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Primary school teachers' views on science, technology, engineering, and mathematics education: A cross-national study

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Abstract

This study examines primary school teachers' perceptions of science, technology, engineering, and mathematics (STEM) education in Türkiye, Portugal, Spain, and Italy. Using a descriptive survey design, 257 teachers shared their views across four thematic areas: STEM education frameworks, curriculum, and policy; teacher professional development and school leadership; student engagement and parental involvement; and resources, infrastructure, and learning environments. The findings point to a broadly similar pattern across the four samples. Teachers generally reported that the motivational and curricular preconditions for STEM engagement are present, while their reports of the institutional, material, and incentive conditions required for sustained implementation were less positive. Within this shared landscape, descriptive differences between countries were observed in administrative support, teacher preparation, resource profiles, and stakeholder engagement. The study contributes a cross-national comparative perspective to a field that has remained predominantly single-country in orientation and suggests that, as perceived by teachers, the STEM implementation gap may be more structural than motivational.

Keywords: STEM education, primary school teachers, teacher perceptions, cross-national research, STEM implementation

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has become one of the defining priorities of contemporary educational policy. Bibliometric analyses trace a steady expansion of STEM education research over the past two decades, reflecting a growing global recognition of STEM as fundamental to economic competitiveness, workforce development, and societal innovation (Abdi et al., 2024). Reviewing a decade of scholarship, Chiu et al. (2025) identify conceptual frameworks, curriculum integration, and equity as the dominant emerging themes. This illustrates how the field has matured from early definitional debates to more complex empirical and policy-oriented questions. At the international level, this trajectory has been accompanied by a surge of policy initiatives. The European Commission's (2025) STEM education strategic plan, for instance, positions STEM as a cornerstone of Europe's strategy for technological independence and innovation capacity. It calls for coordinated investment across curriculum, teacher preparation, and institutional infrastructure. As Tytler (2020) notes, this global policy momentum reflects a

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Contribution to the literature

- This study contributes to the STEM education literature by providing a cross-national comparative survey of primary school teachers' views across four nationally distinct educational systems, in contrast to much existing research that has examined STEM implementation conditions within single-country contexts. Its findings suggest that the gap between motivational readiness and structural capacity, as perceived by teachers, may not be confined to a single national context.
- The descriptive findings suggest that the STEM implementation gap, as perceived by teachers, may be more structural than motivational. In all four samples, teachers' reports of enthusiasm and student readiness coexist with less positive reports of institutional support, resource provision, and reward mechanisms across all four national systems.
- The study elucidates the particular significance of reward mechanisms as a structural dimension of STEM implementation. This dimension has received limited attention in the existing literature. In all four samples, more teachers disagreed than agreed that STEM-engaged teachers are rewarded; this was the finding most consistent in direction across countries.

broader societal shift in which STEM competencies are increasingly regarded as essential not only for economic participation but for informed citizenship in the 21st century.

Translating STEM goals into consistent classroom practice requires more than policy commitment or curriculum design; it requires understanding how those closest to implementation experience the conditions in which they work. As Margot and Kettler (2019) demonstrate through a systematic review of 25 empirical studies, teachers are the primary agents of curriculum enactment in STEM education. Their beliefs, perceptions, and professional experiences are decisive in shaping whether and how STEM learning is realized in the classroom. More recent empirical work reinforces this argument across different national contexts. Papagiannopoulou and Vaiopoulou (2024), drawing on a large sample of Greek primary and secondary school teachers, show that teachers' readiness dimensions, including cognitive preparedness, self-efficacy, and affective conditions, directly predict their attitudes toward STEM education. This underscores that implementation outcomes cannot be understood independently of how teachers perceive their own professional context. Similarly, Sellami et al. (2024) examine STEM teachers in Qatar's secondary schools. They identify student-related, technology-related, school-related, and instruction-related factors as the barriers teachers themselves foreground when accounting for what is and is not achievable in their classrooms. Lin et al. (2025) further demonstrate this through case studies in Taiwanese schools. They show that structural factors such as scheduling constraints, limited planning time, and the absence of collaborative support mechanisms shape implementation as powerfully as individual teacher capacity does. Taken together, these findings, drawn from contexts as varied as Greece, Qatar, and Taiwan, suggest that teachers' views constitute an indispensable source of evidence for understanding STEM implementation in practice. Despite this, comparative studies systematically examining primary school teachers' perceptions of STEM education across different national contexts remain limited. This gap constrains our understanding of how systemic, cultural, and institutional factors interact to shape teachers' experiences at the primary level.

Responding to this need, the present study asks how primary school teachers in four national contexts, Türkiye, Portugal, Spain, and Italy, perceive the conditions shaping STEM education in their schools, and whether the tendencies that emerge from their views reflect shared patterns or nationally specific experiences. As Subramaniam and Mok (2023) argue, advancing STEM education requires multiple perspectives from researchers and practitioners and cannot be achieved through single-discipline or single-country analyses alone. Correspondingly, this need for comparative perspectives is echoed at the regional level: a systematic review of STEM education research in the Gulf Cooperation Council countries identified cross-national comparative work as essential for uncovering the structural barriers shaping implementation (Kayan-Fadlelmula et al., 2022). The study explores teachers' perceptions across four thematic areas: STEM education frameworks, curriculum, and policy; teacher professional development and school leadership; student engagement and parental involvement; and resources, infrastructure, and learning environments. By doing so, it aims to contribute to a more grounded understanding of the systemic conditions that enable or constrain STEM implementation at the school level. The findings carry implications for policy, teacher training, and resource allocation.

LITERATURE REVIEW

The challenges outlined above do not emerge in isolation. They are shaped by the conceptual frameworks through which STEM education is defined, the curricular structures through which it is organized,

and the policy environments within which it is expected to operate. Understanding why implementation remains uneven across different national contexts, therefore; requires a closer look at the theoretical and empirical foundations of STEM education. The sections that follow review the literature across four interconnected areas that directly inform the present study: STEM education frameworks, curriculum, and policy; teacher professional development and school leadership; student engagement and parental involvement; and resources, infrastructure, and learning environments.

STEM Education Frameworks, Curriculum, and Policy

Contemporary research on STEM education reflects a growing consensus on the need for coherent conceptual frameworks, integrated curricular structures, and supportive policy environments. Foundational definitional work has played a critical role in clarifying the aims and scope of the field. Kelley and Knowles (2016) offer one of the most widely cited conceptual frameworks for integrated STEM education, while Roehrig et al. (2021) build on this by providing a more detailed account of how integration principles can be operationalized across different learning contexts. Complementing these contributions, Falloon et al. (2020) conceptualize STEM as a multidimensional endeavor that links knowledge, skills, and dispositions to authentic problem contexts. Jackson et al. (2021) extend this perspective by embedding STEM literacy within an equity and identity framework. Rumjaun et al. (2024) further argue that national interpretations of STEM are shaped by economic, civic, and cultural priorities, while Deehan et al. (2025) draw attention to the contextual nature of STEM by highlighting the unique demands of rural and remote communities and challenging universalist assumptions in earlier frameworks. In a broader mapping of the field, Li et al. (2020) demonstrate through a systematic review of journal publications that STEM education research has grown considerably in both volume and scope over recent decades.

Debates surrounding integrated versus disciplinary approaches to STEM reflect a similar conceptual evolution. English (2016) was among the first to map the spectrum of integration models in K-12 STEM education. Systematic reviews such as Portillo-Blanco et al. (2024) continue to demonstrate that curricular coherence emerges when disciplinary boundaries are intentionally blurred to support knowledge creation. Wan et al. (2023) focus specifically on primary school contexts and show that integration in this phase is particularly complex, involving not only curriculum design but also teacher readiness and school-level conditions. Central to these discussions is the notion of STEM literacy as an overarching educational goal. In this regard, Gavrilas and Kotsis (2025) identify educator competencies, including content knowledge, collaboration, and pedagogical adaptability, as essential drivers of literacy development. This underscores the pivotal role of teacher capacity in realizing STEM's broader ambitions.

These conceptual and curricular developments are closely intertwined with expanding national and international STEM policy efforts. Comparative analyses, such as the one by Zhang and Chen (2023), show that governance structures across different national contexts shape STEM policy emphases and implementation mechanisms, while Lhakard (2024) reveals how some nations leverage STEM curriculum design as a strategic driver of national economic development. The persistent gap between policy and practice is addressed in studies such as Manokore and Sibanda (2024), which highlight how insufficient teacher capacity and infrastructure can undermine even well-intentioned policy frameworks. At the institutional level, resistance to STEM integration, whether from management, academic staff, or entrenched educational practices, constitutes a barrier that operates independently of formal policy frameworks and further complicates translating policy intent into classroom reality (Nesterenko et al., 2024). In line with this, Konstantinidou and Evagorou (2025) synthesize empirical evaluations of policy-informed programs. They observe uneven effects on engagement and achievement, pointing to the enduring challenge of translating policy ambition into meaningful classroom impact. Broader theories of educational reform help explain why this gap exists. Fullan (2007) frames this as a persistent gap between the personal meaning individuals attach to change and the organizational capacity needed to sustain it, while Spillane (2004) shows empirically that policy messages are progressively reinterpreted, and often distorted, as they pass through successive administrative layers on their way to the classroom.

Teacher Professional Development and School Leadership

The successful implementation of STEM education depends fundamentally on teachers' competence and preparedness. As Margot and Kettler (2019) demonstrate in a systematic literature review, teachers trained in single-discipline frameworks frequently struggle with the design, implementation, and evaluation of integrated STEM learning processes. This challenge is compounded at the systemic level: the European Commission (2025) identifies inadequate professional development and the absence of effective assessment frameworks for STEM competencies as the two most persistent barriers to quality STEM instruction across member states. Addressing these barriers requires a sustained, rather than episodic, approach to teacher preparation, both at the pre-service and in-service stages. Surahman and Wang (2023) conducted a systematic review of in-service STEM teacher

professional development programs between 2018 and 2022. Their findings show that fragmented, one-off training initiatives consistently fail to produce lasting pedagogical change, whereas collaborative, contextually embedded models yield more durable outcomes. Extending this argument, Hurley et al. (2024) conducted a systematic review. They find that immersive industry placements offer teachers rare opportunities to develop STEM competencies beyond what conventional training programs can provide, though their reach across educational systems remains limited.

The competencies demanded of STEM teachers are multidimensional. Huang et al. (2022) conducted a systematic review of K-12 STEM teacher professional development programs. They identify the technological pedagogical content knowledge (TPACK) framework as the most comprehensive model for capturing the integrated competencies teachers need, spanning content knowledge, pedagogical knowledge, and technological knowledge. Darling-Hammond et al. (2017) argue that high-quality professional development must be content-focused, sustained over time, coherent with broader reform efforts, and grounded in active learning and collective participation. When these conditions are met, professional development programs produce significant gains in STEM teachers' self-efficacy. This is shown by Zhou et al. (2023) in a meta-analysis of experimental studies. The finding is consistent with Bandura's (1997) foundational work linking mastery experiences and collaborative learning to sustained belief in one's own instructional capacity. Beyond formal training provision, teachers' attitudes toward integrated STEM are also shaped jointly by personal background characteristics and the school context in which they work, underscoring that professional development alone cannot fully account for variation in instructional uptake (Thibaut et al., 2018).

School leadership plays an equally critical role in enabling or constraining STEM implementation. Rose et al. (2019) propose that effective STEM leadership requires a broad set of competencies encompassing mission-building, facilitation of professional development, and resource management. Natarajan et al. (2021) extend this by arguing for a theorization of STEM leadership centered on agency, identity, and community, positioning school leaders not merely as administrators but as active architects of a shared STEM culture. Principals' instructional leadership style has been identified as a direct enabler of STEM implementation and it guides teachers toward integrating science, technology, engineering, and mathematics into their practice (Van Dat et al., 2023). Wieselmann et al. (2021) demonstrate that distributed leadership models, in which authority is shared across the school rather than concentrated in a single figure, are particularly effective in fostering teachers' interdisciplinary collaboration and professional commitment. Holincheck and Galanti (2025) further show through a cross-case analysis that STEM teachers who develop a strong professional identity as agents of equity are more likely to take on leadership roles within their school communities, including peer collaboration and instructional coaching, provided that administrative support structures are in place. Administrative support of this kind extends to recognition and incentive structures, which likewise bear on whether teachers remain engaged in STEM teaching over time. A recent systematic review of recruitment and retention interventions proposes that job-preview approaches showed the most promise, whereas pure financial incentives were often insufficient (Thompson-Lee et al., 2025). At the structural level, Giamellaro et al. (2025) show that flexible scheduling and dedicated planning time for cross-disciplinary work directly enhance teachers' capacity to implement project-based STEM. Centralized examination pressures and rigid curriculum frameworks remain the most commonly cited constraints. Cross-case evidence further indicates that the cultural and structural dimensions shaping STEM schools, such as school vision, scheduling, and interdisciplinary collaboration, vary considerably across elementary, middle, and high school contexts (Lesseig et al., 2019). Taken together, these findings suggest that the quality of STEM education at the school level is not solely a function of individual teacher competence, but is deeply shaped by the leadership culture, organizational structures, and professional development ecosystems within which teachers operate.

Student Engagement and Parental Involvement in STEM

Research on student engagement and parental involvement in STEM education highlights the interplay among motivational, identity-based, and contextual factors that shape learners' trajectories. Bayanova et al. (2023), in a systematic review, identify expectancy-value beliefs, teacher practices, and perceived utility as central drivers of STEM motivation. Jiang et al. (2025), in a meta-analysis, position STEM identity as one of the strongest predictors of long-term persistence and career intentions. Together, these reviews establish that student engagement in STEM emerges from the convergence of individual beliefs, instructional contexts, and broader structural conditions.

Parental involvement emerges consistently as one of the most influential factors shaping students' STEM trajectories. Gülhan (2023) demonstrates through a systematic literature review that parental involvement predicts students' STEM interest and achievement across diverse contexts. Rozek et al. (2017) show that parent-targeted utility-value interventions significantly increase adolescents' STEM course-taking and career interest, highlighting the power of parental communication about STEM's relevance. Experimental

evidence corroborates this pattern: a utility-value intervention that informed parents about the relevance of mathematics and science significantly increased adolescents' enrolment in advanced STEM courses (Harackiewicz et al., 2012), reinforcing the role parental communication plays in shaping STEM motivation. Akindipe (2025) further confirms that structured parental involvement improves students' mathematics achievement and self-efficacy. This underscores the malleability of parental practices and their downstream influence on motivational development. Wulani et al. (2025), drawing on a large sample of Indonesian high school students, add an important cross-cultural dimension to this picture. They demonstrate that both intrinsic and extrinsic motivation, together with parental encouragement, significantly predict students' STEM career interest, a pattern that holds equally for young women and men. Ryan et al. (2025) extend this perspective to school contexts, demonstrating that pre-service teachers can effectively engage families through hands-on STEM events, thereby positioning parents as active collaborators rather than passive observers.

Gender-related factors add further complexity to the picture. Studies by Sáinz et al. (2020) and Chaffee and Plante (2022) show that parents' and teachers' stereotypical beliefs about gender influence students' perceptions of competence and career aspirations in mathematics and science. Ferreira et al. (2025) specifically examine Portuguese students and pre-service teachers and document similar patterns within a European context directly relevant to the present study. Alongside gender, socioeconomic status shapes STEM participation through pathways of self-efficacy, exploration, and perceived opportunity. Research by Hu et al. (2022) demonstrates that family socioeconomic background influences career aspirations and decision-making. This reinforces the importance of financial accessibility as a structural factor, a dimension captured directly in the survey used in the present study.

Resources, Infrastructure, and Learning Environments

The quality of physical learning environments constitutes a foundational dimension of STEM education. Research on laboratory and classroom design consistently shows that spatial arrangements, equipment availability, and environmental affordances significantly influence students' opportunities to engage in authentic scientific inquiry (Borch & Svabo, 2025). Empirical studies reinforce this connection. Access to high-quality laboratory facilities enhances both teacher and student engagement (Recoco et al., 2025). Inadequate infrastructure, by contrast, acts as a persistent barrier in under-resourced settings, where outdated or insufficient laboratories constrain curriculum implementation and limit participation in science coursework (Hai et al., 2023; Wanyama, 2022). The resource gap is particularly pronounced in rural and geographically isolated settings, where inadequate infrastructure and limited access to STEM toolkits continue to constrain implementation across multiple national contexts (Gan et al., 2024). These findings collectively establish that physical infrastructure is not a peripheral concern but a structural determinant of what STEM education can realistically achieve in schools.

The availability and accessibility of educational materials and digital resources are closely related challenges. Haleem et al. (2022), in a review of digital technologies in education, document the rapid diversification of tools available for STEM instruction, from simulations to virtual laboratories, while emphasizing that their effective use requires parallel investment in teacher training and institutional infrastructure. Without this parallel investment, digital tools risk remaining underutilized or inaccessible, particularly in contexts where connectivity and device availability are uneven.

Budgetary constraints remain a persistent structural challenge shaping the adequacy and sustainability of STEM learning environments. Crawford et al. (2018) demonstrate that even well-established STEM programs can struggle to remain viable when external funding ends. This underscores the importance of stable institutional financing rather than reliance on competitive grants. At an institutional level, STEM education centers have been identified as important organizational mechanisms for sustaining STEM capacity, serving as hubs for curriculum reform, faculty development, and cross-departmental collaboration (Carlisle & Weaver, 2018). Looking further ahead, Motz et al. (2025) argue that coordinated data platforms and research-practice networks constitute an enabling condition for cumulative, equitable, and high-quality STEM education research. This frames research infrastructure not merely as a support mechanism but as a prerequisite for progress. Collectively, the findings suggest that improving STEM outcomes requires attention not only to what happens in classrooms but to the broader resource ecosystems that make quality instruction possible. Grounded in these observations, the present study examines four thematic areas of this enabling environment: STEM education frameworks, curriculum, and policy; teacher professional development and school leadership; student engagement and parental involvement; and resources, infrastructure, and learning environments. These areas are examined as perceived by primary school teachers in Türkiye, Portugal, Spain, and Italy. The aim is to determine whether these conditions vary across national contexts or reflect a more widely shared pattern.

METHODOLOGY

This study adopts an exploratory, descriptive survey design to examine primary school teachers' views on

STEM education across four national contexts (Cohen et al., 2018; Creswell, 2012). Descriptive survey designs are well-suited to studies of this kind, as they allow for the systematic collection of standardized data from a defined population, enabling the researcher to describe characteristics, attitudes, and perceptions without experimental manipulation (Fowler, 2009). The focus on teachers' views reflects the premise that understanding how practitioners perceive STEM education is a necessary precondition for any meaningful reform at the school level (Margot & Kettler, 2019). Rather than testing a predefined theoretical model, the study sought to capture the range and tendencies of teachers' views through a structured set of statements, and to explore how these tendencies are distributed across the four national contexts. A survey developed for this purpose served as the primary data collection instrument, and the resulting response patterns were examined descriptively within and across the four national contexts. This design is exploratory and descriptive in scope; reported differences between countries reflect observed variation in response distributions rather than statistically tested effects and should be read as indicative rather than confirmed patterns.

Procedure and Data Collection

During the development of the survey, three researchers, two academics with expertise in education and linguistics and one practitioner working in the education field, generated an initial pool of 54 statements based on the literature and their professional experience, aiming to capture primary school teachers' views on STEM education. The statements were reviewed in a series of collaborative sessions held by the research team, in which each one was examined for clarity, relevance, and coverage. Statements that overlapped substantially in meaning, failed to sufficiently address STEM education, or did not reach team consensus were removed through iterative discussion until the team reached agreement on a final set of 28 statements.

This process was consensus-based and exploratory in nature rather than psychometric. The instrument was not intended as a validated multidimensional scale, and no factor-analytic procedures were applied at this stage; accordingly, no factor loadings, internal consistency coefficients, or model-fit statistics are reported. Instead, the aim was to construct a broad, non-redundant pool of statements capable of capturing the range and tendencies of teachers' views on STEM education. Once the 28 statements were finalized, the research team grouped them into four thematic areas based on their shared conceptual focus: STEM education frameworks, curriculum, and policy (e.g., "*STEM education is mentioned in the curriculum as a component of literacy teaching*"), teacher professional development and school leadership (e.g., "*STEM education is taught theoretically in the teacher training program*"), student engagement and parental involvement (e.g., "*Students can make connections between science, technology, engineering, and mathematics*"), and resources, infrastructure, and learning environments (e.g., "*There is a laboratory at the school where STEM activities can be implemented*"). These thematic areas represent conceptually grounded groupings that arrived through expert consensus, rather than empirically derived factors. The 28 statements were combined with questions on participants' demographic characteristics to form the final survey. Participants indicated their level of agreement with each statement on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), and the average completion time was approximately seven minutes.

The survey was originally developed in English and subsequently translated into Turkish, Spanish, Portuguese, and Italian by the researchers from each participating country. A back-translation procedure was applied to verify linguistic and conceptual equivalence across the four language versions (Brislin, 1970).

This study was conducted as part of the "Integrated STEM education with an interactive digital library for curious kids" project, funded under the Erasmus+ KA220 program. In addition, the ethical approval was obtained before data collection from the Scientific Research and Publication Ethics Committee of Social and Humanities Sciences at Akdeniz University, Antalya, Türkiye (decision no: 392; date: September 5, 2023).

Participants

The sample was formed using a convenience sampling approach, which was preferred given the cross-national scope of the study and the practical constraints of reaching primary school teachers across four different countries. Participants were recruited from state (public) primary schools in each of the four participating countries. A total of 257 teachers participated in the study. As shown in **Table 1**, 108 participants were from Türkiye, 52 from Portugal, 50 from Spain, and 47 from Italy. No missing data were observed for the 28 STEM survey items; all participants completed these in full.

Regarding gender, the Türkiye sample included 81 female (75%) and 27 male (25%) participants; the Portugal sample included 41 female (78.8%) and 11 male (21.2%); the Spain sample included 26 female (54.2%) and 22 male (45.8%), with two participants not reporting gender; and the Italy sample included 41 female (87.2%) and 6 male (12.8%) participants. In terms of education level, most teachers in Türkiye held a bachelor's degree (75; 69.4%), followed by a master's degree with thesis (30; 27.8%) and a PhD (3; 2.8%); there were no cases in the non-thesis master's category. In Portugal, 27 teachers held a bachelor's degree (51.9%), 20 a master's degree with thesis (38.5%), three (3) a non-thesis master's degree

Table 1. Demographic information

Characteristics		Türkiye	Portugal	Spain	Italy
Gender: N (%)	Female	81 (75.0)	41 (78.8)	26 (54.2)	41(87.2)
	Male	27 (25.0)	11 (21.2)	22 (45.8)	6 (12.8)
Education level: N (%)	Bachelor's	75 (69.4)	27 (51.9)	21 (42.0)	19 (40.4)
	Master's (thesis)	30 (27.8)	20 (38.5)	7 (14.0)	23 (48.9)
	Master's (non-thesis)	-	3 (5.8)	19 (38.0)	-
	PhD	3 (2.8)	2 (3.8)	3 (6.0)	5 (10.6)
Age: Mean (years)		42.90	48.20	46.20	48.70
Experience in teaching service: Mean (years)		18.80	19.96	15.40	14.20

* Two participants from Spain did not report gender

(5.8%), and two (2) a PhD (3.8%). In Spain, 21 teachers held a bachelor's degree (42%), seven (7) a master's degree with thesis (14%), 19 a non-thesis master's (38%), and three (3) a PhD (6%). In Italy, 19 teachers held a bachelor's degree (40.4%), 23 a master's degree with thesis (48.9%), none held a non-thesis master's, and five (5) held a PhD (10.6%). The mean age of participants was 42.9 in Türkiye, 48.2 in Portugal, 46.2 in Spain, and 48.7 in Italy. The mean years of teaching service were 18.80 in Türkiye, 19.96 in Portugal, 15.4 in Spain, and 14.2 in Italy.

Two open-ended questions were included in the demographic section to capture a broader, more nuanced picture of the sample's professional backgrounds: one asking about participants' fields of education and the other about their teaching subjects. Across all four national samples, teacher education and primary school teaching emerged as the most consistently shared background, alongside mathematics, language-related fields, and general science, suggesting a common professional foundation among primary school teachers across these contexts despite their different national systems.

Beyond this shared core, each sample carried a distinct profile. The Türkiye sample was most prominently shaped by foreign language education, particularly English, alongside mathematics and primary classroom teaching, with a wider range of backgrounds including science fields, Turkish language and literature, early childhood education, special education, information technologies, and various vocational-technical disciplines. The Portugal sample was the most strongly teacher-education-oriented of the four, with primary and basic education backgrounds clearly dominant and relatively limited representation from technical or social science fields. The participants was brought in a broader range of disciplines, including psychology, environmental engineering, and natural sciences. The Spain sample was the most technically and vocationally diverse, with strong representation from mathematics, informatics, electrical and electrotechnical fields, and vocational programs, alongside more traditional school backgrounds, and also included participants in student support roles, such as guidance and special education. The Italy sample showed a different kind of diversity, being more heavily weighted toward the humanities, including language and literature, philosophy, and primary teacher education and pedagogy, with a notable presence of special education support teachers alongside more limited but still present representation from mathematics and natural sciences.

Taken together, while the four samples share foundational characteristics in terms of primary teaching and general subject backgrounds, they vary in their disciplinary emphases, and this diversity reflects the broad reach of STEM education across subject areas, suggesting that teachers from a wide range of disciplinary traditions are engaging with STEM in their professional contexts. Responses to these open-ended questions were analyzed using a simple content analysis approach: each national team member categorized the responses from their country, after which a cross-country consensus meeting was held among national team representatives to agree on shared category labels for the comparative summary presented in the results section.

RESULTS

In this study, the findings have been examined across the four thematic areas established during survey development:

(1) STEM education frameworks, curriculum, and policy,

(2) teacher professional development and school leadership,

(3) student engagement and parental involvement, and

(4) resources, infrastructure, and learning environments.

The results point to a complex picture in which shared cross-national patterns and descriptively notable country-level differences coexist. This suggests that while school teachers across Türkiye, Portugal, Spain, and Italy report broadly similar perceived conditions, their reported experiences of STEM education appear to be shaped by distinct national contexts in ways that are both consistent and, at times, divergent.

Table 2. Opinions on the (1) STEM education frameworks, curriculum, and policy

Opinions about STEM education	Country	Percentage (%)				
		1	2	3	4	5
STEM education is mentioned in the curriculum as a component of literacy teaching.	Türkiye	8.3	12.0	36.1	22.2	21.3
	Portugal	-	5.8	30.8	53.8	9.6
	Spain	4.0	6.0	24.0	48.0	18.0
	Italy	4.3	8.5	14.9	61.7	10.6
The curriculum has clear goals and tasks supporting STEM education activities.	Türkiye	5.6	12.9	32.4	28.7	20.4
	Portugal	-	9.6	34.6	51.9	3.9
	Spain	4.0	8.0	20.0	46.0	22.0
	Italy	4.3	12.8	29.9	44.7	8.4
Textbooks enable STEM education activities to be implemented easily.	Türkiye	8.4	20.4	44.4	14.8	12
	Portugal	-	21.2	38.5	38.5	1.8
	Spain	2.0	30.0	30.0	28.0	10.0
	Italy	2.1	27.7	31.9	34.0	4.3
Laws and regulations require the implementation of STEM education.	Türkiye	10.2	22.2	42.6	14.8	10.2
	Portugal	1.9	11.6	59.6	25.0	1.9
	Spain	2.0	20.0	32.0	34.0	12.0
	Italy	6.4	14.9	36.2	34.0	8.5
National exams require access to STEM education content for success.	Türkiye	7.4	10.2	35.2	23.1	24.1
	Portugal	1.9	5.8	28.8	48.1	15.4
	Spain	4.0	24.0	32.0	30.0	10.0
	Italy	4.3	6.4	38.3	48.9	2.1
Authorities adequately support STEM education activities.	Türkiye	11.1	17.6	40.7	18.5	12.1
	Portugal	-	11.6	59.6	28.8	-
	Spain	8.0	24.0	28.0	38.0	2.0
	Italy	10.6	40.4	23.4	23.4	2.1

Note. $N_{Türkiye} = 108$; $N_{Portugal} = 52$; $N_{Spain} = 50$; $N_{Italy} = 47$

As indicated in **Table 2**, regarding STEM education frameworks, curriculum, and policy, teachers across all four countries reported a consistently high level of agreement that STEM education is explicitly embedded in the curriculum. Both the items "STEM education is mentioned in the curriculum as a component of literacy teaching" and "The curriculum has clear goals and tasks supporting STEM education activities" received strong agreement in Türkiye, Portugal, Spain, and Italy, suggesting that STEM is formally recognized and articulated within national curricula. However, a more cautious pattern emerged regarding instructional materials. For the item "Textbooks enable STEM education activities to be implemented easily" responses across all countries clustered around the neutral category, suggesting a possible gap between curricular intentions and classroom implementation. This ambivalence may reflect limitations in physical resources or in teachers' capacity to translate textbook content into practice. Descriptive differences appeared more pronounced in policy-related items. For "National exams require access to STEM education content for success" Portugal (63.5%) and Italy (51%) had the highest agreement percentages. In comparison, Türkiye (47.2%) also showed a relatively positive profile, and Spain (40%) remained comparatively lower. Similarly, for "Laws and regulations require the implementation of STEM education" Spain (46%) and Italy (42.6%) had higher agreement percentages, while Portugal showed more neutral tendencies; Türkiye, however, presented a mildly negative profile on this item, with disagreement (32.4%) outweighing agreement (25.0%), suggesting a degree of skepticism about the regulatory embedding of STEM at the national level.

In contrast, perceptions of authority-level support were generally weak. Italy had the highest percentage of disagreement (51.1%) that authorities adequately support STEM activities. Portugal offered a different kind of ambiguity, with 59.6% of teachers selecting the neutral response, reflecting neither clear endorsement nor outright rejection, a profile that may point to uncertainty or limited direct experience of policy-level engagement rather than active dissatisfaction. This suggests that although STEM is embedded in curricula, it does not appear to be equally reinforced at the policy implementation level, and the nature of that gap differs across national contexts.

Teacher professional development and school leadership emerged as one of the areas showing the most descriptive variation across the four contexts (**Table 3**). Formal preparation appeared as a shared concern. In both Türkiye and Portugal, responses to statements on theoretical and practical STEM content in pre-service programs, as well as in-service training for classroom implementation, clustered heavily around the neutral midpoint. This does not necessarily indicate straightforward dissatisfaction; it may instead reflect a perceived absence of coherence in formal training, with

Table 3. Opinions on the (2) teacher professional development and school leadership

Opinions about STEM education	Country	Percentage (%)				
		1	2	3	4	5
School administrators support STEM education.	Türkiye	6.4	14.8	38.0	20.4	20.4
	Portugal	-	7.7	42.3	42.3	7.7
	Spain	2.0	14.0	26.0	44.0	14.0
	Italy	2.1	23.4	48.9	12.8	12.8
Administrators encourage teachers and students to design and implement STEM education projects.	Türkiye	5.6	18.5	40.7	25.0	10.2
	Portugal	-	7.7	48.1	36.5	7.7
	Spain	2.0	24.0	24.0	36.0	14.0
	Italy	2.1	14.9	36.2	38.3	8.5
STEM education is taught theoretically in the teacher training program.	Türkiye	8.3	16.7	43.5	20.4	11.1
	Portugal	-	25.0	46.2	25.0	3.8
	Spain	10.0	20.0	36.0	30.0	4.0
	Italy	4.3	17.0	21.4	48.9	6.4
STEM education is taught practically in the teacher training program.	Türkiye	9.3	14.8	47.2	19.4	9.3
	Portugal	-	21.2	46.2	28.8	3.8
	Spain	10.0	28.0	34.0	24.0	4.0
	Italy	12.8	23.4	25.5	31.9	6.4
In-service training programs prepare teachers to design and implement STEM activities.	Türkiye	8.3	13.9	41.7	22.2	13.9
	Portugal	-	23.1	46.2	23.1	-
	Spain	8.0	22.0	32.0	28.0	10.0
	Italy	8.5	27.7	21.3	38.3	4.3
Teachers I know design STEM education activities.	Türkiye	13.9	21.3	27.8	22.2	14.8
	Portugal	1.9	15.4	40.4	42.3	-
	Spain	6	14.0	32.0	40.0	8.0
	Italy	4.3	23.4	29.8	36.2	6.4
Teachers I know implement STEM education activities.	Türkiye	16.7	14.8	35.2	19.4	13.9
	Portugal	1.9	13.5	48.1	36.5	-
	Spain	6.0	16.0	32.0	38.0	8.0
	Italy	4.3	19.1	19.1	51.1	6.4
Teachers who design and implement activities, tasks, or projects for STEM education are rewarded.	Türkiye	16.7	22.2	29.6	13.9	17.6
	Portugal	2.0	32.7	36.5	28.8	-
	Spain	22.0	34.0	28.0	16.0	-
	Italy	19.1	34.0	23.4	17.0	6.4

Note. $N_{Türkiye} = 108$; $N_{Portugal} = 52$; $N_{Spain} = 50$; $N_{Italy} = 47$

teachers in these two settings appearing uncertain whether their preparation had equipped them to work with STEM in any consistent way. Spain and Italy presented a different picture. Agreement percentages for the statements "Teachers I know design STEM activities" and "Teachers I know implement STEM activities" were higher in Spain (48% and 46%) and Italy (42.6% and 57.4%), suggesting that peer-level STEM engagement is more visible in these contexts. Teacher motivation, by contrast, did not emerge as a primary constraint across any of the four settings. Respondents across all countries expressed broad agreement that some of their colleagues approach STEM teaching with genuine enthusiasm, with Portugal having the highest agreement percentage (63.4%). Administrative support, however, told a more divided story. Türkiye, Portugal, and Spain all returned broadly positive responses on whether school administrators support STEM education, while Italy's agreement percentage was lower, at 25.5% on the same statement. Spain had the highest agreement percentage (50%) that administrators actively encourage STEM project development, whereas the remaining three countries clustered around more neutral positions. The most consistent pattern in direction across all four contexts concerned the recognition of STEM-engaged teachers: respondents in every country more often disagreed than agreed that those who design and implement STEM activities receive institutional rewards for doing so. This pattern held regardless of national context and suggests a perceived gap in how STEM-engaged teachers feel their efforts are acknowledged at the institutional level.

Student engagement and parental involvement in STEM showed a broadly consistent pattern in direction across the dataset (**Table 4**). Teachers in all four countries broadly agreed that students are interested in STEM activities, capable of making interdisciplinary connections, and curious about STEM-related topics. Student readiness, overall, is perceived as a strength rather than a concern. Some descriptive variation did emerge around awareness, however. For the statement "Students are aware of the importance of STEM content," Italy had the highest agreement percentage

Table 4. Opinions on the (3) student engagement and parental involvement in STEM

Opinions about STEM education	Country	Percentage (%)				
		1	2	3	4	5
Some teachers are enthusiastic about teaching through STEM education.	Türkiye	6.5	10.2	25.9	34.3	23.1
	Portugal	-	2.0	34.6	61.5	1.9
	Spain	2.0	8.0	28.0	46.0	16.0
	Italy	2.1	8.5	29.8	40.4	19.1
Students are interested in STEM activities.	Türkiye	3.7	11.1	20.4	29.6	35.2
	Portugal	-	3.8	25.0	55.8	15.4
	Spain	-	2.0	30.0	46.0	22.0
	Italy	2.1	10.6	8.5	36.2	42.6
Students can make connections between science, technology, engineering, and mathematics.	Türkiye	1.7	13.0	20.4	26.9	38
	Portugal	-	19.2	30.8	46.2	3.8
	Spain	2.0	-	28.0	48.0	22.0
	Italy	2.1	14.9	27.7	40.4	14.9
Students are very interested in STEM education topics.	Türkiye	3.7	6.4	27.8	30.6	31.5
	Portugal	-	11.5	30.8	48.1	9.6
	Spain	-	14.0	32.0	46.0	8.0
	Italy	2.1	8.5	12.8	48.9	27.7
Students are aware of the importance of the content of STEM education.	Türkiye	9.3	20.3	27.8	25.0	17.6
	Portugal	-	17.3	50.0	30.8	1.9
	Spain	6.0	18.0	44.0	28.0	4.0
	Italy	4.3	17.0	23.4	51.1	4.2
Teachers can easily obtain the materials they will use in STEM education activities.	Türkiye	24.1	31.5	22.2	15.7	6.5
	Portugal	3.8	32.7	40.4	21.2	1.9
	Spain	12.0	32.0	34.0	18.0	4.0
	Italy	17.0	40.4	19.1	23.4	-
Parents support students' participation in STEM education.	Türkiye	8.3	21.3	39.8	20.4	10.2
	Portugal	-	9.6	55.8	34.6	-
	Spain	2.0	14.0	46.0	32.0	6.0
	Italy	8.5	12.8	25.5	48.9	4.3
Media informs students about STEM education.	Türkiye	16.7	31.5	29.6	13.9	8.3
	Portugal	5.8	32.7	50.0	11.5	-
	Spain	10.0	32.0	36.0	22.0	-
	Italy	6.4	21.3	25.5	44.7	2.1
Parents can easily cover the fees required for their students' STEM education.	Türkiye	28.7	33.3	18.5	11.1	8.3
	Portugal	11.5	40.4	40.4	7.7	-
	Spain	8.0	40.0	34.0	16.0	2.0
	Italy	14.9	42.6	27.7	14.9	-

Note. $N_{Türkiye} = 108$; $N_{Portugal} = 52$; $N_{Spain} = 50$; $N_{Italy} = 47$

(55.3%), followed by Türkiye (42.6%). Portugal (32.7%) and Spain (32%) returned comparatively lower rates, with neutral responses predominating in both contexts. Parental involvement told a more mixed story. Italy again showed the numerically highest agreement rate for parental support of students' STEM participation at 53.2%, while agreement levels were comparatively lower in Spain (38%), Portugal (34.6%), and Türkiye (30.6%), with neutral responses predominating across all three contexts. The picture shifted somewhat when external information channels came into view. Italian teachers had a higher agreement percentage (46.8%) that the media informs students about STEM education, whereas in Türkiye, disagreement on the same statement was higher (48.2%). Despite these cross-national differences, one finding held consistently across all four contexts: in every country, more teachers disagreed than agreed that parents can easily cover the costs of STEM education, suggesting that financial accessibility is a shared and persistent perceived barrier across national contexts.

Finally, in relation to resources, infrastructure, and learning environments, the most descriptively pronounced cross-country differences emerged (**Table 5**). Türkiye presented a highly negative profile regarding school laboratories, with 63.9% disagreement for the statement "There is a laboratory at the school where STEM activities can be implemented." In contrast, Italy had the highest agreement percentage (61.7%), suggesting that teachers there perceived more favorable infrastructure conditions. A similar pattern was observed for financial resources, with Türkiye reporting a high level of disagreement (60.2%) regarding the availability of school budgets for STEM activities, reinforcing the perception of resource constraints. At the same time, several shared limitations were evident across all countries. The statement on material

Table 5. Opinions on the (4) resources, infrastructure, and learning environments

Opinions about STEM education	Country	Percentage (%)				
		1	2	3	4	5
There is a laboratory at the school where STEM activities can be implemented.	Türkiye	38.9	25.0	17.6	8.3	10.2
	Portugal	7.7	25.0	26.9	32.7	7.7
	Spain	8.0	30.0	14.0	28.0	20.0
	Italy	8.5	14.9	14.9	46.8	14.9
The physical design of the classroom enables STEM education activities.	Türkiye	32.4	25.0	25.0	9.3	8.3
	Portugal	1.9	25.0	30.8	38.5	3.8
	Spain	12.0	30.0	22.0	18.0	18.0
	Italy	10.6	36.2	19.1	29.8	4.3
The school has a budget to support STEM education activities.	Türkiye	36.1	24.1	19.4	11.1	9.3
	Portugal	5.7	23.1	50.0	21.2	-
	Spain	20.0	30.0	30.0	16.0	4.0
	Italy	10.6	21.3	34.0	27.7	6.4
The environment close to the school (yard, garden, etc.) contains natural space for STEM education activities.	Türkiye	19.4	15.7	29.6	20.4	14.8
	Portugal	1.9	21.2	23.1	48.1	5.8
	Spain	10.0	32.0	18.0	34.0	6.0
	Italy	19.1	34.0	23.4	19.1	4.3
There are ponds, rivers or geological formations near the school where students can observe for STEM education activities.	Türkiye	27.8	16.7	26.8	18.5	10.2
	Portugal	3.8	17.3	23.1	40.4	15.4
	Spain	22.0	30.0	22.0	22.0	4.0
	Italy	38.3	36.2	10.6	12.8	2.1

Note. $N_{Türkiye} = 108$; $N_{Portugal} = 52$; $N_{Spain} = 50$; $N_{Italy} = 47$

accessibility (teachers' ability to obtain materials easily) received relatively low levels of agreement in all contexts, while statements related to natural learning environments (e.g., availability of outdoor spaces such as gardens, rivers, or geological formations) received relatively low levels of agreement in most contexts, with Portugal as the main exception. This suggests that material constraints represent a commonly perceived challenge, and environmental constraints were also perceived in most contexts, regardless of national differences in overall reported infrastructure conditions.

DISCUSSION

Across four nationally distinct contexts, this study identifies both a shared structural pattern and a set of nationally specific divergences. Motivational and curricular readiness is consistently present, while teachers' perceptions of the institutional capacity to translate it into sustained STEM practice are consistently less positive, and the nature of this gap differs across countries. This structural observation is consistent with what reform scholarship has long identified. Fullan (2007) describes the gap between the meaning that individuals assign to change and the organizational capacity required to sustain it as one of the central challenges of educational reform. Spillane (2004) extends this by demonstrating that even when policy intentions are clearly articulated, their enactment becomes progressively distorted as they travel through administrative layers towards the classroom. STEM education is particularly susceptible to this dynamic, given the multiple and intersecting demands it places simultaneously on pedagogical preparation, resource provision, and institutional coordination. This pattern has been documented in single-country contexts: teachers value STEM integration yet consistently report barriers rooted not in a lack of motivation but in inadequate structural support (Margot & Kettler, 2019; Wan et al., 2023). The present study extends this evidence by indicating that a similar pattern holds across four distinct national systems. STEM education research has remained predominantly single-country in orientation (Li et al., 2020), and comparative work across national contexts has been identified as essential for understanding the structural conditions that shape implementation (Kayan-Fadlelmula et al., 2022). The patterns identified here suggest that the implementation gap, as perceived by teachers, is not confined to a single national context. It appears to be a broader, cross-nationally shared condition.

Formal curricular recognition of STEM is a shared feature of all four national systems in this study. Recognition alone, however, does not guarantee integrated implementation, and the conditions that shape what happens between policy and practice appear to differ across contexts. This distinction matters because genuine STEM integration demands more than a place in the curriculum: it requires carefully designed frameworks, teacher readiness, and school-level support that formal policy documents cannot provide on their own (Falloon et al., 2020; Wan et al., 2023). The national findings examined here bring this gap into focus. Portugal had the highest agreement percentage that national examinations require access to STEM content, while Spain had the lowest across the four countries. This contrast may point to a broader variation in how

examination systems shape curriculum alignment, and as Kelley and Knowles (2016) caution, examination pressures can also constrain the pedagogical openness that meaningful STEM integration requires. Italy's profile on authority-level support was notably more negative than the other contexts in the dataset, with a higher percentage of teachers there expressing disagreement than their counterparts in Türkiye, Portugal, and Spain, who tended towards neutral positions. Wieselmann et al. (2021) demonstrate that administrator engagement is a critical enabler of STEM implementation at the school level, and its absence can leave teacher-driven practice without the institutional foundation it needs to become sustainable. Italy's profile reflects this pattern closely. Across all four contexts, the data suggest that formal recognition is a starting point rather than an end in itself. What determines whether that recognition translates into practice is a set of institutional and structural conditions that appear to vary across national systems.

In all four national contexts, teacher enthusiasm for STEM is reported as a genuine strength while the professional preparation needed to build on it is reported less positively. In Türkiye, Portugal, and Spain, neutral profiles were observed for initial and in-service training, while in Italy, more positive reports on theoretical preparation coincided with higher agreement percentages on peer-level classroom implementation, but this co-occurrence requires careful interpretation. The neutral profiles observed in three of the four countries align with a well-established finding: teachers who value STEM integration continue to report barriers rooted not in a lack of willingness but in inadequate preparation and structural support (Margot & Kettler, 2019). Effective professional development requires sustained engagement and coherence with broader reform efforts rather than one-off training events, and the neutral profiles observed here suggest these conditions are not consistently in place (Darling-Hammond et al., 2017). Italy's case is different and instructive. More positive reports on theoretical preparation in initial training, combined with the highest agreement percentages on peer-level STEM implementation in the dataset, suggest that when pre-service education more deliberately foregrounds integrated STEM competencies, teachers may be better positioned to carry that foundation into daily practice. The TPACK framework identifies precisely these competencies as central to effective STEM teaching across K-12 contexts (Huang et al., 2022). This reading requires qualification, however. School context and personal factors shape teachers' attitudes and practices in ways that initial preparation alone cannot fully determine (Thibaut et al., 2018), and gains in pedagogical confidence depend on continued access to mastery experiences, collaborative structures, and institutional reinforcement (Bandura, 1997; Zhou et al., 2023). Across all four contexts, teacher enthusiasm is reported as a genuine and shared asset. What appears consistently limited is the professional infrastructure needed to develop and sustain it.

Of all the thematic areas examined in this study, school leadership was among the areas with the largest descriptive differences between countries. Spain had the highest agreement percentage on administrative support for STEM, Türkiye and Portugal occupied intermediate positions, and Italy had the lowest. That Italy simultaneously had the highest agreement percentages on peer-level classroom implementation makes this one of the most theoretically noteworthy findings, as STEM practice there appears to be teacher-driven rather than institutionally supported. Spain's profile is consistent with what the literature identifies as enabling conditions for STEM implementation: effective STEM leadership extends beyond administrative management to encompass mission-building, the cultivation of shared professional vision, and the creation of institutional cultures in which STEM practice is actively valued (Natarajan et al., 2021; Rose et al., 2019). The intermediate positions of Türkiye and Portugal point to a different but equally important concern. Effective school leadership in STEM requires more than the absence of resistance; it demands structural conditions, including flexible scheduling and protected time for interdisciplinary planning, that actively enable teachers to work across disciplinary boundaries (Giamellaro et al., 2025; Lesseig et al., 2019). Italy's case is the most complex. The coexistence of the lowest agreement percentage on administrative support with the highest agreement percentages on peer-level classroom implementation points to a fundamental tension. Van Dat et al. (2023) argue that school leaders must actively shape the pedagogical infrastructure of their institutions, and that where this does not occur, individual teacher initiative is left to carry a burden that institutional structures are better positioned to shoulder. Italy's data reflect this condition closely: classroom STEM practice appears to be sustained by individual commitment in the absence of the institutional backing needed to make it durable.

The material conditions for STEM education proved to be one of the most varied areas within the four national contexts. No single country presented a uniformly strong or weak resource profile, and the patterns that emerged point to the multidimensional, context-specific nature of infrastructure as a condition for STEM practice. Across all four countries, teachers' ability to obtain the materials needed for STEM activities was rated poorly, pointing to a shared baseline constraint that cuts across national differences. Beyond this common floor, however, the profiles diverged in ways that were not always predictable. Laboratory access showed the largest descriptive contrast between countries: Türkiye had the lowest agreement percentage

on laboratory provision in the dataset, while Italy had the highest. School budgeting followed a similar pattern, with Türkiye again having the highest percentage of disagreement and Spain also showing a high percentage of disagreement as well. The outdoor and natural learning environment item, however, produced a contrasting pattern. Italy, which had the highest agreement percentage on laboratory access, had the highest percentage of disagreement on outdoor learning environments, while Portugal, whose overall resource profile was otherwise constrained, had the highest agreement percentage on this item. Giamellaro et al. (2025) demonstrate that the affordances and constraints teachers encounter at the structural level shape what is practically possible in STEM classrooms, regardless of individual motivation. Margot and Kettler (2019) identify resource deficits as among the most persistent structural barriers to STEM implementation in K-12 contexts, and the present data indicate that this constraint appears across all four national systems, even as its particular form varies from one context to the next.

Student interest in STEM emerged as a consistent strength across all four national contexts, but the conditions that shape and support that interest are considerably more uneven. Parental engagement and media portrayal produced nationally distinct profiles, while financial accessibility was reported as a shared constraint across all national settings. Teachers across all four countries widely agreed that students are interested in STEM activities, capable of making connections across disciplines, and broadly curious about STEM topics. That this picture is so consistent is itself notable: whatever perceived structural shortfalls exist at the institutional level, students appear genuinely ready to engage. The national picture shifts, however, when attention turns to the conditions surrounding that readiness. Italy had the highest agreement percentage on parental support for student participation in STEM, while the three remaining countries registered lower percentages. Media portrayal produced the largest descriptive divergence in this section. Italy was the only national context in which teachers held a positive view of how media shapes student awareness of STEM, while Türkiye, Spain, and Portugal returned profiles in which disagreement exceeded agreement. Financial accessibility was the one area in which responses pointed in the same direction in all four countries. Teachers in all four countries widely disagreed that parents could easily bear the costs associated with STEM participation, a finding notable for its consistency in direction across otherwise quite different national systems. Bayanova et al. (2023) confirm that student motivation is among the most consistently documented assets in STEM education, and the data here reinforce that picture. Harackiewicz et al. (2012) demonstrate that parental engagement with the value of STEM is a meaningful predictor of student motivation, suggesting that when parental support is weaker, the motivational foundation students bring to STEM rests on a less stable base.

Where other thematic areas showed at least some degree of national variation, reward mechanisms did not. In all four countries, more teachers disagreed than agreed that those who design and implement STEM activities are rewarded for doing so. Although the proportion who disagreed varied, from 34.7% in Portugal to 56% in Spain, the direction of responses was the same in all four countries. The similarity in direction is telling it may point to a condition reported across different governance arrangements, resource levels, and institutional cultures. STEM teaching appears to be everywhere expected, and, according to teachers, seldom rewarded. Keeping this in mind, the finding sits in productive tension with the sustained teacher enthusiasm and student readiness documented consistently across all four contexts. Teachers genuinely invest in STEM practice; the institutions they work within are reported by teachers to offer little formal recognition of that investment. Holincheck and Galanti (2025) demonstrate that recognition is a constitutive dimension of STEM teacher identity and that its absence gradually erodes the professional self-concept required to sustain long-term engagement with integrated STEM practice. Hence, a teacher asked to maintain this commitment without institutional validation may carry a burden that recognition systems are specifically designed to reduce. Thompson-Lee et al. (2025) confirm that recognition and incentive structures are among the key determinants of whether teachers remain engaged in STEM teaching over time. It can be argued, therefore, that enthusiasm alone may not be a sustainable basis for STEM practice. Without institutional acknowledgement that transforms individual commitment into professionally valued work, the motivational foundation documented across all four contexts may remain precarious.

Limitations and Strengths of the Study

A primary methodological limitation concerns the study's reliance on teacher perceptions captured through a self-report survey. This design reflects how practitioners interpret their professional environments and cannot be taken as a direct measure of structural conditions in schools. Convenience sampling, necessitated by the cross-national scope of the study and the logistical constraints of reaching primary school teachers across four different countries, further limits the generalizability of the findings. The cross-sectional design does not permit causal claims about the relationships between the conditions identified and STEM outcomes, and the sample, drawn within a European partnership project, may not fully represent the broader teacher population in each country. The statement pool used in this study was developed

through expert consensus rather than a formal psychometric validation process; no pilot testing was conducted prior to data collection, and the criteria used for expert selection were not systematically documented. As such, the instrument should be understood as a structured set of statements designed to capture teachers' tendencies and views, rather than a validated multidimensional scale, and the findings should be interpreted accordingly. Relatedly, while a back-translation procedure was used to support linguistic and conceptual equivalence across the four language versions of the survey, formal measurement invariance was not tested; the extent to which teachers across the four countries interpreted the statements in an equivalent manner therefore cannot be fully verified. Consistent with the exploratory and descriptive aims of the study, the analyses reported here are based on response frequencies and percentages rather than inferential statistical testing; reported differences between countries should therefore be read as observed patterns rather than statistically confirmed effects. Future research employing validated instruments and inferential or multivariate techniques (e.g., ANOVA, regression, or structural modelling) would be valuable in testing the robustness of the patterns identified here.

These limitations, however, are partially offset by several notable strengths. The comparative framework spanning four nationally distinct educational systems is the study's most distinctive contribution: it enables identification of patterns that would remain invisible within any single national context. Examining four thematic areas simultaneously, from curricular policy to reward mechanisms, allows for a richer and more layered account of teachers' perceptions of the conditions shaping STEM implementation than studies focused on a single area typically permit. The multi-national research team, with researchers embedded in each participating country, strengthens the credibility of the data collection process, and the back-translation procedure applied to the survey supports linguistic and conceptual equivalence across the four language versions. Where these conditions hold together, comparative survey research becomes a productive tool for revealing shared patterns in teachers' perceptions that national systems, working in isolation, may neither see nor address.

CONCLUSION

This study set out to examine whether the challenges facing STEM education at the primary school level, as perceived by teachers, reflect local circumstances or a more broadly shared condition. The evidence, drawn from four nationally distinct educational systems and across four thematic areas, points consistently in one direction: teachers' reports of motivational and curricular readiness for STEM engagement are broadly positive, while their reports of the institutional, material, and incentive structures needed to sustain that engagement are consistently less positive. This pattern does not emerge in a single country or two. It appears across all four, despite their different governance arrangements, resource environments, and cultural contexts. The implementation gap, as perceived by teachers in this study, does not appear to be confined to a single national context awaiting a local solution; it appears instead to be a more broadly shared condition that may call for coordinated, structural responses.

What makes this finding particularly noteworthy is its cross-national consistency. The shared perceived shortfalls in reward mechanisms, resource provision, and institutional support are not artefacts of any single national system; they appear as shared features of teachers' experiences across the STEM education environments examined here. At the same time, the nationally specific profiles documented in the preceding analysis each illuminate how this shared pattern takes different forms in different settings, shaped by distinct governance arrangements, leadership cultures, and resource environments. Hence, the findings do not simply confirm what is known from single-country research. They extend it by suggesting that this pattern may be broad in reach, while remaining locally varied in form.

The findings carry potential implications for policy, teacher education, and institutional practice. Most immediately, teachers' consistent reports of limited reward mechanisms for STEM teaching point to a gap that educational systems in all four countries may wish to address. Recognizing STEM-engaged teachers, whether through formal evaluation criteria, professional development pathways, or institutional acknowledgement, appears to be far from a peripheral concern. It may be an important precondition for sustaining the individual commitment that, according to teachers in this study, drives STEM practice in the absence of stronger institutional support.

At the level of teacher education, the findings suggest the potential value of pre-service programs that foreground integrated STEM competencies as a core professional commitment rather than a specialized addition. At the policy level, moving beyond curricular recognition toward the provision of material, institutional, and incentive structures may be an important step toward more sustained implementation. Teacher enthusiasm, as this study documents, is already reported as present. What appears to be needed now is a stronger institutional commitment to meet it.

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investigation, writing – original draft. All authors agreed with the results and conclusions.

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Ethical statement: This study was approved by the Scientific Research and Publication Ethics Committee of Social and Humanities Sciences at Akdeniz University, Antalya, Türkiye, on 5 September 2023 (approval number 392). This approval covered data collection in all four participating countries (Türkiye, Portugal, Spain, and Italy), and no separate ethics approval was required by the partner institutions. Participation was voluntary. Participants were informed about the aims of the study, the voluntary nature of participation, and their right to withdraw at any time. The survey was anonymous: no names, contact details, or other directly identifying information were collected. Responses were stored on password-protected systems accessible only to the research team, and are reported only in aggregate form, in line with the general data protection regulation and the Turkish personal data protection law.

AI statement: During the preparation of this work, the authors used Claude with 2026 version to improve the language and punctuation of the manuscript, to check the consistency and formatting of the reference list, and to revise the text for clarity and style. The tool was not used to generate the study design, data, analysis, or findings. After using the tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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