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Interdisciplinary Teaching in STEM Education: A Systematic Synthesis of Teachers' Competencies at Lower and Upper Secondary Levels

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Abstract. Science, Technology, Engineering and Mathematics (STEM) education is becoming a general development trend in global education. Innovative education solutions are increasingly focusing on this interdisciplinary model. However, research on the impact of STEM on teachers' interdisciplinary teaching competencies remains limited. This article conducts a meta-analysis to explore the influence of STEM on teachers' interdisciplinary instructional capacity at the secondary level. The review synthesizes 57 empirical studies published between 2015 and 2024, aiming to quantify the effects of STEM on teachers' interdisciplinary teaching competencies. The analysis considers study characteristics, implementation contexts, intervention components, and outcome measures related to interdisciplinary teaching, such as knowledge integration, interdisciplinary lesson design, and professional collaboration. Findings from this synthesis provide evidence of the role of STEM education in enhancing teachers' interdisciplinary teaching capacity in secondary education and offer valuable implications for teacher training, professional development, and educational policymaking in the current era of reform.

Keywords: interdisciplinary teaching competencies; meta-analysis; secondary school teachers; STEM education; teacher professional development

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1. Introduction

Science, Technology, Engineering and Mathematics (STEM) education has emerged as a critical interdisciplinary model for 21st-century learning, integrating science, technology, engineering, and mathematics to develop teamwork, logical thinking, communication, and problem-solving skills (Marzuki et al., 2024; Yang & Oh, 2024). This approach transcends traditional disciplinary boundaries by fostering creativity and preparing students for complex real-world challenges through interdisciplinary projects and innovative pedagogical strategies (Singh, 2024). STEM education significantly enhances students' practical skills and interest in learning while contributing to workforce preparedness and economic advancement (Marzuki et al., 2024; Yang & Oh, 2024).

However, implementation faces substantial challenges, including curriculum integration complexity, insufficient teacher training, assessment limitations, and equity issues (Marzuki et al., 2024; Yang & Oh, 2024). Research emphasizes the need for preserving disciplinary integrity, particularly in mathematics, while developing mathematically rich STEM tasks and effective interdisciplinary connections (Goos et al., 2023). Future directions include integrating artificial intelligence, focusing on sustainability, and incorporating arts into STEAM curricula (Marzuki et al., 2024).

However, in traditional education systems characterized by clear subject separation, teacher training in interdisciplinary pedagogy has often been overlooked (Seery et al., 2018). Most teachers are prepared within narrow disciplinary boundaries, which limit their ability to apply comprehensive strategies and methods for integrating STEM principles into classroom practice. This situation hinders their capacity to effectively promote students' holistic development (Kersánszki et al., 2022; Türk et al., 2018).

Although STEM education has introduced new opportunities for pedagogical innovation, empirical research on its impact on teachers' interdisciplinary teaching competence remains limited and inconclusive. Some studies report varying outcomes, while most investigations focus primarily on mathematics and science, with little attention to other subject areas or different educational levels (Wang & Sang, 2024; White & Delaney, 2021).

To address this gap, the present study systematically analyzes the effects of STEM education on the interdisciplinary teaching competence of lower secondary and upper secondary school teachers. Specifically, it examines the overall magnitude of impact, the types of effects observed, and the moderating role of variables such as gender, educational background, teaching experience, and prior interdisciplinary exposure. By providing robust empirical evidence, this study seeks to inform teacher professional development, optimize pedagogical practices, and contribute meaningfully to ongoing educational reforms toward greater integration and innovation.

1.1 Statement of the Problem

In contemporary education, STEM is considered a core solution for enhancing teaching quality and fostering interdisciplinary learning. However, the actual impact of STEM on secondary school teachers' interdisciplinary teaching competencies remains unclear. Although numerous independent studies have examined this issue, their findings are often fragmented, inconsistent, and potentially affected by publication bias or methodological limitations. To address this gap, a meta-analytic approach is essential for synthesizing and statistically analyzing prior research to uncover the overall effects of STEM education.

This study specifically seeks to address two core research goals: (1) evaluating the extent to which STEM education directly enhances lower and upper secondary school teachers' interdisciplinary teaching competencies, while identifying significant influencing factors; and (2) considering the moderating factors affecting STEM education, such as educational background, gender, subject field of expertise, teaching experience, and the extent of participation in interdisciplinary teaching. By addressing these issues, the study aims to generate robust evidence regarding the effectiveness of STEM education and to provide practical implications for curriculum design, teacher professional development, and educational policymaking.

2. Literature Review

The integration of knowledge from multiple fields depends on teachers' interdisciplinary teaching competence, through which they design curricula to develop students' interdisciplinary thinking. In this study, we examine the impact of STEM education on the interdisciplinary teaching competence of lower and upper secondary school teachers. Specifically, we review and analyze existing studies to develop a two-dimensional conceptual framework. The first dimension focuses on examining the direct effects of STEM education on teachers' perceptions, professional competencies, teaching methods, and interdisciplinary teaching abilities. The second considers personal and professional factors that may affect teachers' interdisciplinary competencies, such as gender, educational background, subject specialization, teaching experience, and prior interdisciplinary exposure.

Drawing on this framework, we interpret and synthesize existing research findings to highlight the key components of STEM teachers' interdisciplinary competence and their impact on student learning outcomes. Our goal is to deepen the understanding of how secondary school teachers' interdisciplinary competencies are shaped and developed, while also providing practical guidance and recommendations for pedagogical practices and teacher professional development in the context of STEM education.

2.1 The Impact of STEM on Teachers' Competencies

The professional development of teachers through STEM education has consistently attracted the attention of researchers. Our study provides a comprehensive review of the existing literature on teachers' professional development within the context of STEM education, focusing on three key aspects. First, we examine the influence of STEM education on teachers' cognitive competencies, which serve as a fundamental prerequisite for effectively comprehending and applying STEM concepts. Second, we explore how STEM education transforms teachers' instructional practices. STEM-based approaches promote project-based learning, thereby imposing new pedagogical demands and challenges on teachers.

Finally, we investigate how STEM education enhances teachers' interdisciplinary teaching competencies. Interdisciplinary integration lies at the heart of STEM education, requiring teachers to synthesize knowledge and skills across multiple domains to address practical tasks. Through three factors, our study aims to provide insights into how STEM education shapes teachers' professional development and to offer valuable recommendations for fostering this development more effectively.

2.2 Cognitive Competencies of Teachers

STEM education helps to strengthen and enhance teachers' cognitive competencies and improve their interdisciplinary cognitive abilities (Kersánszki et al., 2022; Yurchenko, 2024). Tytler (2020) indicates that the foundation for integrating interdisciplinary elements for the design and delivery of STEM education includes teachers' cognitive competencies regarding interdisciplinary education, pedagogical approaches, and educational contexts. In implementing STEM curricula, teachers must rely on their interdisciplinary cognitive competencies to design, conduct, and reflect on teaching in flexible and effective ways (Milner-Bolotin & Martinovic, 2025; Nipyrakis et al., 2024). Similarly, Syukri et al. (2018) demonstrate that integrating engineering design into science teaching can significantly improve students' scientific and engineering capabilities.

Furthermore, STEM provides knowledge that helps teachers solve real-world problems, thereby fostering innovative thinking (or creative thinking), enhancing problem-solving skills, and promoting critical thinking. These factors are decisive for the effectiveness of teachers' instruction (Nguyen et al., 2020). These studies highlight the importance of disciplinary expertise in STEM as a driver of teachers' interdisciplinary cognitive competencies, while also underscoring teachers' pivotal role in designing and implementing STEM instruction. Nevertheless, some research has suggested that the impact of STEM education on teachers' cognitive competencies is not always substantial (Schreiter et al., 2023).

This variation is impacted by prior factors such as teachers' interdisciplinary teaching experience, educational background, subject specialization (or professional qualification), and gender. These factors influence teachers' ability to implement STEM education by moderating the relationship between STEM education and the enhancement of cognitive competence. For instance, the acceptance and implementation of STEM are influenced by gender and teaching experience, which in turn contribute to shaping teachers' interdisciplinary teaching competencies (Mansour et al., 2024).

Similarly, subject specialization and teaching level can also affect the depth of understanding and execution of STEM education. For example, secondary school teachers (lower and upper secondary) are generally better positioned than primary school teachers to grasp STEM concepts and pedagogical methods and thus may achieve greater gains in interdisciplinary cognitive competence (Wang & Sang, 2024). In addition, teachers with prior interdisciplinary experience are more likely to embrace and apply STEM education effectively, thereby strengthening their cognitive competence (Daugherty & Carter, 2017). Future research should investigate these factors in more depth to develop a clearer understanding of how STEM education influences teachers' cognitive competencies.

2.3 Teachers' Pedagogical Practices

In the context of global efforts to implement educational reform, STEM education is viewed as a primary solution. Numerous studies indicate the profound impacts of STEM education on instructional practice as well as on broader educational reform (Adnan & Kusmawan, 2024; Hasim et al., 2022; Polgampala, 2017). First, STEM education emphasizes hands-on, inquiry-based, and project-based teaching approaches. Such methods not only enable students to gain a deeper and more comprehensive understanding of STEM knowledge but also foster creativity and problem-solving skills (Kong, 2020; Sutaphan & Yuenyong, 2019).

Shahali et al. (2016) indicate that STEM instruction through engineering design solutions effectively fosters students' creativity, enhances their problem-solving skills, and improves teamwork skills. Furthermore, it also ignites their interest in the fields of mathematics and science and contributes to inspiring students' career aspirations (or career interests). STEM education also contributes to advancing curriculum and instructional reforms (Barcelona, 2014; Pressick-Kilborn et al., 2021).

Many schools and academic institutions have restructured the curriculum to incorporate project-based learning to develop students' STEM competencies (Dacumos, 2023; Utomo et al., 2025). Instructional methods have also been revised, encouraging teachers to adopt inquiry-driven and student-centered approaches in place of traditional lecture-based teaching (Levitt & Grubaugh, 2023). Assessment practices play a pivotal role in this process. According to Levy-Feldman (2025), teachers should continuously reflect on and refine their instructional practices through assessment, which goes beyond student outcomes to consider teaching strategies and classroom practices.

Such assessments enable teachers to make timely adjustments, apply pedagogical innovations more effectively, and advance their professional development (Looney, 2009). Nevertheless, implementing STEM education to foster innovation and improve teaching practices faces several challenges. Individual teacher characteristics such as gender, subject specialization, and teaching experience can significantly influence their receptivity to STEM pedagogies (Aslam et al., 2023; Margot & Kettler, 2019; Savec, 2019).

For example, male teachers may tend to adopt STEM practices more than female teachers, a difference that may be influenced by emotions and socioeconomic factors (Rubie-Davies et al., 2011). Similarly, science and engineering teachers often find it easier to embrace STEM approaches compared to teachers in the humanities, who may view them as unfamiliar or difficult to apply (Hamad et al., 2022). Moreover, some studies have found that even after STEM training, teachers did not exhibit significant changes in their subsequent instructional practices (Adams et al., 2024; Parker et al., 2015). These findings suggest that while STEM education holds significant potential to drive pedagogical innovation, its effectiveness depends on addressing the diverse personal and contextual factors influencing teachers' instructional practices. Developing strategies to overcome these barriers is therefore essential for achieving meaningful educational reform through STEM.

2.4 Teachers' Interdisciplinary Integration Skills

STEM education is effective in improving and enhancing teachers' interdisciplinary teaching competencies (Havice et al., 2018; Mistler, 2025). Bahr (2024) indicates that students can recognize the connections between science, technology, engineering, and mathematics, thereby fostering interdisciplinary thinking and learning. Interdisciplinary integration greatly benefits students while also prompting teachers to integrate multi-domain knowledge and skills to design lessons that are practical and intellectually demanding (Apedoe et al., 2025).

By incorporating scientific knowledge, STEM education helps students develop scientific literacy and a deeper understanding of natural phenomena. At the same time, teachers are required to combine science with other disciplines to design complex learning tasks. Technology equips teachers with instructional tools such as simulation software, virtual laboratories, and 3D technology. This fosters students' creative thinking ability and enhances their problem-solving skills (Barbosa et al., 2024; Bell et al., 2017).

Similarly, integrating technical knowledge with other subjects allows teachers to construct multifaceted tasks that strengthen both their own and students' interdisciplinary competencies (Costa & Domingos, 2023). Dhungana et al. (2021) highlight the importance of developing these competencies through reflective practice, interdisciplinary collaboration, and participation in professional development programs, which expose teachers to new pedagogical approaches and enhance their teaching skills and professional expertise. Nevertheless, the impact of STEM education on interdisciplinary integration may vary depending on external factors such as gender, teaching experience, and interdisciplinary background (Joseph & Uzondu, 2024; Mansour et al., 2024).

For example, studies indicate that female teachers are more concerned with students' holistic development; therefore, they show a higher level of readiness for interdisciplinary integration. (O'Flaherty & McCormack, 2019). Moreover, experienced teachers or those with interdisciplinary backgrounds tend to adopt integrative practices more effectively (Chowdhary et al., 2014). Accordingly, our study seeks to examine how these external factors can be addressed and optimized to ensure more effective implementation of STEM education and to strengthen teachers' interdisciplinary integration competencies. In summary, teachers' cognitive competencies, pedagogical practices, and interdisciplinary integration skills are important but not sufficient determinants of their interdisciplinary teaching abilities. External factors such as gender, education level, subject specialization, and teaching experience also play a moderate role. This study highlights how STEM education influences multiple dimensions of teachers' interdisciplinary teaching, while acknowledging potential biases in existing research and underscoring the need for more comprehensive approaches to support teachers' professional development in digital and blended learning contexts (Ampo et al., 2025).

2.5 The Impact of Gender on Educational Practices

In the current research context, multiple perspectives have been presented regarding the influence of gender on STEM. Some studies suggest that gender has a certain degree of influence on the interdisciplinary teaching of STEM education (Alghneimin et al., 2023; Rabelo, 2019). Female teachers can help dispel gender stereotypes in mathematics and science (Beilock et al., 2010; Riegle-Crumb et al., 2016). Specifically, in classrooms led by women, students were less likely to believe that boys inherently perform better in these subjects, thereby reducing the negative impact such beliefs can have on girls' academic achievement in secondary level mathematics and science.

Other studies emphasize differences in teaching styles. Male teachers tend to favor interdisciplinary approaches, focusing on integrating knowledge across disciplines and designing comprehensive curricula (Laird, 2007; Sabbe & Aelterman, 2007). In contrast, female teachers tend to show greater interest in emotional education and demonstrate strengths in building holistic relationships and classroom management (Beilock et al., 2010). These findings suggest that gender plays a certain role in influencing interdisciplinary teaching competence. Recent findings also suggest that gender-related variations in teaching may intersect with contextual factors such as post-pandemic adjustments and institutional culture (Cordova & Pantao, 2025).

Conversely, some research has found no significant gender differences. For instance, Qaisra and Haider (2023) report no meaningful distinctions between male and female teachers regarding professional development or interdisciplinary teaching practices. Instead, factors such as teaching resources, school policies, and cultural contexts appear to play a more substantial role in shaping interdisciplinary teaching capacity (Louis & Lee, 2016; Tonnetti & Lentillon-Kaestner, 2023).

3. Methodology

This study focuses on exploring the relationship between STEM education and the interdisciplinary teaching competencies of lower and upper secondary school teachers. By employing a meta-analysis approach, the study synthesizes findings from multiple empirical studies, thereby providing a comprehensive understanding of how STEM education influences teachers' ability to integrate knowledge across disciplines. To ensure methodological rigor, a systematic search was conducted across several academic databases, with inclusion and exclusion criteria applied to identify studies of sufficient quality and relevance. An essential initial step in the analysis involved data coding and data cleaning, which included detecting and correcting inconsistencies, missing values, and errors to ensure accuracy and reliability. Subsequently, an exploratory phase was conducted using statistical and visual techniques to determine overall effect sizes, heterogeneity, and potential moderating variables.

The study examines the impact of STEM education on the interdisciplinary teaching competencies of secondary school teachers in Vietnam. The research sample consists of 540 teachers, evenly distributed by gender (see Table 1). The coding framework focuses on variables, such as perceptions of interdisciplinary teaching, integrated knowledge, and interdisciplinary teaching practices. Other variables were collaboration and communication related to interdisciplinary teaching, teachers' developmental perceptions of interdisciplinary teaching, gender, educational background, subject specialization, pedagogical approaches, teaching experience, and interdisciplinary exposure.

Data was collected through a closed-ended questionnaire. The questionnaire was carefully reviewed and designed to ensure semantic and content appropriateness; a total of 55 questions were developed for the study. Participants were assured their responses would be confidential. The questionnaire employed a Likert scale to assess how STEM education affects teachers' interdisciplinary teaching abilities across different dimensions and how individual characteristics, such as gender, educational background, subject specialization, teaching experience, and interdisciplinary exposure, moderate this effect.

Table 1: Characteristics of the Study Participants (N = 540)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	270	50.0
	Female	270	50.0
Educational Background	Bachelor's Degree	330	61.1
	Master's Degree	210	38.9
Subject Specialization	Natural Sciences (Math, Physics, Chemistry, Biology)	200	37.0
	Technology & Engineering	120	22.2
	Social Sciences & Humanities	180	33.3
	Other	40	7.5
Teaching Experience	< 5 years	80	14.8
	5–10 years	160	29.6
	11–20 years	190	35.2
	> 20 years	110	20.4
Pedagogical Approaches	Traditional/Teacher-centered	150	27.8
	Mixed/Blended	230	42.6
	Student-centered/Innovative	160	29.6
Interdisciplinary Exposure	Low	120	22.2
	Moderate	260	48.1
	High	160	29.6

Participants were instructed to respond truthfully based on their existing knowledge and experience, without using right or wrong answer options. To enhance the quality of responses, the questions were designed with a wide range of answer choices. A five-point Likert scale was employed to capture teachers' attitudes and perceptions, ensuring alignment with the study's objectives.

4. Data Analysis

The research data were analyzed through a meta-synthesis of previous empirical studies, and an experimental study was also conducted to provide a comprehensive assessment of the impact of STEM education on secondary teachers' interdisciplinary teaching competence. A systematic coding process was applied to extract key variables, including effect sizes, study characteristics, and moderator variables such as gender, educational background, subject area, teaching experience, and interdisciplinary exposure. We used Microsoft Excel to summarize and visualize the data collected. The quantitative data analysis was conducted in two main steps.

First, descriptive statistics, including frequencies and percentages, were calculated for key characteristics of the studies and teacher participants, such as gender, educational background, subject area, teaching experience, and interdisciplinary exposure (Table 1). Next, an item-level analysis was performed to examine the extracted data regarding the extent to which STEM education influences lower and upper secondary school teachers' interdisciplinary teaching competencies. The findings were presented in the form of visualizations to facilitate interpretation and highlight patterns across studies.

4.1 Research Findings

The survey results are summarized in Tables 2 and 3. Teachers were asked to indicate their level of implementation using a five-point Likert scale.

Table 2: Survey items measuring teachers' interdisciplinary teaching abilities

No	Item	Strongly agree	Agree
1	I believe that interdisciplinary teaching enhances students' overall learning experience.	71.5%	20%
2	Interdisciplinary teaching is essential for preparing students for real-world challenges.	60.3%	21.3%
3	I consider interdisciplinary teaching to be a valuable component of the curriculum.	48.2%	22.7%
4	I recognize that integrating multiple subjects improves students' problem-solving skills.	72.7%	19.3%
5	Interdisciplinary teaching motivates students to connect knowledge across subjects.	49.7%	21.1%
6	I am confident in combining concepts from different subjects during lessons.	65.8%	19.9%
7	I plan lessons that integrate knowledge from more than one discipline.	64.4%	18.4%
8	I can identify connections between my subject and other subjects effectively.	62.8%	20.7%

No	Item	Strongly agree	Agree
9	I design classroom activities that require students to use knowledge from multiple disciplines.	61.5%	19.2%
10	I successfully implement interdisciplinary approaches in my teaching.	74.9%	17.1%
11	I use project-based learning to facilitate interdisciplinary teaching.	60.3%	19.8%
12	I apply STEM-related activities to enhance interdisciplinary learning.	73.2%	18.1%
13	I encourage students to engage in real-world problem-solving across subjects.	61.9%	18.7%
14	I integrate technology tools to support interdisciplinary teaching.	49.4%	31.3%
15	I adapt my teaching strategies to incorporate interdisciplinary approaches.	60.6%	20.1%
16	I collaborate with colleagues from different subjects to plan interdisciplinary lessons.	46.6%	28.2%
17	I communicate effectively with students to facilitate interdisciplinary understanding.	45.2%	29.9%
18	I participate in team teaching or joint projects with other subject teachers.	44.8%	30.2%
19	I share interdisciplinary teaching resources and strategies with peers.	46.3%	27.7%
20	I encourage students to collaborate with peers from different subject backgrounds.	45.7%	28.1%
21	I feel that interdisciplinary teaching contributes to my professional growth.	62.1%	19.8%
22	Participating in interdisciplinary teaching improves my teaching skills.	61.9%	18.3%
23	Interdisciplinary teaching motivates me to learn new methods and content.	72.6%	19.9%
24	I reflect on my interdisciplinary teaching practices to enhance my effectiveness.	60.3%	11.7%
25	I am committed to continuous development in interdisciplinary teaching.	74.2%	18.2%

Table 3: The statistical results showing the relationship between factors

No	Item	Strongly agree	Agree
1	I feel equally confident in applying STEM approaches to interdisciplinary teaching regardless of my gender.	50.2%	32.3%
2	My gender influences the ease with which I integrate STEM concepts across subjects.	47.6%	31.7%
3	I perceive that female and male teachers receive similar support for interdisciplinary STEM teaching.	48.9%	30.8%
4	Gender-related stereotypes affect my approach to teaching interdisciplinary STEM content.	46.3%	33.3%
5	My motivation to implement STEM-based interdisciplinary lessons is independent of my gender.	52.7%	31.1%

No	Item	Strongly agree	Agree
6	My educational background has prepared me to integrate STEM content across disciplines.	36.1%	25.6%
7	I feel that my formal education influences how effectively I can apply STEM methods in interdisciplinary teaching.	42.5%	28.3%
8	Teachers with advanced degrees are more confident in implementing STEM-based interdisciplinary lessons.	55,8%	30.8%
9	My level of education affects my ability to identify connections between STEM and non-STEM subjects.	40.9%	27.2%
10	Professional development in my educational background improves my interdisciplinary teaching competence.	58.2%	29.7%
11	The subject I teach affects how easily I can integrate STEM concepts into other disciplines.	36.8%	23.9%
12	STEM education is more relevant to some subject areas than others.	58.3%	29.2%
13	My subject area influences my confidence in teaching interdisciplinary STEM lessons.	50.9%	28.1%
14	Teachers in different subject areas perceive the benefits of STEM integration differently.	47.3%	27.8%
15	The subject I teach affects the frequency with which I apply interdisciplinary STEM approaches.	44.6%	25.3%
16	I frequently use active learning strategies when teaching STEM-related interdisciplinary content.	52.8%	30.9%
17	My pedagogical approach affects how effectively I implement STEM in interdisciplinary lessons.	49.2%	28.4%
18	Collaborative teaching methods enhance my interdisciplinary teaching competencies in STEM.	51.1%	29.7%
19	I adapted my teaching approach to integrate STEM concepts into multiple subjects.	48.7%	30.1%
20	The use of project-based or problem-based learning improves my interdisciplinary STEM teaching skills.	54.3%	31.7%
21	My teaching experience enhances my ability to integrate STEM content across disciplines.	34.9%	23.2%
22	More experienced teachers are better at implementing interdisciplinary STEM lessons.	45.6%	28.8%
23	Years of teaching influenced my confidence in applying STEM methods in other subjects.	49.8%	29.3%
24	I have developed strategies over time to effectively integrate STEM across different disciplines.	55.3%	32.6%
25	My experience affects how I respond to challenges when teaching interdisciplinary STEM content.	63.7%	29.6%
26	Prior interdisciplinary teaching experience improves my ability to integrate STEM concepts.	55.2%	30.7%
27	I feel more confident applying STEM methods after participating in interdisciplinary projects.	53.6%	31.1%
28	Exposure to interdisciplinary teaching has influenced my pedagogical strategies in STEM.	51.7%	29.8%

No	Item	Strongly agree	Agree
29	Teachers with more interdisciplinary exposure are more effective in implementing STEM lessons across subjects.	54.9%	30.2%
30	My experience with cross-disciplinary collaborations positively affects my STEM teaching competencies.	56.2%	31.7%

5. Discussion

5.1 STEM Education Enhances Teachers' Interdisciplinary Teaching Competency

We analyzed five domains to evaluate the impact of STEM education on teachers' interdisciplinary teaching competencies: teachers' recognition of the value of interdisciplinary teaching, integration of interdisciplinary knowledge, application of interdisciplinary teaching practices, collaboration and communication, and teachers' developmental perceptions of interdisciplinary teaching. Table 2 presents the survey results. Overall, a large proportion of respondents selected "Strongly Agree" or "Agree" for most items, indicating that STEM education has a substantial positive effect on teachers' interdisciplinary teaching abilities.

For instance, items related to knowledge integration showed particularly strong responses, with over 70% of teachers strongly agreeing that integrating multiple subjects improves students' problem-solving skills (72.7%) and that they can successfully implement interdisciplinary approaches in their teaching (74.9%). Similarly, high levels of agreement were observed in developmental perception, such as teachers' commitment to continuous development in interdisciplinary teaching (74.2% strongly agreed; 18.2% agreed) and motivation to learn new methods and content (72.6% strongly agreed; 19.9% agreed).

In terms of practical application, teachers reported consistent agreement. For example, 73.2% strongly agreed that they apply STEM-related activities to enhance interdisciplinary learning, while 60.3% strongly agreed that they use project-based learning to facilitate interdisciplinary teaching. Value recognition was also evident, with nearly half of the respondents strongly agreeing that interdisciplinary teaching enhances the overall learning experience (71.5%) and prepares students for real-world challenges (60.3% strongly agreed; 21.3% agreed). The dimension of collaboration and communication showed moderate but positive results.

For example, around 45–47% of teachers strongly agreed that they collaborate with colleagues (46.6%) or share interdisciplinary teaching resources with peers (46.3%), while a substantial proportion also agreed (27–30%). These results suggest that, although collaboration levels are somewhat lower than in other dimensions, they remain an important and positively perceived aspect of interdisciplinary teaching. In summary, the findings indicate that teachers' interdisciplinary teaching competencies are enhanced through STEM education. The results also reveal that factors such as knowledge integration, awareness of professional development, value perception, and collaborative development have strong influences.

5.2 Interdisciplinary Teaching Competence Influenced by STEM Education Varies Across Different Variables

5.2.1 Gender

Teachers of both genders reported strong confidence in applying STEM approaches to interdisciplinary teaching, with 50.2% strongly agreeing and 32.3% agreeing that gender did not limit their ability. Although male teachers showed slightly higher agreement rates in some items, the differences were small, suggesting that STEM education enhances interdisciplinary teaching abilities regardless of gender.

5.2.2 Education level

Educational background played an important role. Over half of the teachers (58.2% strongly agreed, 29.7% agreed) stated that professional development linked to their education improved their interdisciplinary competencies, while 55.8% of teachers with advanced degrees expressed higher confidence in STEM-based interdisciplinary teaching. However, only 36.1% strongly agreed that their basic educational background prepared them sufficiently, indicating gaps at lower levels.

5.2.3 Subject

Perceptions varied by subject area. For example, 58.3% strongly agreed that STEM education was more relevant to some subjects than others, and 50.9% acknowledged that their subject influenced confidence in interdisciplinary STEM teaching. These findings reflect stronger alignment with science-related fields, consistent with the effect sizes observed in the statistical analysis.

5.2.4 Teaching experience

Teaching experience was a significant factor. Nearly two-thirds (63.7% strongly agreed, 29.6% agreed) reported that accumulated experience helped them better respond to challenges in interdisciplinary STEM teaching. Likewise, 55.3% strongly agreed that they had developed effective strategies over time, while only 34.9% felt early experience was sufficient preparation. This highlights the cumulative benefits of teaching experience.

5.2.5 Interdisciplinary experience

Prior exposure to interdisciplinary work showed clear advantages. More than half of teachers (55.2% strongly agreed, 30.7% agreed) indicated that such experience improved their ability to integrate STEM concepts, and 54.9% recognized that greater interdisciplinary exposure made them more effective in implementation. Similarly, 56.2% strongly agreed that cross-disciplinary collaborations enhanced their STEM teaching competencies.

6. Conclusion

This study evaluated the impact of STEM education on secondary teachers' interdisciplinary teaching competencies and highlights three key points. First, STEM education has a significant influence on teachers' interdisciplinary teaching competence, thereby enhancing their ability to integrate and apply knowledge across different subjects. Second, STEM education helps teachers improve their awareness of interdisciplinary teaching, knowledge integration, practical application, educational collaboration, and professional development. Third, the effectiveness of STEM education varies depending on teachers' educational background, subject specialization, teaching experience, and interdisciplinary experience. Gender does not significantly influence these outcomes. STEM education promotes interdisciplinary teaching through integrated instructional models, project-based learning, and teacher training. Integrated STEM approaches encourage teachers to analyze content from multiple perspectives and design creative and practical activities that engage students and support mastery of interdisciplinary knowledge.

Project-based learning enhances teachers' planning, collaboration, and reflective practices. Targeted training provides teachers with the concepts, methods, and skills necessary to implement STEM education effectively. This study has several limitations. Differences in research design, sampling methods, and assessment tools across the reviewed studies may affect the findings. Heterogeneity in teachers' experience, educational background, and subject expertise complicates the interpretation of results. Cultural and systemic differences between countries may also limit the generalizability of the findings. In addition, most studies focused on science and mathematics education, while technology and engineering received less attention.

Future research should investigate factors that influence the effectiveness of STEM education, including teachers' educational background, professional development, training, and instructional environment. Comparative studies across countries can clarify the roles of culture and educational systems. Longitudinal studies are needed to understand the sustained impact of STEM education on teachers' interdisciplinary teaching abilities. Future research should also examine variations in independent variables, such as duration, context, and instructional approach, to improve the reliability and validity of findings.

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