STEM Education

STEM Education, 4(4): 421–444
DOI: 10.3934/steme.2024023
Received: 04 June 2024
Revised: 03 September 2024
Accepted: 10 September 2024
Published: 25 September 2024

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

Research article

Teachers' perceptions of teaching mathematics topics based on STEM educational philosophy: A sequential explanatory design

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Academic Editor: Ergun Gide

Abstract: STEM education has gained significant attention in educational systems, and integrating mathematics into STEM education is a crucial issue in mathematics education. As teachers are considered highly influential in the educational process, we aimed to identify mathematics teachers' perceptions of teaching mathematics topics within the context of STEM education. We employed a mixed-methods sequential explanatory design. The quantitative sample included 248 mathematics teachers (99 males and 149 females) from the Bisha Governorate in Saudi Arabia. A questionnaire encompassing three dimensions (teachers' perceptions of teaching competence, teachers' perceptions of student interaction and motivation, and teachers' perceptions of the suitability of mathematics textbook content) was used to collect data, and its validity and reliability were verified. Qualitative data were gathered through interviews with eight participants. The results showed that mathematics teachers' perceptions of teaching mathematics topics based on the principles of STEM education were positive at the "agree" level, with an overall mean of 2.41. The dimensions were ranked as follows: Teachers' perceptions of their STEM teaching competence (M = 2.49), perceptions of the suitability of mathematics textbook content for STEM-based practice (M = 2.47), and perceptions of their students' interaction and motivation when teaching mathematics in line with STEM (M = 2.26). There were no statistically significant differences in perceptions due to gender, teaching experience, or educational stage. The qualitative findings attributed the positive perceptions of teaching competence to factors such as the integration of technology and the inherent connections between mathematics and other subjects. However, designing STEM-integrated tasks was challenging due to lack of STEM training and knowledge. Limitations in student interaction were linked to students' limited understanding of STEM, teachers' beliefs, and students' weak mathematics skills. The participants viewed textbook content positively, citing STEM-related components.

Keywords: mathematics teachers, mathematics teachers' perceptions, STEM education, mathematics education

1. Introduction

There is widespread interest internationally in promoting Science, Technology, Engineering, and Mathematics (STEM) education to enhance students' interest and attainment and prepare them for careers in the 21st century. The philosophy of STEM education advocates the integration of knowledge across disciplines and highlights the synthesis of disciplines in various educational contexts. Given the increasing focus on STEM, it is important to consider the value of mathematics for STEM education [1,2] and to recognize the reciprocal relation between the two. Makonye and Moodle [3] emphasize the importance of fairness and equality among disciplines, as the success of one cannot be achieved without the other, while Pllana [4] underscores mathematics' 25% contribution to STEM education and its pervasive influence across all fields.

STEM education is based on real-world problem-solving, and mathematical modeling aligns with STEM practice. Mathematics plays a role in both the goal and tool aspects of STEM activities [5]. The integration of mathematics into all aspects of STEM education helps improve students' performance, their interest in mathematics and their mathematical achievement [6]. It also has a positive impact on students' perceptions and positive engagement in mathematics education [7]. Furthermore, it contributes to student interaction, fostering deep thinking, increasing awareness of the importance of learning mathematics, and facilitating knowledge exchange and openness among learners, in addition to preparing students for future careers [8].

Given the importance of teachers in the educational process in general and specifically in STEM education, it is crucial for mathematics teachers to recognize the value of mathematics in STEM education [2]. Moreover, teachers are the backbone of education and their readiness to engage with change is an essential aspect of making teaching more impactful. Professional learning communities are among the prominent ways of enhancing teachers' teaching competence in STEM [9].

Teachers need to identify aspects of mathematical problems and their suitability for their students. They should have high problem-solving competencies and a broad understanding of students' methods of learning and abilities [10]. It is important for mathematics teachers to be aware of appropriate practices when implementing STEM lessons, and thus, they require the necessary knowledge and ability to adjust their teaching practices [11]. Pllana [4] highlights the importance of providing the necessary educational scaffolds when teaching based on STEM principles, demonstrating the value of mathematics in everyday life, and considering the real-world context. Teachers need positive beliefs and attitudes to STEM principles, as well as to improve their understanding of STEM teaching and develop their knowledge of how to design and implement STEM activities [12]. The provision of expert support and guidance for teachers through collaborative projects is an essential part of developing STEM teaching capabilities and enhancing teaching competencies [13–15]. Ortiz-Laso et al. [13] describe several competencies in STEM education related to modeling, computational thinking, mathematical representations, cooperative work, identity, and positivity.

Content is one of the most influential factors in implementing STEM education. Many educational systems rely on textbooks as a primary source in the educational process, pointing to the importance of carefully designing content, tasks, and mathematical activities in textbooks to achieve the desired goals. Kristensen et al. [5] argue the need to integrate mathematical content with real-world contexts and problems, while Forde et al. [16] point out the significance of employing high-quality mathematical content when teaching STEM, including implementing mathematical tasks, incorporating mathematical thinking, and linking content to students' lives. Activities in textbooks contribute to the development of skills in problem-solving, research and discovery, engineering design, modeling, collaboration, and participation [17]. Hence, Schreiter et al. [14] advocate the design of STEM-specific curricula.

Due to the nature of STEM education and the knowledge, skills, and competencies it requires, teachers may face implementation challenges. These include a lack of knowledge about STEM and the teaching workload [9]. In addition, teachers may lack the ability to relate mathematics teaching to real-life situations and the flexibility needed to choose problem-solving methods and strategies for interpreting information embedded in verbal problems [10]. In addition, conceptual understanding, problem-solving, reasoning, and modeling skills pose challenges for mathematics teachers [11], as do insufficient teaching time and beliefs about STEM [12]. Moreover, as noted by Tytler et al. [8], incorporating STEM in mathematics classrooms requires that teachers adopt student-centered teaching methods that are responsive to their needs and design mathematical tasks in line with STEM principles, which entails integrating different disciplines.

2. Literature review

Several researchers have focused on STEM education. Tambunan and Yang [2] aimed to identify mathematics teachers' perceptions of the value of mathematics in STEM education. They adopted a qualitative approach and concluded the importance of clearly highlighting mathematics in STEM education. Makonye and Moodle [3] addressed teachers' perceptions of the role of mathematics in STEM and found that they recognize the significance of integrating mathematics. They recommended seeking to develop teachers' perspectives on the role of mathematics in STEM education.

Marfuah & Khikmawati [11] aimed to identify the relationship between mathematics teachers' knowledge of STEM education and their teaching practices. The study included 34 secondary school teachers and found a positive relationship between the two. It recommended implementing continuing professional development programs to enhance integration approaches. Al-Salahi [18] aimed to identify the training needs of mathematics teachers to apply the STEM approach. It found a high need in areas such as lesson planning, implementation and assessment. They proposed introducing the STEM approach and providing specialized programs on teaching practices aligned with it.

Faqihi and Al-Maliki [19] explored science and mathematics teachers' perceptions of the STEM approach. In their study, the teachers had good knowledge and they highlighted the importance of training, implementation and providing the necessary technology and materials.

Ongcoy et al. [20] investigated students' experiences of teachers' interactions, educational practices, mathematical content and their relationship with mathematics anxiety, identifying a negative relationship between these factors. Kevin [21] examined the relationship between cognitive and non-cognitive skills and students' overall performance in mathematics following STEM principles and found a strong positive relationship between students' mathematics knowledge and attainment.

3. Conceptual framework

The integration of mathematics into STEM education has been a topic of significant interest due to the reciprocal relationship between mathematics and other STEM disciplines. Given the crucial role of teachers in the teaching/learning process, their perceptions and beliefs regarding the implementation of mathematics within STEM education, as well as their related competencies, have become a focal point of research [9]. Researchers have highlighted the importance of exploring mathematics teachers' beliefs and enhancing their understanding and abilities in teaching mathematics following STEM principles [2,12,14]. This is particularly relevant as the STEM fields have been recognized as essential in preparing both teachers and students for the challenges of the 21st century [22,23].

While many teachers acknowledge the value of integrated STEM approaches, they often feel underprepared to implement them effectively [22,23]. Research suggests that it is essential to strengthen the integration of mathematics within STEM education, which entails teachers employing various strategies to make mathematical concepts more explicit and linking them to other STEM disciplines [24].

Pre-service teacher education programs play a vital role in shaping future educators' perceptions and attitudes toward the integration of STEM in pedagogical practice [25,26]. Effective STEM education practices may include developing core competencies, implementing appropriate instructional designs, and providing necessary support and resources. Continuing professional development and collaborative learning opportunities can further help teachers develop and implement interdisciplinary STEM tasks [27]. Overall, the literature underscores the growing need for targeted training and support to enhance teachers' STEM competencies, particularly in the integration of mathematics, and to promote the widespread implementation of integrated STEM education. Addressing teachers' needs can contribute to the effective integration of mathematics into STEM education and the development of well-prepared STEM-literate students.

Alongside the focus on teachers' competencies and perceptions, students are recognized as the central focus of the educational process and they play an active role in STEM classrooms [10]. It is, therefore, essential for teachers to have a broad understanding of their students' learning methods and capabilities to effectively facilitate their development.

Recent research has highlighted the importance of adopting student-centered, active learning approaches in STEM education [28,29]. These methods have been shown to improve student engagement, learning outcomes and knowledge retention, in contrast with traditional lecture-based teaching. Active learning strategies include, but are not limited to, student research experiences [30], interactive classroom activities [31], and the integration of technology and engineering into science and mathematics curricula [32].

While these student-centered approaches can significantly enhance student motivation and academic performance, their implementation may require shifts in teachers' identities and roles [33].

Some challenges associated with the transition include negative student responses due to unfamiliarity or perceived increased workload [28]. To address these issues, educators are encouraged to adopt a "servant-professor" model, focusing on student needs and measuring learning outcomes [34].

Overall, the existing literature supports the transition towards more student-centered STEM classrooms as a means of better preparing students for their future careers and active citizenship [28,29]. By understanding students' learning methods and capabilities and employing active, student-centered teaching approaches, educators can create learning environments that foster students' engagement, skills, and competencies in STEM-related fields.

In mathematics education, teachers often focus on delivering the content of textbooks according to the prescribed curriculum. However, it is beneficial to incorporate tasks and activities that promote the value of mathematics within the broader scope of STEM education [5,16]. Such an approach can provide opportunities for students to recognize the interconnectedness and reciprocal relations between mathematics and other STEM fields, thereby motivating them to learn and achieve their goals in line with their educational philosophies. Research suggests that incorporating STEM-based activities into mathematics education can be instrumental in promoting student interest, motivation, and academic achievement [35,36]. Studies have shown that integrating mathematics with other STEM disciplines through hands-on experiments, engineering design challenges, and mathematical modeling can help students see the relevance and practical applications of mathematical [27,36].

However, there are challenges in effectively integrating STEM into mathematics education. These include difficulties in aligning tasks and activities with the prescribed mathematics curriculum, as well as ensuring that mathematics is not relegated to a purely utilitarian role within the interdisciplinary framework [35,37]. Addressing these challenges requires careful planning and a strategic approach to curriculum design and instructional practices. The literature emphasizes the importance of adopting a more holistic, STEM-integrated approach to mathematics education. By providing students with opportunities to explore the interconnections between mathematics and other STEM fields, educators can foster a deeper appreciation for and understanding and application of mathematical concepts, ultimately enhancing student engagement, motivation, and achievement in STEM-related domains.

4. Problem statement

There is growing interest in STEM education in many countries, including the Kingdom of Saudi Arabia, which has introduced numerous programs and established various centers across regions. However, the role of mathematics in STEM education, particularly as perceived by mathematics teachers, remains an important and pertinent issue worthy of attention. Studies such as that of Tambunan and Yang [2] have highlighted a lack of clarity regarding the role of mathematics in STEM education, as well as the belief among some teachers that having expertise in STEM education is unnecessary. Moreover, Goos et al. [1] found that mathematics is the most challenging subject to integrate into STEM education, with some teachers preferring to teach mathematical concepts separately. They recommended researching the design of STEM tasks and their implementation. This is consistent with research conducted by Al-Salahi [18], who argues the need for mathematics teachers to receive training in planning, implementation, and assessment when teaching STEM. Goos et al. [1] also pointed to the need to address teachers' beliefs regarding the role of mathematics in STEM education. This latter point is particularly important as there are misconceptions and misunderstandings concerning STEM education, inquiry-based learning, and interdisciplinary integration in particular [12].

Several researchers have recommended undertaking research on the integration of mathematics into STEM education. Tambunan and Yang [2] pointed out the scarcity of research focusing on the role of mathematics teachers in STEM education. Furthermore, research on mathematics teachers' perception of the value of mathematics in STEM education is a worthy area of study. Moreover, Forde et al. [16] and Schreiter et al. [14] noted the lack of research addressing mathematics in STEM education, particularly focusing on teachers' practices. Marfuah and Khikmawati [11] advocated conducting further studies on the integration of mathematics into STEM education and the teaching practices of mathematics teachers. Hussein [38] also contended that more research on interdisciplinary integration is needed, involving specialists from multiple disciplines in research groups. Based on the aforementioned literature, we aimed to identify mathematics teachers' perceptions of teaching mathematics topics in line with the principles of STEM education, addressing three dimensions: Perceptions of teaching competence, perceptions of student interaction and motivation, and perceptions of the suitability of mathematics textbook content.

5. Research questions

We aimed to answer the question, "What are mathematics teachers' perceptions of teaching mathematics topics in line with the principles of STEM education?"

We also addressed the following sub-questions:

1. What are mathematics teachers' perceptions of their teaching competence in STEM education?
2. What are mathematics teachers' perceptions of student interaction and motivation when teaching mathematics in line with the principles of STEM education?
3. What are mathematics teachers' perceptions of the suitability of mathematics textbook content for STEM education?
4. Are there statistically significant differences ($\alpha \leq 0.05$) in mathematics teachers' perceptions of teaching mathematics according to the principles of STEM education attributable to gender, teaching experience, or educational stage?
5. What are the participants' views on mathematics teachers' perceptions of teaching mathematics topics aligned with STEM education?

6. Methodology

We used a mixed-methods approach, collecting and analyzing both quantitative and qualitative data [39]. We adopted a sequential explanatory design, gathering quantitative data first, followed by qualitative data to explain the quantitative results. Figure 1 illustrates the study design.

Figure 1. Study design.

6.1. Study population and sample

We employed a mixed-methods sequential explanatory research design. The study was conducted in Bisha, a town in the southwestern Saudi Arabian province of 'Asir. According to the 2022 Census, Bisha has a population of 202,096 and encompasses nearly 240 villages and 58 larger settlements distributed along both sides of the Bisha Valley, the longest valley in the Arabian Peninsula. The population comprised male and female mathematics teachers in the Education Department of the Bisha Governorate, totaling 1,521 individuals for the 2023–2024 academic year. From this population, 248 teachers (99 males and 149 females), representing 16.3% of the study population, were selected using a simple random sampling technique, identifying participants through an online questionnaire distributed by the Mathematics Teachers Department. Table 1 illustrates the distribution of participants according to the study variables.

Table 1. Distribution of the participants according to the study variables (N = 248).

Variable	Category	Frequency	Percentage
Gender	Male	99	39.9
	Female	149	60.1
Educational stage	Elementary school	124	50
	Middle school	63	25.4
	High school	61	24.6
Teaching experience	≤ 10 years	83	33.5
	> 10 years	165	66.5

In the qualitative study, eight male and female teachers participated, selected from those who responded in the quantitative study. They were chosen in two stages. In the first stage, purposive sampling was used based on the teachers' participation in the quantitative study and their knowledge of STEM education, enabling them to answer the questions in the qualitative interviews. In the second stage, the snowball sampling method was used, leading to the selection of 4 teachers (1 male and 3 females) teachers were selected from the group that participated in the first stage, who were considered to have sufficient experience to answer the questions. Table 2 outlines the characteristics of the study participants, giving their identification codes, gender, and the grade level they taught, as well as the source of their knowledge or experience related to STEM education. This information was gathered through the interviews conducted with the study participants.

Table 2. Participants in the qualitative study.

Code	Gender	Teaching Stage	Teaching Experience	STEM Knowledge Sources
Stage 1				
T1	F	Elementary	15 years	Courses: The acquisition of STEM knowledge is facilitated through academic study within the structured framework of educational curricula
T2	M	Secondary	8 years	Personal interest: Is the teachers' self-motivation to delve into STEM education's fundamental principles and philosophy.
T3	F	Elementary	3 years	Courses and personal research
T4	M	Middle	12 years	Research and training courses
Stage 2				
T5	M	Middle	19 years	Training courses: Represent targeted professional development programs tailored to educators with the aim of bolstering their proficiencies in STEM education.
T6	F	Elementary	1 year	Personal interest and attendance at forums
T7	F	Elementary	8 years	Personal interest
T8	F	Elementary	3 years	Reading on the Internet

6.2. Ethical considerations

In the first phase (quantitative study), we contacted the education administration to obtain approval to apply the questionnaire online. In the second phase (qualitative study), we obtained consent from the participants, explained the purpose of their participation, clarified the connection between the questions and the quantitative results, and highlighted the importance of their participation. Participants were given the freedom to choose their preferred method of response (telephone interview, face-to-face interview, and written response). They could also respond using multiple methods; for example, participant T3 responded both by telephone and in writing.

For the qualitative aspect of the study, the quality criteria were drawn from Al-Abdulkarim [40]. Official approvals were obtained from the relevant authorities before the study commenced. The purpose of the qualitative study and the need for it were clearly explained. Participants with good knowledge of STEM education were selected to provide in-depth information after obtaining their consent. The respondents could participate in their mode of choice: face-to-face interviews, telephone interviews and written responses. The participants included both males and females with diverse teaching experience and teaching different educational stages. The data were collected and reviewed multiple times by several researchers and then organized thematically. The results were presented to a group of participants to verify their validity and the accuracy of representation. Some citations from participants’ direct and indirect statements were added, and the consistency of responses was reviewed.

6.3. Instruments

To achieve our objectives, a questionnaire was used to collect quantitative data, while interviews were used to gather qualitative data.

6.3.1. Questionnaire

The questionnaire was developed through a comprehensive review of the relevant literature and previous studies focused on teaching mathematics in the context of STEM education. This review included the studies by Ortiz-Laso et al. [13], Tyler et al. [8], and Forde et al. [16]. The key constructs and appropriate items for each construct were then identified. At this stage, the research team drew upon both the findings from the literature review and their own professional experience.

The initial version of the questionnaire was then presented to a panel of expert reviewers with diverse backgrounds and expertise in STEM education. The panel consisted of five individuals, including mathematics education experts from universities, mathematics education supervisors, and mathematics teachers. The reviewers provided feedback on the appropriateness of the main topics, the relevance of the individual items to the research objectives, and the overall coherence of the questionnaire. Based on the reviewers' comments and suggestions, the research team revised the questionnaire as necessary. The final version of the instrument comprised three major sections:

1. Mathematics teachers' perceptions of teaching efficacy in light of STEM principles (15 items).
2. Mathematics teachers' perceptions of their students' interaction and motivation to learn in light of STEM principles (9 items).
3. Mathematics teachers' perceptions of the appropriateness of mathematical content for STEM education (10 items).

Item responses were given on a three-point Likert-type scale: 3 = Agree, 2 = Neutral, 1 = Disagree. The category distributions were calculated as follows: (3-1)/3 = 0.66. Table 3 shows the categories.

Table 3. Distribution of categories for questionnaire responses.

Level	Mean Range
Disagree	1.0–1.66
Neutral	1.67–2.33
Agree	2.34–3.00

Validity was established based on feedback from arbitrators regarding the appropriateness of the dimensions in terms of idea and formulation, consistency of the items with the philosophy of STEM education and linguistic integrity. Based on their feedback, some items were reformulated linguistically and others were modified, deleted, or added. The items for which the arbitrators' agreement rate reached 80% or higher were approved.

Reliability was determined using Cronbach's alpha coefficient to identify the internal consistency of the dimensions and overall questionnaire based on responses from a sample of 30 teachers (13 males, and 17 females) (see Table 4).

Table 4. Reliability coefficients for the questionnaire dimensions and overall.

Dimension	α
1. Teachers' perceptions of teaching competence	0.947
2. Teachers' perceptions of student interaction and motivation	0.933
3. Teachers' perceptions of the suitability of mathematics textbook content	0.948
Overall reliability	0.962

As can be seen from Table 4, reliability was high both for the individual dimensions and overall (α = 0.962), indicating the applicability of the questionnaire for the study.

6.3.2. Interviews

Interviews are the instrument most commonly used for qualitative data collection, aimed at enriching a study and providing in-depth information. We employed different modes (telephone, face-to-face, written). The questions were structured progressively from general to specific, as illustrated in Figure 2.

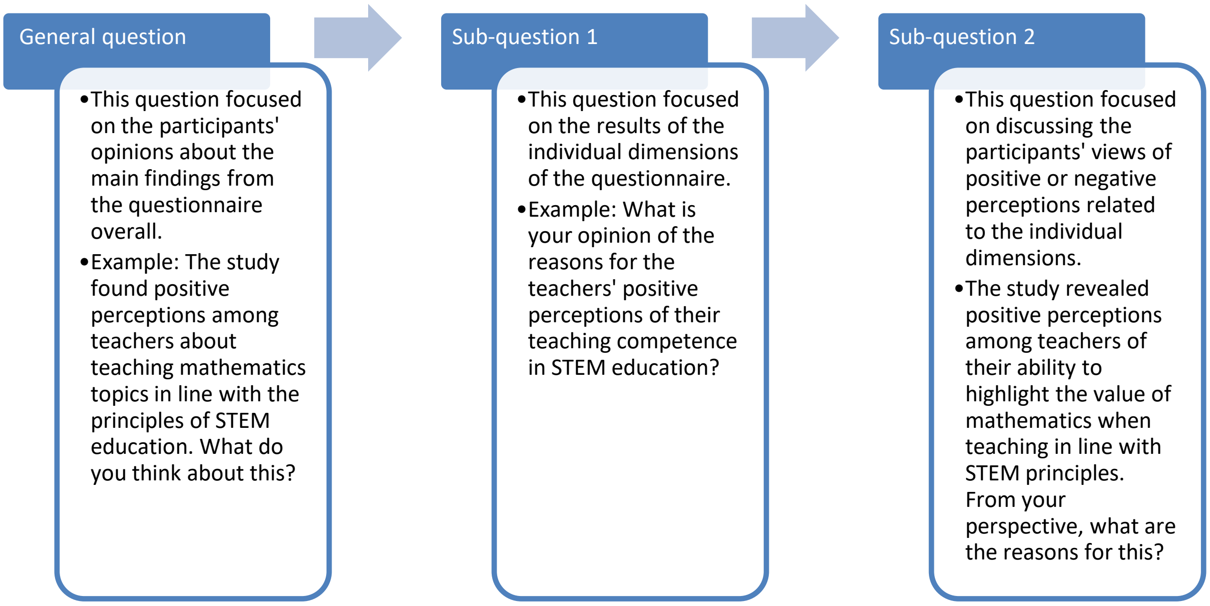

Figure 2. Interview questions.

7. Results

7.1. Quantitative questionnaire

To answer the main research question concerning mathematics teachers' perceptions of teaching mathematics topics in line with the principles of STEM education, we addressed several sub-questions, the first of which was: What are mathematics teachers' perceptions of their teaching competence in STEM education? Table 5 shows the results, giving the means and standard deviations of the questionnaire responses, as well as the overall position.

As can be seen from Table 5, the overall mean for mathematics teachers' perceptions of their competence teaching according to the principles of STEM education corresponded to "agree" (M = 2.49). The item "I can diversify the use of assessment tools" had the highest mean (2.67), representing "agree", while the item "I have sufficient knowledge of STEM education and pedagogy" had the lowest mean (2.15), representing "neutral".

Table 5. Mathematics teachers' perceptions of their competence in teaching in line with the principles of STEM education.

No.	Item	M			Overall	SD	Position
		Agree	Neutral	Disagree			
1	I have the ability to plan mathematics lessons in line with STEM principles	43.1	46.8	10.1	2.33	0.652	Neutral
2	I can integrate mathematics with STEM fields during teaching	52.4	38.3	9.3	2.43	0.658	Agree
3	I can provide appropriate instructional scaffolding when assigning STEM-based tasks to students	42.7	45.2	12.1	2.31	0.676	Neutral
4	I can manage the class to deliver mathematical knowledge in line with STEM principles	55.2	35.9	8.9	2.46	0.654	Agree
5	I can design mathematical tasks that integrate STEM fields	41.1	46.8	12.1	2.29	0.671	Neutral
6	I can monitor students' progress and provide necessary feedback when teaching in line with STEM principles	50	37.9	12.1	2.38	0.692	Agree
7	I can plan necessary projects that achieve lesson objectives in line with STEM principles	45.1	44	10.9	2.34	0.667	Agree
8	I have sufficient knowledge of STEM education and pedagogy	33.9	46.7	19.4	2.15	0.716	Neutral
9	I have the ability to connect mathematical knowledge to real-life problems	65.7	28.2	6.1	2.60	0.603	Agree
10	I can use teaching strategies that align with the philosophy of STEM (problem-based learning, inquiry-based learning, etc.)	51.2	44	4.8	2.46	0.599	Agree
11	I can achieve fairness and balance among STEM fields according to lesson objectives	46.8	44.8	8.4	2.38	0.638	Agree
12	I have the ability to highlight the value and usefulness of mathematics when integrated with STEM fields	54.8	37.9	7.3	2.48	0.629	Agree
13	I can manage cooperative groups while solving mathematical problems	66.5	30.2	3.3	2.63	0.546	Agree
14	I have the ability to assess students' performance in mathematics lessons designed according to STEM principles	50.8	42.3	6.9	2.44	0.620	Agree
15	I can diversify the use of assessment tools	69.8	27	3.2	2.67	0.537	Agree
	Overall Mean	51.27	37.9	8.99	2.49		Agree

Table 6 shows the results for the second question, "What are mathematics teachers' perceptions of their students' interaction and motivation when teaching mathematics in line with STEM education?"

Table 6. Mathematics teachers' perceptions of their students' interaction and motivation when teaching mathematics in line with STEM principles.

No.	Item	M			Overall	SD	Position
		Agree	Neutral	Disagree			
1	Students have the ability to solve STEM-based mathematical problems	36.7	51.6	11.7	2.25	0.650	Neutral
2	Students have good mathematical communication skills in STEM lessons	40.3	48	11.7	2.29	0.663	Neutral
3	Students can provide appropriate, evidence-based mathematical reasoning and arguments when solving problems in STEM lessons	34.3	52	13.7	2.21	0.663	Neutral
4	Students have the ability to collaborate and engage productively in solving problems in STEM fields	43.1	45.2	11.7	2.31	0.672	Neutral
5	Students can provide multiple solutions to problems based on integrating STEM fields	35.9	52	12.1	2.24	0.652	Neutral
6	Students show mathematical creativity when solving STEM-based problems	40.3	46.4	13.3	2.27	0.682	Neutral
7	Students can model different STEM-based mathematical situations	38.7	48	13.3	2.25	0.676	Neutral
8	Students can absorb mathematical knowledge when integrated with STEM fields	40.7	48	11.3	2.29	0.660	Neutral
9	Students enjoy studying mathematics in line with the principles of STEM education	38.3	48.8	12.9	2.25	0.670	Neutral
	Overall Mean	38.7	48.8	12.4	2.26		Neutral

Table 6 shows that the overall mean for mathematics teachers' perceptions of their students' interaction and motivation when studying mathematics in line with the principles of STEM education is "neutral" (M = 2.26). The item "students have the ability to collaborate and engage productively in solving problems in STEM fields" had the highest mean (2.31), corresponding to "neutral", while the item "students can provide appropriate, evidence-based mathematical reasoning and arguments when solving problems in STEM lessons" had the lowest mean (2.21), representing "neutral".

For the third question, "What are mathematics teachers' perceptions of the suitability of mathematics textbook content for STEM education?", the results are presented in Table 7.

Table 7. Mathematics teachers' perceptions of the suitability of mathematics textbook content for STEM education.

No.	Item	M			Overall	SD	Position
		Agree	Neutral	Disagree			
1	The content of mathematics textbooks promotes integration between STEM fields	46	44.7	9.3	2.37	0.648	Agree
2	The content of mathematics textbooks provides context-based problems (personal, societal, professional, etc.)	56.4	36.3	7.3	2.49	0.630	Agree
3	The content of mathematics textbooks includes mathematical problems related to students' needs	59.2	32.7	8.1	2.51	0.643	Agree
4	Embedded activities in the textbook develop research and exploration skills	62.5	32.3	5.2	2.57	0.592	Agree
5	Mathematical content includes situations and activities that allow student collaboration and cooperation	64.9	27.8	7.3	2.58	0.625	Agree
6	Mathematical content includes tasks and activities that require mathematical modelling	60.8	32.3	6.9	2.54	0.622	Agree
7	Mathematics textbook activities develop 21st-century skills associated with STEM education	44.8	46.3	8.9	2.36	0.640	Agree
8	The textbook includes scientific concepts consistent with STEM education	48.8	41.5	9.7	2.39	0.658	Agree
9	The textbook provides students with instructions and guidance for performance tasks consistent with the integration of STEM fields	48.4	40.3	11.3	2.37	0.679	Agree
10	Mathematical activities and tasks in the textbook support students' deep understanding	58.8	32.3	8.9	2.50	0.655	Agree
	Overall Mean	55.06	36.65	8.29	2.47		Agree

Table 7 shows that the overall mean for the dimension of mathematics teachers' perceptions of the suitability of mathematics textbook content for STEM education corresponded to "agree" (M = 2.47). The item "mathematical content includes situations and activities that allow student collaboration and cooperation" had the highest mean (2.58), representing "agree", while the item "mathematics textbook activities develop 21st-century skills associated with STEM education" had the lowest mean (2.36), also representing "agree".

The fourth question was concerned with whether there were statistically significant differences ($\alpha \leq 0.05$) in mathematics teachers' perceptions of teaching mathematics according to the principles of STEM education attributable to gender, teaching experience, or educational stage taught. For gender and teaching experience, the analysis was conducted using independent sample t-tests (see Table 8), and for educational stage taught, one-way analysis of variance (ANOVA) was used (see Table 9)

Table 8. Differences in teachers' perceptions attributable to gender and teaching experience.

Dimension	Variable	Category	N	M	SD	t-value	p-value
Perceptions of teaching competence	Gender	Male	99	36.31	7.60	0.056	0.905
		Female	149	36.37	7.70		
	Teaching experience	≤ 10 years	83	36.17	7.70	0.259	0.796
		> 10 years	165	36.45	7.70		
Perceptions of student engagement	Gender	Male	99	20.76	5.03	0.727	0.468
		Female	149	20.28	5.17		
	Teaching experience	≤ 10 years	83	20.73	5.03	0.583	0.561
		> 10 years	165	20.33	5.16		
Perceptions of textbook content	Gender	Male	99	22.03	4.59	0.399	0.690
		Female	149	22.28	5.04		
	Teaching experience	≤ 10 years	83	22.12	5.19	0.140	0.889
		> 10 years	165	22.21	4.70		
Overall		Male	99	81.61	15.96	0.86	0.932
		Female	149	81.42	16.78		
		≤ 10 years	83	81.51	16.65	0.007	0.995
		> 10 years	165	81.49	16.36		

As can be seen from Table 8, there were no statistically significant differences ($p \geq 0.05$) in mathematics teachers' perceptions of teaching mathematics according to the principles of STEM education attributable to either gender or teaching experience.

Table 9. Differences in teachers' perceptions attributable to educational stage taught.

Variable	Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Educational Stage	Between groups	23.847	2	11.92	0.044	0.957
	Within groups	66618.149	245	271.91		
	Total	66641.996	247			

As can be seen from Table 9, there were no statistically significant differences ($p \geq 0.05$) in mathematics teachers' perceptions of teaching mathematics in accordance with STEM education attributable to the educational stage taught.

7.2. Qualitative interviews

To gain a more in-depth understanding of the responses to the questionnaire, interviews were conducted with a group of participants differing in terms of gender, teaching experience, educational stage taught, and prior knowledge of STEM education. The responses provided by the teachers were concentrated on distinct themes, including positive perceptions of teaching competence in STEM education, challenges encountered in formulating mathematical tasks integrating STEM disciplines, constraints on student interaction within STEM-based classrooms, favorable assessments of school mathematics textbooks, and the determinants impacting the responses.

There was broad consensus on the rationale for the positive perceptions identified concerning teaching competence in STEM-based education. Notably, the teachers reported that the integration of technology has become a common practice among teachers and students, with many applications and software related to mathematical knowledge being used. T5 noted, “Currently, there is a significant and noticeable expansion in the use of technology in general, which aligns with STEM education”. Others attributed teachers’ positive perceptions to the nature of mathematics and its connection to other sciences, meaning that they were accustomed to integrating subjects as part of the curriculum was dedicated to this. As T1 stated, “Mathematics is inherently integrative with other subjects; hence, teachers feel competent”. Moreover, T2 recounted, “Strategies required in STEM education, such as projects and portfolios, are commonly used in high school”.

However, the participants considered that designing mathematical tasks based on the integration of STEM disciplines was among the challenges teachers faced, for several reasons: The lack of training on this, the lack of in-depth knowledge of STEM, and the focus on this field being dependent on the teachers’ efforts and their awareness of its importance. T5 stated that “there is a lack of awareness of the importance of STEM education, and part of the deficiency is due to lack of training”, while T6 contended that “the lack of in-depth knowledge of other specializations weakens the ability of the mathematics teacher to design a mathematical task that considers integration”.

Regarding the limitations perceived in relation to student interaction in STEM-based classrooms, the participants attributed this to several factors, including the students themselves, the teachers, and the nature of STEM education and issues with implementation. For example, T1, T4, and T7 pointed out, “Students’ limited understanding of other STEM disciplines may hinder their interaction”. T3 suggested that “teachers’ beliefs about their students” were a reason for the lack of interaction, and T5 argued that “a lack of basic mathematical (conceptual and procedural) knowledge is a primary reason”.

Regarding positive perceptions of the content of school mathematics textbooks, the participants pointed out that school mathematics curricula had undergone development and changes, both overall and in the structure of each lesson. Each lesson consists of several parts related to STEM, including a section on higher-order thinking skills, activities designed to connect with daily life, and activities related to other specializations, with the respective field identified. In addition, the nature of mathematics as a science and school subject is based on problem-solving, which is consistent with the philosophy of STEM education. In relation to this, T6 mentioned the presence of a section in each lesson dedicated to higher-order thinking skills, which includes diverse ideas. T7 and T8 pointed out the variety of activities that support thinking broadly and critical thinking in particular.

The participants also noted that the lack of statistically significant differences in responses attributable to gender, stage, and teaching experience was due to several factors, including the absence of a general orientation in applying STEM education in mathematics teaching, the unified approach to training programs and curricula for both genders, the lack of a standard for evaluating teachers’ performance in this regard, and all courses at different educational stages being within unified within that developmental stage. T2 also mentioned the possibility that students had the same motivations. With regard to teachers, T3 noted that “self-motivation and interest are key factors in change” and T5 highlighted that “experience is a crucial factor for improvement; the more experienced the teacher, the better they understand teaching realities, strategies, and STEM education”.

8. Discussion

We found that mathematics teachers' perceptions of teaching in relation to STEM education were predominantly positive, with an overall mean of 2.41 indicating "agree" with statements across the three dimensions. Their perceptions of their teaching competence in STEM-based education ranked first (M = 2.49), and their perceptions of the suitability of mathematics textbook content for STEM education ranked second (M = 2.47). Finally, their perceptions of their students' interaction and motivation when teaching mathematics in accordance with STEM principles ranked third (M = 2.26). The high level of positive perceptions among mathematics teachers may be due to the significant interest in the STEM field in the Kingdom of Saudi Arabia. This is confirmed by Goos et al. (2023), who highlighted the interest of various countries in promoting STEM on a large scale. In addition to the general focus on integrating technology into education and the interest of mathematics teachers in applications and software, mathematics is inherently integrative; this is reflected in the textbooks on which teachers rely.

With regard to the teachers' knowledge of STEM and related teaching methods, the responses were "neutral". This may be due to the teachers' need to transition to applied training programs than studying theoretical aspects, consistent with previous research. It was noted that the importance of mathematics teachers continuing to develop their knowledge of STEM education and Ortiz-Laso et al. [13] argued the need to support teachers and guide them to work on projects in cooperation with experts in STEM education. Moreover, Marfuah and Khikmawati [11] highlighted the need to enable teachers to acquire the necessary knowledge of STEM and subsequently adjust their teaching practices.

The teachers' responses concerning their students' interaction and motivation corresponded to the "neutral" level, with the lowest mean of 2.26. This may be due to the students' need for multiple competencies, such as modeling, creativity, and solving complex problems, when working on STEM projects, as pointed out by Ortiz-Laso et al. [13]. This may also be indicative of teachers' knowledge of their students' level in mathematics. Kevin [21] found a strong positive relationship between the student's level of mathematics knowledge and performance in STEM. Additionally, Oppong-Gyebi et al. [6] concluded that self-competence and communication have a significant impact on mathematical achievement. Additionally, there are factors related to mathematics teachers' beliefs about their students, which are influential in shaping perceptions, as well as the awareness of students and the community regarding the STEM approach and the importance of integration.

The mathematics teachers' perceptions of the suitability of mathematics textbook content were broadly positive as they opted for "agree" in response to the statements (M = 2.47). This may be due to the focus in textbooks on the link to the local context and incorporating performance-based activities, consistent with Kristensen et al.'s [5] argument that it is important to consider the local context and address real-world problems to support STEM education. The findings are consistent with previous studies that reported that the level of consideration of STEM aspects in mathematics textbooks was high. The mathematics textbooks currently used include sections that align with the philosophy of STEM education, such as allocating part of each lesson structure to connect with daily life, part to higher-order thinking skills, and part to activities related to other disciplines, with reference to the specialization addressed.

The results also showed no statistically significant differences in the teachers' perceptions of teaching mathematics topics according to STEM principles attributable to gender, teaching experience, or educational stage taught. This differs from previous studies, which identified differences in favor of males and more experienced teachers. However, our findings align with Al-Salahi's [18] research, who found no differences in training needs for STEM teaching based on teaching experience or the number of programs provided to teachers in STEM education. Our results reflect the increasing global, regional, and local emphasis on STEM education, as well as the proliferation of STEM centers, schools, training programs, conferences, and scientific forums attended by mathematics teachers. The increasing interest in STEM in Saudi Arabia has also been evident recently in the take-up of training programs, which are offered to teachers across all educational stages, irrespective of teaching experience.

9. Conclusions

We conclude that mathematics teachers generally hold positive perceptions regarding the integration of STEM education into their teaching practices, as evidenced by an overall mean score of 2.41. Their confidence in teaching competence in STEM ranked highest, suggesting a strong belief in their ability to effectively deliver STEM-based instruction. Additionally, the positive perceptions regarding the suitability of mathematics textbook content for STEM education highlight the alignment of instructional materials with STEM principles, reflecting a commitment to enhancing student learning through real-world applications.

However, the results indicate that integrating mathematics into STEM education requires further support and a transition to practical implementation. Teachers need a thorough grounding in both the theoretical and applied aspects of STEM. This includes training in designing mathematical tasks that meet lesson objectives, deepen mathematical knowledge, and connect to other STEM fields.

Despite the positive perceptions, teachers expressed a neutral level of knowledge concerning STEM and related teaching methodologies, indicating a potential gap that necessitates further professional development. The findings suggest a need for applied training programs that prioritize practical skills over theoretical knowledge, aligning with previous research advocating for continuous professional growth in STEM education.

Moreover, the neutral perceptions regarding students' interaction and motivation highlight challenges in fostering the competencies required for successful engagement in STEM projects. It is essential for the education system and mathematics teachers to identify students' needs to enable them to attain in-depth knowledge by integrating mathematics lessons with other STEM fields. This includes considering relevant emotional aspects that support students, stimulate interaction, and foster learning motivation, while also enhancing skills in communication, collaboration, creativity, and problem-solving.

Our results also revealed no significant differences in teachers' perceptions based on gender, teaching experience, or educational stage, contrasting with previous research that identified such differences. This suggests a growing consensus among mathematics teachers regarding the importance of STEM education, regardless of demographic factors.

Our findings underscore the increasing emphasis on STEM education within Saudi Arabia, propelled by various training programs and initiatives aimed at enhancing teachers' capabilities. Given the significance of textbooks as a link between teachers, students, and the community, they must be designed to ensure integration and alignment with other fields in a manner that suits lesson objectives. Enriching activities based on STEM can also be incorporated into each lesson. As educators continue to engage with STEM principles, it is crucial to provide ongoing support and resources that facilitate the integration of these methodologies into their teaching practices, thereby enriching the educational experience for students.

10. Limitations and future studies

This study was conducted in the context of the Kingdom of Saudi Arabia, which may limit the generalization of the findings to other educational settings and contexts. The sample was drawn from mathematics teachers in the Bisha region, and thus, the results may not fully reflect the perceptions and experiences of teachers in other parts of the country or different educational systems. The study relied on self-reported perceptions of mathematics teachers, which could be subject to potential biases and may not always align with observed classroom behaviors and student performance. The study focused solely on mathematics teachers' perceptions and did not include the perspectives of other key stakeholders, such as students, school administrators, or experts in STEM education. Incorporating a wider range of stakeholder views could have provided a more comprehensive understanding of the implementation of STEM education. These research limitations should be considered when interpreting the findings of this study and when designing future research on the implementation of STEM education in the Kingdom of Saudi Arabia and beyond. Researchers could explore additional avenues, such as conduct qualitative or mixed-methods research to gain deeper insights into teachers' perceptions and experiences beyond the numerical data, investigate the mathematics teachers' classroom practices when implementing the core principles of STEM education, and examine the factors and variables that influence mathematics teaching in the context of STEM education.

Author contributions

Ibrahim Khalil: Conceptualization, Methodology creation, Investigation, Resources, Writing - Original Draft; Amirah AL Zahrani: Data curation, Result Analysis; Bakri Awaji: Methodology, Writing – review & editing; Mohammed Mohsen: Investigation, Result Analysis; Supervision. All authors have read and approved the final version of the manuscript for publication

Acknowledgements

The authors extend their appreciation to the Deanship of Scientific Research, University of Bisha for funding this research through Promising Program under Grant Number (UB- Promising - 4-1445).

Conflict of interest

The authors declare there is no conflict of interest in any part of this article.

Ethics declaration

The authors declared that the ethics committee approval was waived for the study.

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Appendix

Appendix A. Research questionnaire

1. Mathematics teachers' perceptions of their competence in teaching in line with the principles of STEM education				
No.	Item	Responses		
		Disagree	Neutral	Agree
1	I have the ability to plan mathematics lessons in line with STEM principles			
2	I can integrate mathematics with STEM fields during teaching			
3	I can provide appropriate instructional scaffolding when assigning STEM-based tasks to students			
4	I can manage the class to deliver mathematical knowledge in line with STEM principles			
5	I can design mathematical tasks that integrate STEM fields			
6	I can monitor students' progress and provide necessary feedback when teaching in line with STEM principles			
7	I can plan necessary projects that achieve lesson objectives in line with STEM principles			
8	I have sufficient knowledge of STEM education and pedagogy			
9	I have the ability to connect mathematical knowledge to real-life problems			
10	I can use teaching strategies that align with the philosophy of STEM (problem-based learning, inquiry-based learning, etc.)			
11	I can achieve fairness and balance among STEM fields according to lesson objectives			
12	I have the ability to highlight the value and usefulness of mathematics when integrated with STEM fields			
13	I can manage cooperative groups while solving mathematical problems			
14	I have the ability to assess students' performance in mathematics lessons designed according to STEM principles			
15	I can diversify the use of assessment tools			
2. Mathematics teachers' perceptions of their students' interaction and motivation when teaching mathematics in line with STEM principles				
1	Students have the ability to solve STEM-based mathematical problems			
2	Students have good mathematical communication skills in STEM lessons			
3	Students can provide appropriate, evidence-based mathematical reasoning and arguments when solving problems in STEM lessons			
4	Students have the ability to collaborate and engage productively in solving problems in STEM fields			
5	Students can provide multiple solutions to problems based on integrating STEM fields			
6	Students show mathematical creativity when solving STEM-based problems			
7	Students can model different STEM-based mathematical situations			
8	Students can absorb mathematical knowledge when integrated with STEM fields			
9	Students enjoy studying mathematics in line with the principles of STEM education			
3. Mathematics teachers' perceptions of the suitability of mathematics textbook content for STEM education				

1	The content of mathematics textbooks promotes integration between STEM fields			
2	The content of mathematics textbooks provides context-based problems (personal, societal, professional, etc.)			
3	The content of mathematics textbooks includes mathematical problems related to students' needs			
4	Embedded activities in the textbook develop research and exploration skills			
5	Mathematical content includes situations and activities that allow student collaboration and cooperation			
6	Mathematical content includes tasks and activities that require mathematical modelling			
7	Mathematics textbook activities develop 21st-century skills associated with STEM education			
8	The textbook includes scientific concepts consistent with STEM education			
9	The textbook provides students with instructions and guidance for performance tasks consistent with the integration of STEM fields			
10	Mathematical activities and tasks in the textbook support students' deep understanding			

Appendix B. Research interview questions

Please feel free to refrain from answering any questions you do not wish to address or to end the interview at any time.

1. **Introduction to STEM Education:**
   STEM education is a modern trend that concerns all educational systems, aiming to prepare generations for future professions and achieve global competitiveness. Mathematics is one of the main fields within STEM. Given the importance of teachers in any educational system, this qualitative study follows the results of a quantitative study that produced several findings.
2. **Self-Introduction:**
   Can you introduce yourself, including your name, the academic level you teach, and your years of teaching experience?
3. **Prior Knowledge of STEM Education:**
   How did you gain your knowledge and experience related to STEM education? (e.g., through study, courses, personal interest, etc.)

Section 1: Teacher Perceptions of Competence in Teaching Mathematics in Light of STEM

- **Teaching Competence:**
  Teaching competence and the teacher's perception of their ability to teach mathematics within the STEM framework are influential factors. The quantitative results indicated a positive perception among teachers regarding their competence in this area.
  - Based on your experience in teaching mathematics and your knowledge of the STEM approach, what reasons do you believe contributed to the positive perceptions of teachers regarding their competence in teaching mathematics within STEM?
  - Teachers reported a high level of confidence in demonstrating the value of mathematics when teaching within the STEM context. What do you think accounts for this positive perception?
  - Teachers expressed a neutral (average) perception of their competence in designing interdisciplinary mathematical tasks. In your opinion, what factors contribute to this?

- Teachers also rated their knowledge of the STEM approach at a neutral (average) level. What do you think explains this?

Section 2: Teachers' Perceptions of Student Interaction in Mathematics Teaching within STEM

- **Student Engagement:**
  It is clear that students play a significant role in the learning process, highlighting the importance of their interaction. Quantitative findings indicated that teachers perceive their students' ability to engage well in mathematics when taught within the STEM context at a neutral (average) level. What do you believe contributes to this perception?
  - Teachers rated their students' ability to reason and present mathematical arguments at a neutral (average) level. What are your thoughts on this?
  - Teachers also expressed a neutral (average) perception of their students' ability to provide creative solutions. What do you think accounts for this?

Section 3: Teachers' Perceptions of the Suitability of Mathematics Textbook Content for STEM Teaching

- **Textbook Content:**
  Regarding the mathematical content in school textbooks, teachers have expressed positive perceptions, suggesting that the content is suitable for teaching within the STEM framework. What reasons do you believe contribute to this positive stance?

Section 4: Differences in Opinions Based on Study Variables

- **Variability in Perceptions:**
  The quantitative study included several variables, such as gender (male and female teachers), different educational levels (primary, intermediate, secondary), and varying teaching experiences (10 years or less, more than 10 years). The results indicated no differences across these variables. In your opinion, what might explain the absence of differences in perceptions?

Additional Comments

- Would you like to add any aspects that you believe are relevant to the research topic but were not covered in the questions above?