method, applications and issues. *Health Care for Women International*, 13(3), 313–321. https://doi.org/10.1080/07399339209516006

El Nagdi, M. and Roehrig, G. (2020). Identity evolution of STEM teachers in Egyptian STEM schools in a time of transition: A case study. *International Journal of STEM Education*, 7, 41. https://doi.org/10.1186/s40594-020-00235-2

El Nagdi, M., Leammukda, F. and Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education*, 5, 36. https://doi.org/10.1186/s40594-018-0136-1

Epstein, R. M. and Hundert, E. M. (2002). Defining and assessing professional competence. *Journal American Medical Association*, 287(2), 227–235. https://doi.org/10.1001/jama.287.2.226

Fleiss, J. L. (1981). *Statistical Methods for Rates and Proportions* (2nd ed). John Wiley.

Graefe, A. and Armstrong, J. S. (2011). Comparing face-to-face meetings, nominal groups, Delphi and prediction markets on an estimation task. *International Journal of Forecasting*, 27, 183–195. https://doi.org/10.1016/j.ijforecast.2010.05.004

Halawa, S., Lin, T. C. and Hsu, Y.-S. (2024). Exploring instructional design in K-12 STEM education: A systematic literature review. *International Journal of STEM Education*, 11, 43. https://doi.org/10.1186/s40594-024-00503-5

Helmer, O. (1966). *The Use of the Delphi Technique in Problems of Education Innovation*. Rand Corporation.

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. *Journal of STEM Teacher Education*, 48(1), 96–122. https://doi.org/10.30707/JSTE48.1Herschbach

Honey, M., Pearson, G. and Schweingruber, H. (2014). A descriptive framework for integrated STEM education, in *STEM Integration in K-12 Education: Status, prospects, and an agenda for research* (pp. 31–50). The National Academies Press.

Houston, W. R. (1987). *Exploring Competency Based Education*. McCutchan Publishing Corporation.

Hsu, Y.-S. and Fang, S.-C. (2019). Opportunities and challenges of STEM education, in Y.-S. Hsu and Y.-F. Yeh (eds), *Asia-Pacific STEM Teaching Practices: From theoretical frameworks to practices* (pp. 1–16). Springer. https://doi.org/10.1007/978-981-15-0768-7_1

Hurley, M., Butler, D. and McLoughlin, E. (2024). STEM teacher professional learning through immersive STEM learning placements in industry: A systematic literature review. *Journal for STEM Education Research*, 7, 122–152. https://doi.org/10.1007/s41979-023-00089-7

International Technology and Engineering Educators Association. (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. Available at: https://www.iteea.org/stel.

Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology*, 25(2), 284–301. https://doi.org/10.1007/s10956-015-9593-1

Johnson, C. C., Peters-Burton, E. E. and Moore, T. J. (eds) (2015). *STEM Road Map: A framework for integrated STEM education*. Routledge. https://doi.org/10.4324/9781315753157

Jolly, A. (2017). *STEM by Design*. Routledge. https://doi.org/10.4324/9781315679976

Keegan, R. J., Barnett, L. M., Dudley, D. A., Telford, R. D., Lubans, D. R., Bryant, A. S., Roberts, W. M., Morgan, P. J., Schranz, N. K., Weissensteiner, J. R., Vella, S. A., Salman, J., Ziviani, J., Okely, A. D., Wainwright, N. and Evans, J. R. (2019). Defining physical literacy for application in Australia: A modified Delphi method. *Journal of Teaching in Physical Education*, 38 (2), 105–118. https://doi.org/10.1123/jtpe.2018-0264

Kelley, T. R. and Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3, 11. https://doi.org/10.1186/s40594-016-0046-z

Koeppen, K., Hartig, J., Klieme, E. and Leutner, D. (2008). Current issues in competence modeling and assessment. *Zeitschrift für Psychologie*, 216(2), 61–73. https://doi.org/10.1027/0044-3409.216.2.61

Korthagen, F. A. J. (2017). Inconvenient truths about teacher learning: Towards professional development 3.0. *Teachers and Teaching*, 23(4), 387–405. https://doi.org/10.1080/13540602.2016.1211523

Lavado-Anguera, S., Velasco-Quintana, P.-J. and Terrón-López, M.-J. (2024). Project-based learning (PBL) as an experiential pedagogical methodology in engineering education: A review of the literature. *Education Sciences*, 14(6), 617. https://doi.org/10.3390/educsci14060617

Leake, H. B., Heathcote, L. C., Simons, L. E., Stinson, J., Kamper, S. J., Williams, C. M., Burgoyne, L. L., Craigie, M., Kammers, M., Moen, D., Pate, J. W., Szeto, K. and Moseley, G. L. (2019). Talking to teens about pain: A modified Delphi study of adolescent pain science education. *Canadian Journal of Pain*, 3(1), 200–208. https://doi.org/10.1080/24740527.2019.1682934

Lestari, I. F. (2021). Experiential learning using STEM approach in improving students' problem solving ability. *Journal of Physics: Conference Series*, 1806, 012005. https://doi.org/10.1088/1742-6596/1806/1/012005

Lin, K.-Y., Wu, Y.-T., Hsu, Y.-T. and Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education*, 8, 1. https://doi.org/10.1186/s40594-020-00258-9

Loughlin, K. G. and Moore, L. F. (1979). Using Delphi to achieve congruent objectives and activities in a pediatrics department. *Academic Medicine*, 54(2), 101–106. https://doi.org/10.1097/00001888-197902000-00006

McKenna, H. P. (1994). The Delphi technique: A worthwhile research approach for nursing? *Journal of Advanced Nursing*, 19(6), 1221–1225. https://doi.org/10.1111/j.1365-2648.1994.tb01207.x

Merriam, S. B. and Grenier, R. S. (2019). *Qualitative Research in Practice: Examples for discussion and analysis*. Jossey-Bass.

Miles, M. B. and Huberman, A. M. (1994). *Qualitative Data Analysis: An expanded sourcebook*. SAGE.

Milner-Bolotin, M. (2018a). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education*, 3. https://doi.org/10.3389/feduc.2018.00092

Milner-Bolotin, M. (2018b). Technology-supported inquiry in STEM teacher education: From old challenges to new possibilities, in *K-12 STEM Education: Breakthroughs in research and practice* (pp. 893–915). IGI Global. https://doi.org/10.4018/978-1-5225-3832-5.ch042

Moore, T. J., Johnson, C. C., Peters-Burton, E. E. and Guzey, S. S. (2015). The need for a STEM road map, in C. C. Johnson, E. E. Peters-Burton and T. J. Moore (eds), *STEM Road Map: A framework for integrated STEM education* (pp. 3–12). Routledge. https://doi.org/10.4324/9781315753157-1

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W. and Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education, in *Engineering in Pre-College Settings: Synthesizing research, policy, and practices* (pp. 35–60). Purdue University Press. https://doi.org/10.2307/j.ctt6wq7bh.7

National Research Council. (2012). *Discipline-Based Education Research: Understanding and improving learning in undergraduate science and engineering*. National Academies Press.

National Research Council. (2014). *STEM Integration in K-12 Education: Status, prospects, and an agenda for research*. National Academies Press.

OECD. (2017). *PISA 2015 collaborative problem-solving framework*. Available at: https://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Collaborative%20Problem%20Solving%20Framework%20.pdf.

Radloff, J. and Guzey, S. (2016). Investigating preservice STEM teacher conceptions of STEM education. *Journal of Science Education and Technology*, 25(5), 759–774. https://doi.org/10.1007/s10956-016-9633-5

Reeve, E. M. (2015). STEM thinking! *Technology and Engineering Teacher*, 75(4), 8–16.

Ring, E. A. (2017). *Teacher conceptions of integrated stem education and how they are reflected integrated stem curriculum writing and classroom implementation* (Unpublished doctoral dissertation). Minnesota University.

Rinke, C. R., Gladstone-Brown, W., Kinlaw, C. R. and Cappiello, J. (2016). Characterizing STEM teacher education: Affordances and constraints of explicit STEM preparation for elementary teachers. *School Science and Mathematics*, 116(6), 300–309. https://doi.org/10.1111/ssm.12185

Sandall, B. K., Sandall, D. L. and Walton, A. L. (2018). Educators' perceptions of integrated STEM: A phenomenological study. *Journal of STEM Teacher Education*, 53(1), 3. https://doi.org/10.30707/JSTE53.1

Sanders, M. (2009). Integrative STEM education: Primer. *The Technology Teacher*, 68(4), 20–26.

Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N. and Skinner, E. A. (2014). A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. *Studies in Educational Evaluation*, 40, 18–35. https://doi.org/10.1016/j.stueduc.2013.11.005

Scheele, D. S. (2002). Reality construction as a product of Delphi interaction, in H. A. Linston, M. Turoff and O. Helmer (eds), *The Delphi Method Techniques and Applications* (pp. 35–67). NJIT.

Selvi, K. (2010). Teachers' competencies. *Cultura International Journal of Philosophy of Culture and Axiology*, 7(1), 167–175. https://doi.org/10.5840/cultura20107133

Shernoff, D. J., Sinha, S., Bressler, D. M. and Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, 4, 13. https://doi.org/10.1186/s40594-017-0068-1

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Song, M. (2020). Integrated STEM teaching competencies and performances as perceived by secondary teachers in South Korea. *International Journal of Comparative Education and Development*, 22(2), 131–146. https://doi.org/10.1108/IJCED-02-2019-0016

Srikoom, W., Faikhamta, C. and Hanuscin, D. (2018). Dimensions of effective STEM integrated teaching practice. *K-12 STEM Education*, 4(2), 313–330.

Tam, A. C. F. (2015). Exploring teachers' beliefs about teacher learning in professional learning communities and their influence on collegial activities in two departments. *Compare: A Journal of Comparative and International Education*, 45(3), 422–444. https://doi.org/10.1080/03057925.2013.872025

Tersine, R. J. and Riggs, W. E. (1976). The Delphi technique: A long-range planning tool. *Business Horizons*, 19(2), 51–56. https://doi.org/10.1016/0007-6813(76)90081-1

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Strufy, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P. and Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1), 02. https://doi.org/10.20897/ejsteme/85525

Thomas, T. A. (2014). *Elementary teachers' receptivity to integrated science, technology, engineering, and mathematics (STEM) education in the elementary grades* (Unpublished doctoral dissertation). University of Nevada.

Tigelaar, D. E. H., Dolmans, D. H. J. M., Wolfhagen, I. H. A. P. and van der Vleuten, C. P. M. (2004). The development and validation of a framework for teaching competencies in higher education. *Higher Education*, 48, 253–268. https://doi.org/10.1023/B:HIGH.0000034318.74275.e4

Wagner, T. (2010). *The Global Achievement Gap: Why even our best schools don't teach the new survival skills our children need-and what we can do about it. ReadHowYouWant*. Perseus Books Group.

Wang, H. H., (2012). *A new era of science education: Science teachers perception and classroom practices of science, technology, engineering, and mathematics (STEM) integration* (Unpublished doctoral dissertation). University of Minnesota.

Warford, M. K. (2011). The zone of proximal teacher development. *Teaching and Teacher Education*, 27(2), 252–258. https://doi.org/10.1016/j.tate.2010.08.008

Weinberg, A. E., Balgopal, M. M. and Sample McMeeking, L. B. (2021). Professional growth and identiy development of STEM teacher educators in a community of practice. *International Journal of Science and Mathematics Education*, 19(1), 99–120. https://doi.org/10.1007/s10763-020-10148-9

Yuksel, A. O. (2025). Design-based STEM activities in teacher education and its effect on pre-service science teachers' design thinking skills. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-025-10215-2

Ziglio, E. (1996). The delphi method and its contribution to decision-making, in M. Edler and E. Ziglio (eds), *Gazing into the Oracle: The Delphi method and its application to social policy and public health* (pp. 3–33). Jessica Kingsley Publishers.

APPENDIX A: FOCUS GROUP INTERVIEW QUESTIONS

1. From the perspective of the engineering design process, what competencies should a STEM teacher possess?
2. In terms of preparing a STEM lesson plan, what competencies should a STEM teacher have?
3. Considering inquiry and the process of conducting inquiry, what competencies should a STEM teacher demonstrate?
4. When evaluated through Project-Based Learning, Design-Based Learning, or Problem-Based Learning approaches, what competencies are expected from a STEM teacher?
5. What should a STEM teacher pay attention to when preparing STEM activity guidelines? What are the essential components that such a guideline must include?
6. Is effective use of technology a core competency for STEM teachers?
7. How should a STEM teacher assess and evaluate their students?
8. What are the indicators/criteria/evidence that show a STEM teacher is competent in subject matter knowledge (e.g., physics, chemistry, mathematics, biology), pedagogical knowledge, and pedagogical content knowledge?
9. What are the criteria for determining whether a STEM teacher is sufficiently knowledgeable in STEM disciplines outside of their own area of expertise?
10. What should the curriculum knowledge competency of a STEM teacher include?
11. Does relating national learning objectives (e.g., MoNE gains) to real-life contexts demonstrate curriculum knowledge competency? What are your thoughts on the STEM curriculum?
12. Is the ability to make interdisciplinary connections a competency for STEM teachers? What teaching strategies are effective in achieving this?
13. Should a STEM teacher be a lifelong learner? To what extent should they value professional development, research, and training?
14. Does collaborating and communicating with colleagues, parents, and stakeholders benefit a STEM teacher? How?
15. What student characteristics should a STEM teacher consider during lesson planning? Is being aware of learning difficulties, learning differences, and misconceptions a STEM teaching competency?
16. What do you think is the role of a STEM teacher in students' career planning? What should it look like?

APPENDIX B

Table B1. Sub-themes and codes obtained after the first Delphi round under the CCST

Theme	Sub-theme	Code
CCST	STEM content knowledge	He knows the mistakes of students who are new to design.
		Directs her students to establish cause-effect relationships throughout the activity.
		Reaches diverse students at different times with STEM activities and content.
		Asks her students questions to assess their science and mathematics knowledge.
		Examines students' decision-making processes.
		Directs her students to make them understand the problem first.
		Knows and applies the steps of engineering design process rather than memorizing them step by step.
		Guides the learning process.
		Ensures the successful and effective participation of students and guides them correctly.
		Enables students to learn the content knowledge in depth depending on the learning activity.
		Asks right questions to his students and evaluates them.
		Has content knowledge and pedagogical knowledge depending on the context.
		Offers students projects that are sufficiently meaningful and relevant to daily life.
		Integrates content knowledge in a meaningful way.
		Has pedagogical, measurement and evaluation knowledge for the management of the engineering design process.
		Dominates design-based thinking.
		Highlights the skills that students should have.
		Being aware of students' learning difficulties, differences in learning styles, interests and misconceptions.
		Uses the language of engineering and science.
		Prepares STEM activities by focusing on her own discipline.
		Provides group teaching.
		Has a level of awareness in content knowledge related to other disciplines.
		Being aware of the misconceptions that may occur due to the connection among different disciplines.
		Being aware of students' interests.
		Applies learning walks.
		Internalizes the engineering design process steps at the skill level.
		Applies the engineering design process to other disciplines.
		Knows the misconceptions regarding the subject.
		Knows her students well.
		Able to change the perspectives of students and parents.
		Guides students with the existence of intriguing projects.
		Integrates disciplines and presents them to her students.
		Improves herself in other disciplines.
		Has sufficient content and context knowledge.
		Has problem solving skills in the design process according to her level.
		Knows how to adapt the design to different contexts, implements the designs and evaluates process.
	Making inter-disciplinary connections	Makes preliminary preparations for interdisciplinary connections and plans these connections.
		Plans interdisciplinary connections and establishes necessary relationships.
		Adapts information to the appropriate context and problem.
		Determines appropriate teaching strategy to make interdisciplinary connections.
		Plans interdisciplinary connections.
		Makes connections between disciplines in a way that is appropriate to the context.
		Specializes in a different discipline for interdisciplinary connections.
	Curriculum knowledge	Prepares an integrated STEM activity by adding other disciplines to the subject according to the conditions.

Note. CCST: Cognitive characteristics in STEM teaching

The competence indicators removed during the second Delphi round based on the Group-1's suggestions:

- Has content and pedagogical knowledge depending on the context.
- Has design based thinking knowledge.
- Highlights the skills that students should have.
- Is aware of students' interests.
- Applies learning walks.
- Makes connections between disciplines in a way that is appropriate to the context.

APPENDIX C

Table C1. Components and competency items under the CCST with their agreement percentages obtained after the third Delphi round

Component	Competency items	Agreement (%)
STEM content knowledge	Has problem solving skills in engineering design process.	80
	Knows and internalizes the engineering design process steps.	80
	Has STEM content and context knowledge.	80
	Knows STEM content that will appeal to students at different levels.	80
	Has content knowledge about other disciplines at the level of awareness.	80
	Knows the misconceptions that may occur when different disciplines are used together.	80
	Knows how to adapt engineering design to different contexts.	80
	Can assess students' prior knowledge who are new to design.	80
	Encourages students to think systematically and establish cause-effect relationships during the STEM activity.	80
	Supports students' learning by assessing their science and/or math knowledge, using engineering language, and giving feedback to them.	100
STEM interdisciplinary connection knowledge	Makes preliminary preparations for interdisciplinary connections.	80
	Plans interdisciplinary connections and establishes the necessary relationships.	80
	Places knowledge in STEM context and adapts it to daily life problems.	80
	Identifies instructional teaching strategies to establish interdisciplinary connections.	100
	Specializes in a different discipline in order to establish interdisciplinary connections.	80
	Follows publications (articles, books, documentaries, etc.) related to disciplines outside her own field.	80
STEM curriculum knowledge	Knows how to implement the curriculum related to her discipline.	100
	Has knowledge about the curriculum content of other disciplines.	80
	Defines the goals related to his own discipline from the curriculum goals related to other disciplines.	80
	Knows why disciplines have connections between each other epistemologically.	80
Technology literacy	Decides how to use instructional technologies as a motivating, attention-gathering, and focusing resource in STEM activities.	100
	Knows instructional technologies at the awareness level.	80
	Knows and applies instructional technologies to be used for her instructional purpose.	100
	Makes plans to improve students' computational thinking skills by using technological tools.	80

APPENDIX D

Table D1. Mean (M), median (MD) and interquartile range (IQR) values of the competency items under the CCST after the fourth Delphi round

Components and competency items	Mean	Median	IQR
STEM content knowledge component			
Has problem solving skills in engineering design process.	4.70	5.00	0.75
Knows and internalizes the engineering design process steps.	4.65	5.00	0.75
Has STEM content and context knowledge.	4.73	5.00	1.00
Knows STEM content that will appeal to students at different levels.	4.35	5.00	1.00
Has content knowledge about other disciplines at the level of awareness.	4.58	5.00	1.00
Knows the misconceptions that may occur when different disciplines are used together.	4.40	4.00	1.00
Knows how to adapt engineering design to different contexts.	4.53	5.00	1.00
Can assess students' prior knowledge who are new to design.	4.40	5.00	1.00
Encourages students to think systematically and establish cause-effect relationships during the STEM activity.	4.68	5.00	0.75
Supports students' learning by assessing their science and/or math knowledge, using engineering language, and giving feedback to them.	4.45	5.00	1.00
STEM interdisciplinary connection knowledge component			
Makes preliminary preparations for interdisciplinary connections.	4.63	5.00	1.00
Plans interdisciplinary connections and establishes the necessary relationships.	4.60	5.00	1.00
Places knowledge in STEM context and adapts it to daily life problems.	4.75	5.00	0.00
Identifies instructional teaching strategies to establish interdisciplinary connections.	4.68	5.00	1.00
Specializes in a different discipline in order to establish interdisciplinary connections.	3.58	3.50	1.00
Follows publications (articles, books, documentaries, etc.) related to disciplines outside her own field.	3.80	4.00	1.75
STEM curriculum knowledge component			
Knows how to implement the curriculum related to her discipline.	4.85	5.00	0.00
Has knowledge about the curriculum content of other disciplines.	4.23	4.00	1.00
Defines the goals related to his own discipline from the curriculum goals related to other disciplines.	4.55	5.00	1.00
Knows why disciplines have connections between each other epistemologically.	4.33	4.00	1.00
Technology literacy component			
Decides how to use instructional technologies as a motivating, attention-gathering, and focusing resource in STEM activities.	4.38	5.00	1.00
Knows instructional technologies at the awareness level.	4.20	4.00	1.00
Knows and applies instructional technologies to be used for her instructional purpose.	4.45	5.00	1.00
Makes plans to improve students' computational thinking skills by using technological tools.	4.28	4.00	1.00

Some of the eliminated competence indicators:

- Knows the misconceptions that may occur when different disciplines are used together.
- Follows publications (articles, books, documentaries, etc.) related to disciplines outside of his/her field.
- Knows why disciplines are interconnected epistemologically.

APPENDIX E

Table E1. Frequency and percentage values of the final consensus competency items under the CCST

Cognitive characteristics	Experts and teachers who gave 5 (absolutely necessary) on the Likert scale	
	Frequency	Percentage (%)
Knows how to implement the curriculum related to her discipline Places knowledge in STEM context and adapts it to daily life problems.	34	85.0
Has problem solving skills in engineering design process.	32	80.0
Knows and internalizes the engineering design process steps.	30	75.0
Encourages students to think systematically and establish cause-effect relationships during the STEM activity.	30	75.0
Has STEM content and context knowledge.	30	75.0
Identifies instructional teaching strategies to establish interdisciplinary connections.	29	72.5
Makes preliminary preparations for interdisciplinary connections.	29	72.5
Supports students' learning by assessing their science and/or math knowledge, using engineering language, and giving feedback to them.	26	65.0
Plans interdisciplinary connections and establishes the necessary relationships.	25	62.5
Defines the goals related to his own discipline from the curriculum goals related to other disciplines.	25	62.5
Knows and applies instructional technologies to be used for her instructional purpose.	25	62.5
Knows STEM content that will appeal to students at different levels.	25	62.5
Knows how to adapt engineering design to different contexts.	24	60.0
Has content knowledge about other disciplines at the level of awareness.	24	60.0
Decides how to use instructional technologies as a motivating, attention-gathering, and focusing resource in STEM activities.	23	57.5
Can assess students' prior knowledge who are new to design.	22	55.0