EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2026, 11(1), 11
eISSN: 2468-4368

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Research paper

Beyond Teacher Perceptions: Classroom Evidence of STEM Integration in Saudi Mathematics Education

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Citation: Ben-Motreb, K. S. (2026). Beyond teacher perceptions: Classroom evidence of STEM integration in Saudi mathematics education. *European Journal of STEM Education, 11*(1), 11. https://doi.org/10.20897/ejsteme/18040

Published: March 5, 2026

ABSTRACT

STEM education has become central to fostering the problem-solving and innovation capacities required in knowledge-based societies, prompting global reforms that seek to connect science, technology, engineering, and mathematics through authentic classroom learning. In Saudi Arabia, national initiatives, notably Vision 2030, reflect this momentum toward innovation and interdisciplinary integration. Yet how these ambitions translate into day-to-day mathematics instruction remains insufficiently understood. This qualitative-dominant mixed-methods study investigated how middle-school mathematics teachers in Al-Ahsa incorporate STEM principles into their teaching and the challenges they encounter. Twenty-five teachers were observed across fifty lessons using an observation checklist derived from the STEM integration in K–12 Education framework, and fifteen teachers participated in semi-structured interviews. Descriptive statistics captured patterns of practice, while thematic analysis provided deeper interpretive insight. Findings revealed modest levels of STEM integration: interdisciplinary links emerged occasionally, whereas inquiry-based and project-based learning appeared only sporadically. Four interrelated constraints were identified: limited professional preparation, insufficient technological resources, curriculum rigidity, and resistance to pedagogical change. Together, these factors help explain why STEM implementation in the observed context appears more aspirational than routine. The study highlights the need for context-sensitive professional-development models, reliable technological support, and greater curricular flexibility to make integrated STEM pedagogy a sustainable component of mathematics education.

Keywords: STEM integration, mathematics education, teacher professional development, curriculum reform, educational technology, Saudi Arabia.

In today's rapidly evolving world, marked by technological acceleration and shifting labor market demands, education systems are under increasing pressure to equip students for participation in a knowledge-based economy. Mathematics, including at the middle school level, plays a central role in advancing this mission. Mathematics develops logical reasoning, quantitative literacy, and transferable problem-solving skills that extend across science and engineering domains. At the same time, STEM education (science, technology, engineering, and mathematics) has gained global recognition as an approach to connecting disciplinary knowledge through authentic, real-world problem solving. Honey et al. (2014) emphasize the potential of integrated STEM to promote deeper learning through meaningful cross-disciplinary tasks, while Kelley & Knowles (2016) conceptualize integrated STEM education as a framework that supports interdisciplinary coherence and authentic learning experiences.

In Saudi Arabia, Vision 2030 shows considerable convergence with STEM education priorities, particularly in its focus on innovation, applied skills, and preparing students for a diversified economy (Kingdom of Saudi Arabia, 2016). Within this agenda, mathematics is envisioned as a gateway subject through which interdisciplinary, project-based, and technology-supported approaches can be realized. Even so, the reality inside many classrooms tells a different story. Teaching remains largely traditional and exam-oriented. Earlier research documented this persistent disconnect between policy aspirations and classroom realities, showing that inquiry-based and project-based pedagogies are seldom practiced (Al-Dosari, 2016; Madani, 2020). The middle school stage is especially pivotal for STEM integration. At this stage, instruction often shifts toward more abstract algebraic reasoning, extending earlier arithmetic foundations and offering potential links to scientific and engineering applications. Innovation in pedagogy at this level is therefore essential, it shapes students' attitudes toward mathematics and builds the transferable competencies required for sustained engagement with STEM fields. However, much of the existing local research in Saudi Arabia has relied primarily on survey-based accounts of teacher perceptions, providing limited insight into classroom-level instructional practices (Madani, 2020; Aldahmash et al., 2019; Al-Najjar & Hammad, 2024; Azhar & Rashid, 2024). This limitation underscores the need for empirical research that captures classroom realities rather than self-reported beliefs. Against this backdrop, the present study examines middle school mathematics teaching in Al-Ahsa, a major educational district in the eastern region of Saudi Arabia, to address two intertwined questions: to what extent are STEM practices genuinely embedded in everyday instruction, and what systemic barriers hinder their adoption? The contribution of this study lies in its dual methodological focus, classroom observation combined with teacher interviews, which together offer a comprehensive view of both the challenges and the opportunities shaping STEM integration in Saudi schools. Globally, STEM education has been widely promoted as a framework for interdisciplinary integration and authentic problem-solving in response to complex societal and workforce demands (Honey et al., 2014). Scholars consistently identify four foundational pillars of effective STEM practice: interdisciplinary integration, technology integration, inquiry-based learning (IBL), and project-based learning (PBL) (Honey et al. 2014; Kelley & Knowles, 2016). Yet, the adoption of these pillars varies across contexts, influenced by cultural expectations, curricular rigidity, and the availability of instructional resources. To examine these dimensions more closely, the following section reviews existing literature on the four key pillars of STEM integration as reflected in mathematics education: interdisciplinary integration, technology use, IBL, and PBL.

Interdisciplinary integration

Interdisciplinary integration is often described as a defining feature of STEM education, as it encourages learners to approach authentic, real-world problems from multiple disciplinary perspectives (Sanders, 2009; English, 2017). When mathematics is purposefully connected with science or engineering, students develop not only stronger conceptual understanding but also transferable problem-solving abilities (Thibaut et al., 2018). In the Saudi context, however, such integration remains limited. Madani (2020) observed that although national curricula include references to cross-disciplinary activities, classroom practice rarely moves beyond surface-level links. More recent reviews confirm that, despite the momentum created by Vision 2030, teachers' capacity to implement interdisciplinary strategies is still emerging (Azhar & Rashid, 2024). In a broader regional perspective, Al-Najjar & Hammad (2024) reported that many mathematics teachers express genuine enthusiasm for STEM integration yet struggle to translate that enthusiasm into sustained instructional practice, an insight that highlights the tendency of local reform efforts to stall at the implementation stage.

Technology use

Technology stands at the center of contemporary STEM pedagogy. It enables visualization, dynamic modeling, and real-time exploration of mathematical concepts (Kim et al., 2021). International evidence shows that tools such as GeoGebra or virtual laboratories can heighten engagement and deepen learning (Li et al., 2020). Yet Saudi classrooms still depend primarily on basic presentation software. Al-Kahtani (2017) emphasized that inadequate infrastructure and sporadic professional development restrict teachers' ability to harness digital resources. Likewise, Halawa (2024) noted that even when devices are available, their educational potential often remains untapped without institutional backing. These findings resonate with global calls to view technology not as an add-on but as an enabler of conceptual inquiry, one that transforms how students visualize and test mathematical relationships.

Inquiry-based learning (IBL)

IBL positions students as questioners, hypothesis makers, and evidence-based reasoners (Bybee, 2013; Lazonder & Harmsen, 2016). In supportive systems, IBL fosters deep conceptual understanding and long-term retention. In contrast, in exam-driven environments its adoption can be severely constrained. Saudi teachers often endorse IBL in principle yet seldom practice it because of rigid curricular pacing (Madani, 2020). Similar tensions have been documented in China and Turkey, where high-stakes testing shapes instructional culture (Lyu et al., 2022; Kirici & Bakırci, 2021). Recently, Wan et al. (2023) argued that unless systemic structures shift, IBL will remain difficult to scale. The implication is clear: reform efforts must go beyond advocating inquiry to redesigning institutional contexts that make inquiry feasible.

Project-based learning (PBL)

PBL situates mathematics in authentic contexts that demand collaboration, creativity, and applied reasoning (Kelley & Knowles, 2016). International studies demonstrate its impact: students taught through projects become more motivated and innovative (Capraro et al., 2013; Lee, 2025) while cultivating adaptability and resilience, qualities vital in post-pandemic education (Martín-Páez et al. 2022). Experimental and quasi-experimental findings further show that STEM-oriented instruction enhances mathematics achievement and engagement (Eshaq, 2024). Even so, Saudi classrooms rarely implement PBL. Madani (2020) found that exam preparation consumes most instructional time, leaving minimal space for extended projects. Similarly, AlAli et al. (2024) reported that gifted-education programs exhibit only modest alignment with project-based STEM methods. Collectively, these patterns across the four pillars suggest that, while teachers recognize the value of STEM-oriented pedagogy, classroom implementation remains inconsistent and fragmented.

Critical gaps in the literature

Taken together, existing studies affirm the promise of interdisciplinary integration, technology use, IBL, and PBL. Yet the Saudi evidence reveals three enduring gaps. First, much of the existing research relies on self-reported data rather than systematic classroom observation (Azhar & Rashid, 2024; Aldahmash et al., 2019; Al-Najjar & Hammad, 2024). Second, little is known about how these four pillars interact in the texture of daily teaching. Third, sustainable models for scaling STEM integration across public schools remain elusive (Saad et al., 2025). Addressing these gaps requires research that captures classroom realities, foregrounds teacher voices, and situates findings within both local and global discourse. Nicol (2023) reminds us that mathematics for STEM must be understood "as place", inseparable from the cultural and institutional contexts in which it occurs. Framing the issue this way transforms local evidence into part of a wider conversation about how global reform ideals adapt to national realities. In response to these gaps, the present study provides observation- and interview-based evidence from middle-school mathematics classrooms in Al-Ahsa, Saudi Arabia. By grounding the analysis in classroom practice, the study connects local instructional realities with the broader international dialogue on STEM education reform.

From a theoretical perspective, the uneven and generally modest implementation of the four STEM pillars observed in this study can be interpreted through complementary sociocultural and systemic lenses. In particular, the relative presence of brief interdisciplinary links, contrasted with the limited evidence of sustained inquiry-based learning (IBL) and project-based learning (PBL), invites closer reflection on the classroom conditions under which mathematical knowledge is constructed and enacted in practice.

From a sociocultural standpoint, this unevenness can be understood in light of how knowledge develops within classroom communities. Inquiry-based and project-based approaches depend on dialogue, collaboration, and the shared negotiation of meaning among students. In such settings, learning is not simply the transmission of correct procedures but a socially mediated process shaped by interaction and context. When classroom culture prioritizes efficiency, syllabus coverage, and preparation for standardized examinations, opportunities for sustained dialogue and exploratory reasoning naturally become limited. Teachers may still introduce contextual examples or brief interdisciplinary references, yet extended inquiry or collaborative problem-solving becomes more difficult to sustain within tight pacing structures. The relatively low levels of IBL and PBL observed in this study can therefore be interpreted not simply as individual instructional preferences, but as situated responses to classroom norms and expectations that influence how mathematical understanding is developed. This interpretation aligns with socio-constructivist models of integrated STEM, which emphasize collaborative knowledge construction and shared problem-solving as central to deeper forms of integration (Kelley & Knowles, 2016; Toma et al., 2024).

At the same time, a systemic lens helps explain why STEM integration may remain aspirational rather than routine despite clear policy endorsement. National reform agendas, including Vision 2030, emphasize innovation, applied skills, and interdisciplinary thinking. However, when curriculum pacing requirements, assessment structures, and professional development opportunities are not fully aligned with these goals, teachers operate within competing demands. Accountability pressures linked to standardized assessment can encourage instructional predictability and time-efficient delivery, while limited subject-specific STEM preparation may reduce confidence in implementing inquiry-based or extended project work. In this sense, the findings of the present study may be understood as reflecting limited systemic alignment rather than resistance to reform. Together, sociocultural and systemic perspectives provide a balanced framework for understanding why general awareness of STEM principles does not automatically translate into sustained, deep classroom integration.

Drawing on the preceding review of literature and contextual considerations, the present study seeks to provide systematic evidence addressing the following research questions.

Research questions

1. To what extent do middle-school mathematics teachers integrate STEM practices into their instructional activities?
2. Which types of STEM practices are most and least commonly implemented in mathematics classrooms?
3. What challenges do mathematics teachers face when attempting to apply STEM practices in public middle schools?

METHODOLOGY

Research design

This study adopted a qualitative-descriptive design to examine how middle-school mathematics teachers in Saudi Arabia integrate STEM practices into their instruction. Although the study was grounded primarily in qualitative inquiry, classroom observations were summarized numerically to enable structured comparison across teachers and STEM dimensions; thus, the design can be characterized as qualitative-dominant mixed methods with an embedded quantitative component. The conversion of observational evidence into five-point Likert ratings served solely to support systematic cross-case comparison rather than statistical inference.

The design was anchored in the STEM Integration in K–12 Education framework developed by Honey et al. (2014), which specifies four core dimensions: interdisciplinary integration, technology use, inquiry-based learning (IBL), and project-based learning (PBL). This qualitative orientation was intentionally selected to capture instructional behavior in its natural context and to move beyond self-reported perceptions toward observable evidence of practice.

Sample and data collection

The study was conducted in public middle schools across Al-Ahsa, a major educational district in the eastern region of Saudi Arabia. The schools represented both urban and semi-urban settings. A purposive sampling strategy was applied to ensure that participants:

1. Were actively teaching mathematics at the middle school level,
2. Had between five and ten years of teaching experience, and
3. Agreed to participate in both observation and interview phases.

The final sample included 25 teachers. Each teacher was observed during two separate instructional sessions, with two independent observers conducting the visits. The first observer was the author of the study, while the second observer was a doctoral-level specialist in mathematics education. Their ratings were averaged to produce a composite score for each teacher. Complement these observations, 15 teachers also participated in semi-structured interviews, which provided richer insights into their instructional choices and the challenges they encountered. Prior to data collection, both observers completed a joint calibration session in which they practiced applying the observation checklist to sample video lessons. This process ensured a shared understanding of behavioral indicators and minimized interpretive drift during field observations.

Instruments and procedure

Two instruments guided data collection:

Classroom observation checklist

Developed from the STEM Integration in K-12 Education framework, the checklist captured observable indicators across the four dimensions of STEM practice. Teachers were rated on a five-point Likert scale (1 = no inclusion, 5 = very high inclusion). Each teacher was observed twice, and the average score was used as the final measure. Operationally, the four domains were defined as follows:

- Interdisciplinary integration: evidence that mathematical concepts were explicitly linked to science or engineering applications (e.g., modeling speed or force).
- Technology use: the teacher's use of digital tools for dynamic visualization or simulation (e.g., GeoGebra, spreadsheets).

- Inquiry-based learning: moments when students generated questions, tested hypotheses, or used evidence to justify results.
- Project-based learning: instances where students collaborated on extended, real-world tasks requiring mathematical reasoning. Each domain included behavioral descriptors aligned with the same five-point Likert scale (1–5), ranging from 'no observable evidence' to 'consistent and explicit integration throughout the lesson'. These descriptors provided clear operational guidance for rating classroom practices.

Semi-structured interview protocol

The interview guide prompted teachers to articulate their own understandings of STEM, provide illustrative examples from their instructional practice, and reflect on the challenges they encounter as well as the forms of support they consider necessary. All interviews were conducted in Arabic, audio-recorded with informed consent, and transcribed verbatim to ensure accuracy and completeness. Each interview lasted between 30 and 45 minutes and was conducted in a private setting to promote openness and candid discussion.

Data analysis

Both descriptive statistics and thematic analysis was applied. Observation scores were summarized using means and standard deviations for each of the four STEM domains. Interview data were analyzed following Braun & Clarke's (2006) six-phase model: familiarization, coding, theme generation, review, definition, and reporting. Coding was conducted manually and themes were derived inductively. Themes were emerged through iterative reading and discussion. Both observers independently coded the interview transcripts, compared their codes, and refined the categories until consensus was reached. This process ensured that the four major themes reported—training, technology, curriculum, and resistance, were firmly grounded in teachers' accounts rather than observers' assumptions.

Major themes were summarized, along with representative quotations and the number of participants endorsing each theme. For instance, the 'training' theme included statements from 11 teachers who emphasized the scarcity of practical workshops "Most of our sessions are theoretical; we never try STEM tasks ourselves", while the 'technology' theme was supported by nine teachers who cited infrastructure and access barriers. This transparency enhanced analytic traceability and interpretive validity

To strengthen trustworthiness, several measures were employed:

- Triangulation, by comparing findings across observations and interviews.
- Member checking, by sharing preliminary interpretations with five interviewed teachers for feedback. Their comments led to refinements in how the "resistance" theme was framed—shifting emphasis from teacher reluctance to systemic constraints and clarified that some teachers' caution reflected accountability pressures rather than lack of motivation.
- Inter-rater reliability, supported by the dual-observer design; independent scoring of 20% of the classrooms yielded agreement rates above 85%. To provide a more rigorous estimate, Cohen's $\varkappa$ was computed for a subsample of ratings, yielding $\varkappa = 0.81$, indicating strong agreement.

Together, these strategies increased depth and credibility in the findings.

Ethical considerations

Ethical approval was obtained from the Research Ethics Committee at King Faisal University, in accordance with institutional guidelines for human-subject research. All participants were briefed on the study's purpose and procedures, provided written consent, and were assured of confidentiality and anonymity. Participation was voluntary, and teachers were informed of their right to withdraw at any time without consequences.

RESULTS

Participant characteristics

The study involved 25 middle-school mathematics teachers from public schools across Al-Ahsa, encompassing both urban and semi-urban contexts. All participants met the inclusion criteria of having between five and ten years of teaching experience and consenting to both the observation and interview phases. In total, 50 classroom sessions were observed—two per teacher—by two independent observers. Additionally, 15 teachers (60%) participated in semi-structured interviews, providing complementary perspectives on their instructional practices and perceived barriers. These parameters ensured that the sample represented a range of instructional environments while maintaining a consistent baseline of professional experience, as summarized in **Table 1**.

Table 1

Characteristics of the research sample

Characteristic	N	Notes
Total teachers observed	25	All met inclusion criteria
Number of observations	50	Two per teacher, different observers
Interviewed teachers	15	Subset of observed teachers
Teaching experience	5 – 10 yrs	Required for participation
School context	Urban + semi-urban	Al-Ahsa public schools

Overview of findings

The presentation of findings follows the study's three guiding research questions. Evidence was drawn from classroom observations (N = 25 teachers, 50 lessons) and semi-structured interviews (n = 15 teachers). Descriptive statistics provided a broad picture of STEM implementation, while teachers' narratives added interpretive depth, revealing how systemic and cultural forces shape daily practice.

Research question 1: To what extent do middle-school mathematics teachers integrate STEM practices?

The observation data indicated that overall STEM integration in middle-school mathematics classrooms was modest. On a five-point scale (1 = no inclusion, 5 = very high inclusion), teachers achieved an average composite score of 2.0 (SD = 0.75). This mean reflects the sporadic and largely superficial appearance of STEM-related practices across most lessons. Table 2 presents the distribution of integration levels and shows that more than half of the teachers (52%) fell within the low-to-moderate range, whereas only two teachers (8%) demonstrated high levels of integration.

Table 2

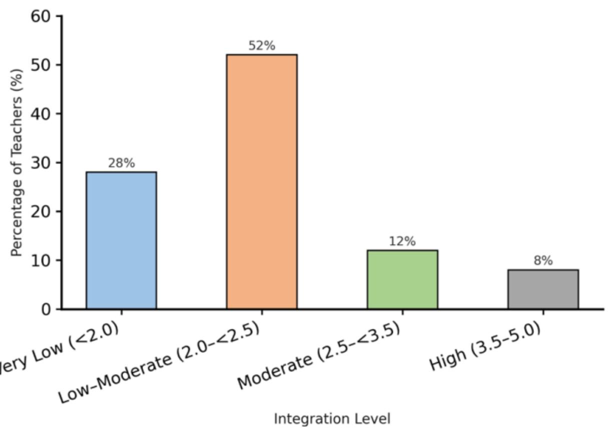
Overall STEM integration levels observed (N = 25)

Integration Level	Frequency	%
High (3.5–5.0)	2	8
Moderate (2.5–<3.5)	3	12
Low to Moderate (2.0–<2.5)	13	52
Very Low (<2.0)	7	28

The pattern illustrated in Table 2 is reinforced visually in Figure 1, where the distribution clusters heavily toward the lower end of the scale. Although the overall mean was low, the relatively wide dispersion (SD = 0.75) points to meaningful variability across classrooms. This variation suggests that integration was not uniformly limited; rather, a small subset of teachers attempted more substantial forms of STEM implementation while the majority engaged in only minimal or incidental connections.

Figure 1

Distribution of observed STEM integration levels among middle-school mathematics teachers (N = 25)



A closer inspection of the observation data revealed that no teacher demonstrated sustained integration, understood here as the coherent activation of all four STEM dimensions within a single instructional session. Even among the two teachers in the high category, integration appeared to stem from personal initiative rather than institutional practice, as patterns of STEM-aligned instruction were inconsistent across lessons. Teachers in the low and very low categories typically displayed only isolated examples, such as brief interdisciplinary references or limited use of digital tools—without progressing toward inquiry-based or project-based learning.

Interview findings offered important insight into these quantitative trends. Teachers with lower ratings frequently attributed their limited integration to curriculum pacing pressures, the emphasis on preparing students for examinations, and the lack of practical, subject-specific professional development. As one teacher noted, "I understand the value of STEM, but I rarely find time or training to apply it. Usually, I'm just trying to finish the lesson plan before the exam" (Teacher 8). Another teacher highlighted the gap between theory and practice in current professional development: "Most workshops we attend are very general. Nothing tells us how to actually integrate technology or projects into a mathematics lesson" (Teacher 3).

Taken together, the observation scores and interview testimonies depict a fragmented and uneven landscape of STEM integration. While a small number of teachers demonstrated promising practices, most classrooms showed only surface-level or episodic incorporation of STEM elements. These patterns suggest that the extent of STEM integration is shaped less by teacher awareness, which appeared generally high, and more by systemic constraints that limit the translation of STEM principles into everyday mathematics instruction.

Research question 2: What types of STEM practices are most and least commonly implemented?

Analysis of the four STEM practice dimensions revealed a clear hierarchy in classroom implementation. Interdisciplinary integration emerged as the most frequently observed dimension, whereas project-based learning (PBL) appeared least evident. This pattern suggests that teachers found it easier to introduce quick conceptual connections between mathematics and related scientific ideas than to facilitate extended tasks requiring sustained inquiry, collaboration, and curricular flexibility.

Table 3 presents the mean scores and standard deviations for each STEM dimension. Interdisciplinary integration achieved the highest mean (M = 2.4, SD = 0.8), followed by technology use (M = 2.1, SD = 0.9). Inquiry-based learning (M = 1.9, SD = 0.6) and PBL (M = 1.8, SD = 0.7) were the least developed dimensions, with classroom evidence often limited to fragmented or short-lived episodes rather than structured pedagogical routines.

Table 3

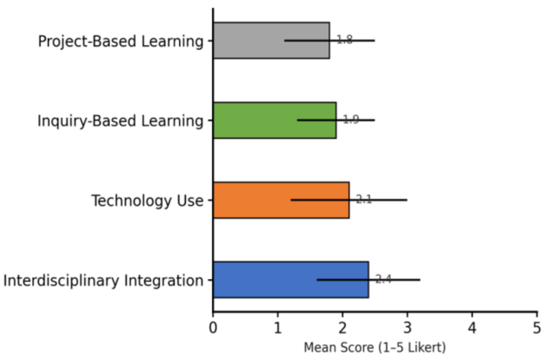
Mean scores across STEM practice dimensions (N = 25)

STEM Domain	Mean Score	SD	Examples of Practice
Interdisciplinary Integration	2.4	0.8	Linking math to science concepts (e.g., speed, rainfall)
Technology Use	2.1	0.9	PowerPoint slides, limited GeoGebra use
IBL	1.9	0.6	Occasional open-ended questions
PBL	1.8	0.7	Small projects (floor plans, area & perimeter)

The pattern shown in Table 3 is further illustrated in Figure 2, where a descending gradient from interdisciplinary integration to PBL is clearly visible. This visual decline reinforces the finding that while teachers occasionally employed cross-disciplinary examples or digital tools, these practices rarely expanded into sustained inquiry or project-based learning that would signal deeper integration.

Figure 2

Mean scores across the four STEM practice dimensions among middle-school mathematics teachers (N = 25)



Interview testimonies helped illuminate the reasons behind this gradient. Several teachers identified interdisciplinary integration as the most feasible form of STEM practice, often limited to brief contextual references such as linking speed, rainfall, or force to mathematics topics. As one teacher explained, "It's easy to connect a math lesson to physics or daily life, like using speed or rainfall as examples. But anything larger, like a project, is almost impossible because of time limits" (Teacher 11).

Technology use, although present, tended to be symbolic rather than exploratory. Digital tools were seldom used for simulation, modeling, or open-ended investigation. One teacher noted, "We have computers, but the training is missing. I know about GeoGebra, but I never had a chance to learn it well enough to use it in class" (Teacher 6). This aligns closely with the quantitative finding that technology use, while slightly higher than IBL and PBL, remained underdeveloped.

Inquiry-based learning appeared only intermittently, usually through short predictive or explanatory questions that were quickly curtailed by curriculum pacing demands. "I sometimes ask my students to predict or explain, but then I have to move on quickly to cover the lesson plan. There is no space for extended inquiry," a teacher explained (Teacher 14).

PBL was the least visible dimension. When present, it took the form of small, isolated assignments rather than multi-step collaborative projects. Teachers commonly attributed this absence to curricular rigidity and time constraints, both of which left little room for extended tasks requiring planning, iteration, and group problem-solving.

Taken together, these findings reveal a consistent and layered pattern: interdisciplinary links are relatively attainable, technology use is emerging but underutilized, inquiry-based interactions remain shallow, and PBL is rare. This hierarchy reflects a structural tension between pedagogical innovation on the one hand and the prevailing exam-driven culture and curriculum pacing pressures on the other. In essence, teachers appear willing to incorporate elements of STEM, but systemic conditions limit their ability to adopt more demanding or time-intensive approaches.

Research question 3: What challenges do teachers face in applying STEM practices?

The thematic analysis of interview data identified four interrelated challenges that collectively help explain the limited and uneven levels of STEM integration observed in classrooms. These challenges—lack of specialized training, limited technological resources, curriculum pressure, and resistance to pedagogical change—emerged inductively through iterative coding and cross-case comparison. As illustrated in **Figure 3**, instructional and infrastructural barriers were the most frequently reported, while cultural and attitudinal constraints appeared less often yet still exerted a notable influence on teachers' instructional decisions.

Lack of specialized training

Twelve teachers (80%) noted that although they regularly attended general professional-development workshops, opportunities focused on practical STEM strategies for mathematics were scarce. Participants repeatedly emphasized the absence of hands-on models or lesson examples that could translate STEM principles into actionable classroom practices. One teacher remarked, "I've attended general PD workshops, but none focused on STEM in mathematics. We need examples of real lessons, not just theory" (Teacher 4). This shortage of targeted preparation creates a clear gap between policy aspirations and classroom capacity, reinforcing the quantitative patterns reported earlier, where STEM integration remained largely superficial.

Limited technological resources

Technological constraints were the second most frequently cited challenge, mentioned by eleven teachers (73%). Participants described unreliable hardware, outdated software, and insufficient technical support, all of which hindered meaningful use of digital tools. As one teacher explained, "Even if I wanted to use technology, the infrastructure isn't there. Our projector breaks often" (Teacher 11). These limitations help clarify why technology-use scores remained modest in the observations and why digital tools were rarely employed for dynamic exploration or simulation. In many cases, technology served a presentational rather than investigative function, restricting opportunities for inquiry and modeling.

Curriculum pressure

Nine teachers (60%) highlighted curriculum pacing and exam-oriented expectations as significant constraints on their ability to incorporate inquiry or project-based approaches. Tight schedules and accountability pressures left little room for extended tasks, collaborative projects, or open-ended exploration. One teacher explained, "The goal is to finish the syllabus. There's no time for projects or inquiry, even if I want to try" (Teacher 6). This theme directly reflects the quantitative finding that PBL scored lowest among the four STEM dimensions. Teachers' accounts suggest that even when they possessed conceptual awareness of STEM, systemic requirements shaped their instructional choices toward more traditional and time-efficient methods.

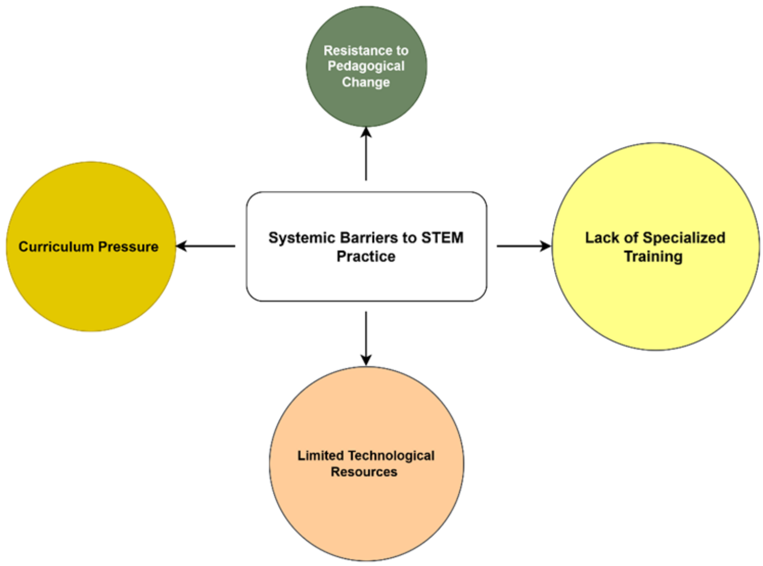
Resistance to pedagogical change

A fourth challenge related to cultural expectations among students and parents, noted by five teachers (33%). Participants described prevailing preferences for clear explanations, step-by-step procedures, and a strong focus on test performance—expectations that made open-ended or exploratory learning less acceptable. "My students and parents want clear answers and high test scores. They're not ready for open-ended learning," one teacher reflected (Teacher 13). These attitudes reinforced conservative instructional habits and reduced teachers' willingness to adopt instructional strategies perceived as risky or unconventional.

Figure 3 illustrates the four main themes identified through interview analysis—training, technology, curriculum, and pedagogy—sized according to their relative frequency across teacher responses (N = 15).

Figure 3

Key challenges to implementing STEM practices in mathematics classrooms



Synthesis of findings

Collectively, these four challenges interact in ways that limit sustainable STEM implementation. Insufficient training and technological support restrict teachers' ability to acquire and apply new skills; rigid curricular structures reduce the time and flexibility needed for inquiry and project-based learning; and cultural expectations reinforce reliance on traditional, exam-oriented practices. This interplay helps explain why the observed levels of STEM integration remained largely surface-level despite clear policy endorsement and general teacher awareness. Overall, the findings depict a system in transition—one in which teachers are aware, willing, and partially capable, yet constrained by structural and cultural conditions that make meaningful STEM integration difficult to realize in everyday mathematics instruction.

DISCUSSION

The findings of this study suggest a noticeable gap between the policy aspirations associated with STEM integration in Saudi Arabia and the classroom practices observed in the participating middle schools. While Vision 2030 emphasizes creativity, innovation, and applied learning, the evidence gathered from the Al-Ahsa context points to modest and uneven implementation. In what follows, the results are interpreted considering existing research, contextual challenges, and broader reform efforts in STEM education.

Extent of STEM integration in mathematics classrooms

The observation data, which showed a composite mean of 2.0, suggest that the observed mathematics classrooms tended to reflect predominantly traditional and exam-oriented instructional patterns. This pattern echoes earlier Saudi findings documenting limited instructional innovation (Al-Dosari, 2016; Aldahmash et al., 2019) and aligns with more recent evidence from regional studies (Kolakkadan, 2024). Al-Najjar & Hammad (2024) reported that teachers across Arab contexts are aware of STEM's value yet often lack the autonomy, time, and scaffolding necessary for authentic integration. At a broader level, Nicol (2023) argued that mathematics education for STEM should be understood "as place"—inseparable from the social, institutional, and cultural ecologies in which it occurs. The modest integration observed in Al-Ahsa classrooms, therefore, appears to be shaped by contextual constraints rather than pedagogical indifference. Teachers' remarks such as "I'm just trying to finish the lesson plan before the exam" (Teacher 8) underscore this systemic limitation. International evidence reinforces these observations. Studies in STEME and other journals have shown that when teachers receive consistent pedagogical support, integration can yield measurable improvements in student motivation and achievement (AlAli & Wardat, 2024). By contrast, contexts lacking structural support—whether in Europe, East Asia, or the Gulf—have been reported to experience policy–practice gaps that constrain innovation (English, 2017; Thibaut et al., 2018). These cross-national parallels suggest that successful STEM reform may depend less on awareness and more on system-level alignment between policy goals, professional learning, and assessment design (Halpern et al., 2025).

Variation across STEM practice dimensions

The data further revealed uneven adoption across the four STEM domains: interdisciplinary activities were most frequent (M = 2.4), while PBL was least evident (M = 1.8). Teachers appeared to find it easier to create brief conceptual links between mathematics and science—such as connecting speed to physics or rainfall to statistics—than to sustain open-ended projects requiring curricular flexibility. As one teacher noted, "It's easy to connect math to daily life, but anything larger, like a project, is almost impossible because of time limits" (Teacher 11). In systems such as Turkey and China, teachers have similarly been reported to favor short interdisciplinary tasks over inquiry or PBL (Kirici & Bakırci, 2021; Lyu et al., 2022; Sarkar, 2025). The limited presence of project-based approaches in the present study may reflect a degree of structural tension, as curricula organized around textbook completion and summative testing tend to leave limited space for exploratory, student-centered learning. Comparative research published in STEM Education suggests that such imbalance between integration depth and curricular rigidity continues to be observed across diverse contexts. Al-Najjar & Hammad (2024) found that even when teachers conceptually embrace STEM, the perceived risk of deviating from standardized pacing may reduce willingness to experiment. These findings suggest the value of curricular frameworks that allow incremental, supported adoption of project- and inquiry-based learning within mathematics instruction (Can & Soylu, 2025).

An additional structural factor that warrants closer consideration is the role of the standardized assessment system in shaping instructional priorities. While high-stakes examinations are designed to ensure accountability and academic standards, they also function as powerful regulators of classroom time, content coverage, and pedagogical risk-taking (Madani, 2020). When teachers perceive that student performance on summative assessments is the primary indicator of effectiveness, instructional decisions tend to favor predictability, procedural fluency, and syllabus completion. In such conditions, extended inquiry, open-ended problem solving, or interdisciplinary projects may be viewed as potentially misaligned with assessment demands, particularly when pacing schedules are tightly defined. The teacher narratives in this study suggest that assessment pressures are not merely external constraints but embedded features of the institutional environment that shape everyday pedagogical judgment. Interpreting the findings through this structural lens helps explain why awareness of STEM principles does not consistently translate into sustained inquiry-based or project-oriented practice (Saad et al., 2025; Prince, 2023). This structural dynamic may also help explain the observed hierarchy of STEM dimensions, where brief interdisciplinary links appeared more feasible than sustained IBL or PBL.

Barriers to STEM implementation

The qualitative analysis identified four interrelated barriers: lack of specialized training, limited technological infrastructure, curriculum rigidity, and cultural resistance to pedagogical change. These themes correspond closely with those reported in earlier Saudi studies (Madani, 2020) and are broadly consistent with international scholarship on STEM reform (Suarta et al., 2022). Technology-related constraints appeared particularly prominent in participants' accounts. Several teachers described frequent hardware failures and insufficient training: "Even if I wanted to use technology, the projector breaks often" (Teacher 11). Similar challenges have been reported in Oman. Al-Kaabi & Al-Maskari (2025) showed that integrating augmented-reality (AR) applications into STEM-focused mathematics courses was associated with enhanced student engagement and reduced motivational barriers. Their findings illustrate how strategic digital innovation may help mitigate both infrastructural and pedagogical constraints. Professional development also emerged as an important factor. As one participant explained, "Most workshops are very general. Nothing tells us how to integrate technology or projects into a math lesson" (Teacher 3). This observation aligns with Bolyard et al. (2024), who argued that effective STEM teacher preparation should cultivate "productive struggle"—the capacity to manage the cognitive demands of inquiry-based learning rather than avoid them. Building such capacity may require ongoing, context-specific mentorship rather than isolated, one-off workshops. These findings are consistent with Saad et al.'s (2025) suggestion that sustainable STEM education in the Arab world is more likely when reform efforts address policy, leadership, teacher preparation, and resource provision in a coordinated manner rather than through fragmented classroom-level initiatives.

Implications for educational reform and practice

Within the broader framework of Saudi Vision 2030, these findings suggest the importance of aligning national aspirations with the daily realities of mathematics instruction in the observed context. Without structural support for inquiry-oriented, project-based, and technology-enhanced pedagogy, STEM reform may risk remaining more rhetorical than transformative.

For teachers, effective STEM integration involves not only awareness but also the development of hands-on, problem-centered strategies. Continuous professional development, peer collaboration, and lesson-study models can support the translation of conceptual understanding into classroom practice.

For school leaders and policymakers, the findings point to several practical considerations:

- Designing localized professional development that links theory with authentic lesson planning;
- Investing in reliable technological infrastructure and digital resources; and
- Introducing curriculum pacing flexibility that supports innovation rather than inadvertently constraining it.

Finally, future research may benefit from longitudinal designs that examine how sustained professional learning influences teachers' classroom behavior over time. Comparative work across gender-segregated schools, or studies exploring students' perspectives within a STEM framework, could provide deeper insights into the sociocultural dimensions of reform.

Ultimately, by situating empirical classroom evidence within global STEM discourse, this study seeks to contribute to ongoing conversations about how national visions for innovation might be more fully supported through context-responsive mathematics education.

Limitations

As with most classroom-based qualitative studies, certain limitations should be acknowledged when interpreting the findings. First, the research was conducted in a single region—Al-Ahsa—which may constrain the generalizability of the findings to other educational settings within Saudi Arabia. Future investigations should therefore expand to multiple regions to capture wider variation in instructional practices and contextual factors.

Second, although each teacher was observed twice by different researchers to enhance reliability, classroom instruction is inherently dynamic and may vary across lessons, topics, or even school cultures. Extended observation periods or longitudinal designs would provide a richer and more nuanced account of how STEM practices evolve over time.

Third, the interview data were obtained from a subset of fifteen teachers. While this sample size was sufficient to achieve thematic saturation, the inclusion of additional participants could have further diversified the range of perspectives, especially in relation to institutional and personal factors influencing instructional choices.

Finally, the study focused exclusively on male teachers, reflecting the gender-segregated structure of Saudi schooling. This limitation precluded the exploration of potential gender-based differences in STEM implementation. Comparative research across male and female schools is therefore recommended to provide a more comprehensive and balanced picture.

These limitations notwithstanding, the study offers valuable empirical insights into the classroom-level realities that shape STEM integration in mathematics education and may inform broader reform initiatives across similar educational contexts.

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH

This study investigated the extent to which middle school mathematics teachers in Al-Ahsa, Saudi Arabia, integrate STEM practices into their instruction and the challenges they encounter in doing so. Drawing on data from fifty classroom observations and fifteen teacher interviews, the findings suggest that overall STEM integration in the observed context remains relatively limited. Most observed practices were confined to basic interdisciplinary links, with minimal evidence of sustained inquiry-based or PBL.

The results point to a continuing gap between the aspirations of national educational reform—embodied in Vision 2030's emphasis on creativity, innovation, and applied learning—and the day-to-day realities of mathematics instruction in the participating schools. Exam-driven pedagogy appears to remain influential, often leaving limited space for exploratory, student-centered approaches that characterize effective STEM education. Without greater alignment in teacher training, curriculum design, and infrastructure provision, these policy ambitions may prove difficult to realize in practice.

At the same time, the study contributes to the international STEM education discourse by combining classroom observation with qualitative teacher narratives. This mixed, qualitative-dominant approach moves beyond self-reported perceptions to offer a contextually grounded portrayal of instructional realities within an underrepresented Gulf setting. The findings suggest that effective STEM integration is shaped not only by teacher awareness but also by sustained, multi-level support that bridges policy ambitions with classroom realities.

Future research may pursue three interrelated directions. First, longitudinal studies could trace how continuous professional development influences teachers' STEM practices and student outcomes over time. Second, comparative investigations across gender-segregated schools may illuminate cultural and structural differences in STEM implementation. Third, incorporating student perspectives would enrich understanding of engagement, motivation, and conceptual development under integrated STEM instruction.

Finally, as recent studies in STEM Education emphasize, fostering productive struggle among teachers (Bolyard et al., 2024) and designing context-sensitive models of STEM learning (Nicol, 2023) represent promising avenues for further exploration. Building on such frameworks may support reform efforts that are both innovative and locally meaningful—contributing to ongoing conversations about transforming mathematics education through STEM within the Saudi context and beyond.

Acknowledgement

The author extends his appreciation to the Deanship of Scientific Research, King Faisal University, Saudi Arabia for supporting this research.

Funding

This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [KFU251641].

Ethical statement

Ethical approval was obtained from the Research Ethics Committee of King Faisal University, Saudi Arabia (Approval No. KFU-2025-ETHICS3316). Informed consent was obtained from all participants.

Competing interests

The author declares that there are no competing interests.

Author contributions

The author conceived the study, designed the research, collected and analyzed the data, and wrote and approved the final manuscript.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AI disclosure

AI language tools were used solely to enhance clarity and readability. All intellectual content, analysis, and conclusions are the author's original work and were carefully reviewed for accuracy and integrity.

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