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Informal STEM experiences, parental influence, and learning outcomes in primary school: A systematic review

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ABSTRACT
This systematic review synthesizes 53 peer-reviewed studies (2010 - 2024) on informal Science, Technology, Engineering, and Mathematics (STEM) education for primary school children. Three focal areas are examined: (1) types of activities and settings, (2) parental mediation with gender and age influences, and (3) the role of parental education and income. Findings show that informal STEM experiences, ranging from home routines and community events to museums and digital games, consistently promote cognitive, affective, and behavioral outcomes. Parental mediation emerges as a central factor, shaping engagement and competence through questioning, scaffolding, and motivational strategies. Higher parental education enhances content-rich STEM talk, whereas income primarily affects access to resources. Despite these advances, evidence for long-term developmental pathways remains limited, with few longitudinal or cross-cultural studies. Practical implications highlight the need to integrate informal STEM into formal education, strengthen school-family-community partnerships, and promote equitable access to STEM opportunities. Future research should investigate cumulative effects over time, sociocultural variations, and interventions that balance parental support with children's autonomy. Overall, informal STEM is shown to be a critical driver of children's interest, competence, and equity in STEM learning.

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Introduction

Parental involvement has long been recognized as a critical determinant of children's academic development, particularly during early childhood and the primary school years, when foundational cognitive, social, and emotional skills are established (Castro et al., 2015; Ma et al., 2016; Welsh et al., 2020). While literacy-focused activities, especially reading, have received substantial attention, engagement in STEM remains underemphasized despite its importance for fostering problem-solving, scientific reasoning, and sustained interest in STEM disciplines (Barnett et al., 2020). Informal STEM learning, encompassing experiences outside formal educational settings, provides authentic opportunities for children to explore STEM concepts through everyday activities at home, such as cooking, hygiene routines, and problem-solving games, as well as in structured yet exploratory environments, including museums, zoos, aquariums, and community centers (Pattison et al., 2020; Alexandre et al., 2022; Acosta et al., 2021; Yıldız Taşdemir & Güler Yıldız, 2024; Özkan et al., 2024; Erol & Erol, 2024).

Participation in informal STEM activities has been shown to enhance children's cognitive, affective, and behavioral outcomes, including improved problem-solving, scientific reasoning, curiosity, and the development of STEM identities and career aspirations (Haden et al., 2014). These benefits are magnified when parents are actively involved, facilitating hands-on interactions, asking questions, and engaging in content-rich conversations, irrespective of the child's age or parental education (Acosta et al., 2021; Dewi & Rahayu, 2024). However, access to and quality of informal STEM experiences are often shaped by socioeconomic and demographic factors. Children from lower-income or marginalized backgrounds may face cumulative disadvantages, including limited resources and opportunities for engagement, highlighting the need for equitable and culturally responsive practices (Evans & Kim, 2013; Marti et al., 2018; Welsh et al., 2020; Kurniahtunnisa et al., 2024).

Despite growing recognition of the importance of informal STEM education, prior research has primarily focused on institutional or programmatic contexts, often neglecting the critical role of families and home environments in shaping children's STEM learning trajectories. Comprehensive syntheses examining how parental characteristics, such as education, beliefs about science, and socioeconomic status, mediate or moderate informal STEM outcomes are scarce. Moreover, the interplay among parental involvement, children's age and gender, and contextual factors remains underexplored. Addressing this gap is timely and necessary to inform evidence-based strategies that support equitable, effective STEM learning for primary school-aged children.

This systematic review synthesizes 53 peer-reviewed studies (2010 - 2024) to examine the types of informal STEM activities, the role of parental mediation, and the influence of parental education and income on children's STEM engagement and learning outcomes. By integrating findings across diverse contexts, the review aims to provide actionable insights for educators, policymakers, and researchers, while identifying priority areas for future investigation to promote inclusive and high-quality early STEM experiences (Zuhaida et al., 2025).

Literature Synthesis and Originality of the Present Study

To position our review within the existing scholarship, it is important to synthesize prior systematic reviews and meta-analyses on informal STEM education and parental involvement. Milner-Bolotin and Marotto (2018) conducted a meta-analysis on parental engagement in children's STEM education, demonstrating the benefits of inquiry-based and hands-on approaches while also highlighting persistent challenges in sustaining engagement across contexts. Alexandre et al. (2022) reviewed informal STEM experiences across everyday and community settings, yet their scope extended from early childhood through adolescence without isolating the specific developmental stage of primary schooling. Reviews on parental involvement more broadly indicate that parents generally support children's STEM outcomes, but findings remain inconsistent and often blur the distinction between formal and informal contexts (Gülhan, 2023). Salvatierra and Cabello (2022) further demonstrate that parental engagement in informal STEM activities in early childhood enhances children's interest and self-efficacy. Complementing these, a recent meta-analysis confirmed that informal/out-of-school STEM programs positively influence students' STEM attitudes and interests, though family dynamics and primary-level learners were not specifically addressed (Xia et al., 2025; Jituafua, 2024).

Taken together, these contributions underscore the importance of informal STEM learning but reveal a critical gap: no review to date has systematically consolidated evidence on primary school children while simultaneously examining the parental role within informal contexts. Addressing this gap, the present study synthesizes 53 peer-reviewed articles published between 2010 and 2024. By integrating findings from home, museum, and community environments, this review provides a novel account of how informal STEM experiences and family engagement interact to shape cognitive, affective, and behavioral outcomes in early STEM education. In doing so, it advances theoretical understanding, informs educational practice, and outlines directions for future research.

Research Questions (RQ)

Building on the identified research gap, this review is guided by the following questions:

RQ1: What types of informal STEM activities and settings are most studied, and how do they influence the cognitive, affective, and behavioral development of primary school children?

RQ2: How do parents mediate and facilitate children's engagement, perceived competence, and interest in informal STEM learning, and how do child gender and age influence these parental interactions?

RQ3: How do parental education and income influence children's engagement and learning outcomes in informal STEM activities?

Methods

A systematic literature review was conducted between February and May 2024 using academic databases including ERIC, EBSCO, MEDLINE, Scopus, and Web of Science. Only peer-reviewed journal articles published between 2010 and 2024 were considered, with priority given to high-impact journals such as Early Childhood Research Quarterly, Educational Psychology Review, International Journal of STEM Education, and Developmental Psychology.

Search Strategy and Screening

Keyword combinations were derived from prior studies, including "informal STEM" AND "primary school" with "parent," "family," "museum," "home," "education," and "event." From 2,542 initial records, duplicates were removed, leaving 982. After title and abstract screening, 442 remained. Full-text screening, guided by predefined inclusion and exclusion criteria, reduced the pool to 102. Finally, 53 studies were retained following quality assessment by three independent reviewers. The process followed the PRISMA framework (see Figure 2).

Selection Criteria

Eligible studies (1) focused on STEM education at the elementary level; (2) involved participants aged 3-14; (3) were written in English; and (4) employed empirical research methods (qualitative, quantitative, intervention, or comparative). Studies outside these parameters were excluded, most often for lacking relevance to informal STEM, having inconsistent methods, or targeting inappropriate age groups.

Data Synthesis

The final 53 studies were coded and analyzed thematically. Two independent reviewers conducted the initial screening, with a third reviewer cross-checking 25% of the data for reliability. Keyword mapping using VOSviewer produced a co-occurrence network (Figure 1), while Table 1 summarizes keyword clusters.

Table 1

List of keywords and keyword phrases

STEM-related phrases	Phrases about places	Phrases about objects
STEM	Home	Student
Technology	Museum	Caregiver
Education	Garden	Pupil
Informal STEM	Events	Child
Science	Science events	Primary school
Math	Aquarium	Teacher
Engineering	Out-of-school	Parents
Smartphones	Afterschool	Father
Robot		Mother
Tables		Education
		Leaners

Figure 1

VOSviewer cluster chart of keyword results: Minimum number of keywords appearing is 5

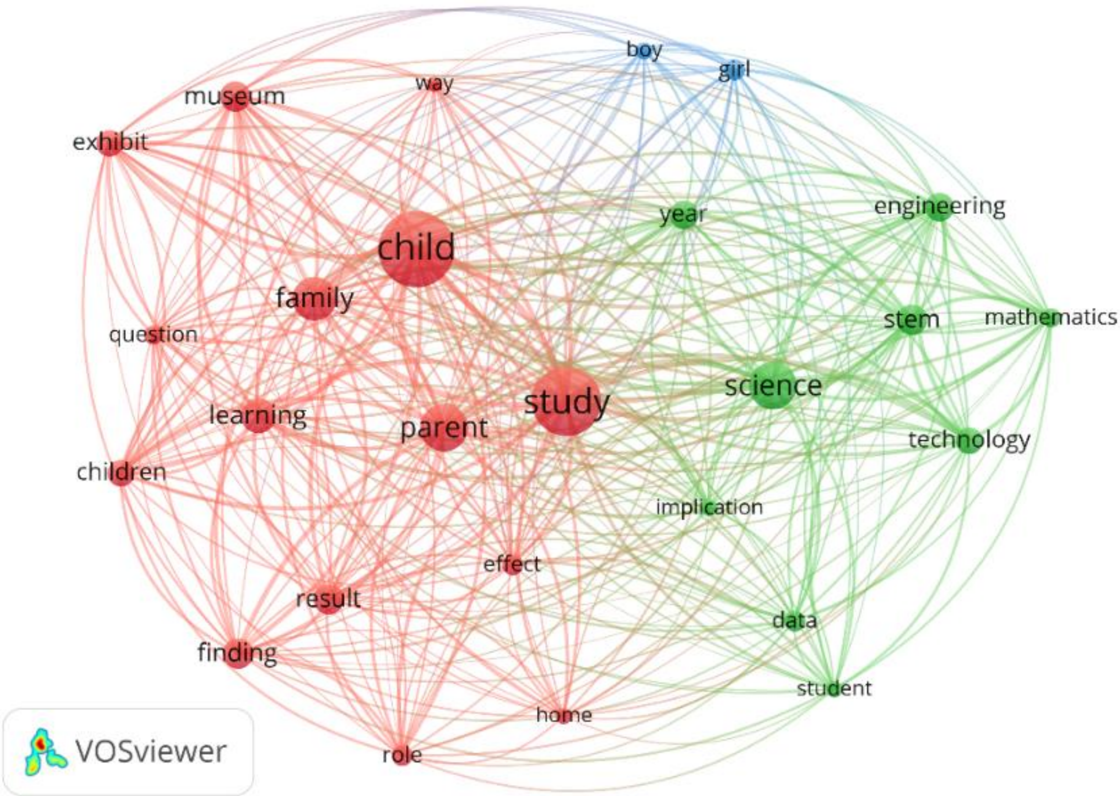
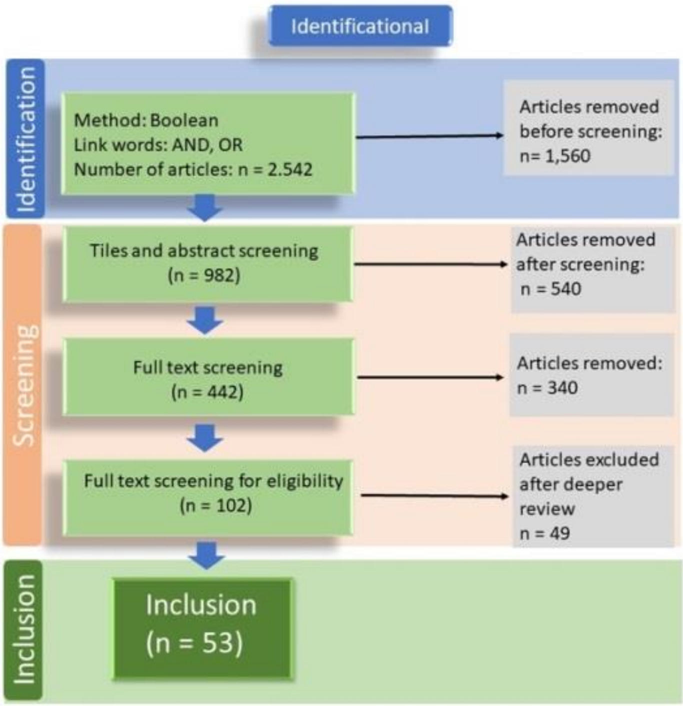


Figure 2

PRISMA flowchart for screening



Findings

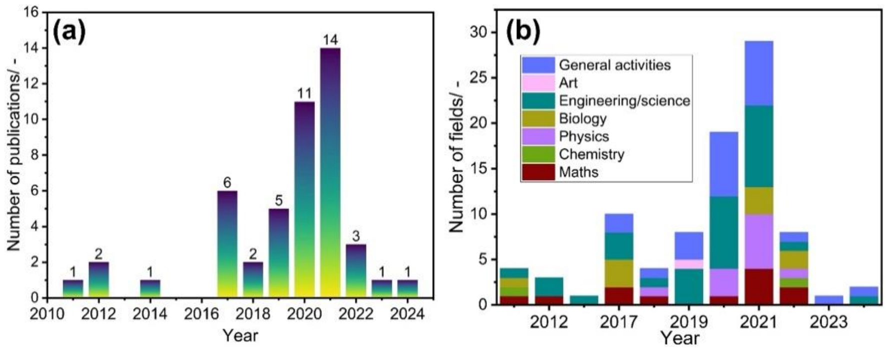
RQ1-Findings: Types of Informal STEM Activities, Settings, and Their Influence

Scope of the Literature

A total of 53 peer-reviewed studies (2000 - 2024) were reviewed, with most published between 2017 and 2021 (Table 3a). The majority were conducted in the United States (n = 38), followed by Europe (n = 9) and Asia (n = 2). Regarding quality, 30 studies were in Q1 journals and 20 in Q2. The disciplines included educational sciences (n = 30), psychology (n = 21), engineering (n = 2), and multidisciplinary fields, reflecting the broad relevance of informal STEM education. Figures 3a and 3b illustrate the temporal distribution and thematic focus of the selected studies. Regarding research fields, general STEM activities and engineering/science were most frequently studied. In contrast, other fields such as art, biology, physics, chemistry, and mathematics showed more limited and fluctuating contributions over time (Figure 3b).

Figure 3

(a) Annual distribution of published articles. (b) Annual distribution of main research fields



Methodological Approaches in Studying Informal STEM

Mixed methods were the most frequent (43.5%), and integrated interventions, scaffolding, observations, surveys, and interviews (Figure 4). Surveys/interviews accounted for 30.4%, capturing parental beliefs and children's attitudes. Observational/video methods (21.7%) provided real-time insights into family interactions. Case studies and test-based designs were rare (2.2% each). A summary of the main methodological groups, their descriptions, and distribution across the reviewed studies is provided in Table 2. In contrast, detailed information on the methods used and specific findings of individual studies can be found in Table S2 (Supplementary Data).

Figure 4

Main research method groups in the reviewed articles

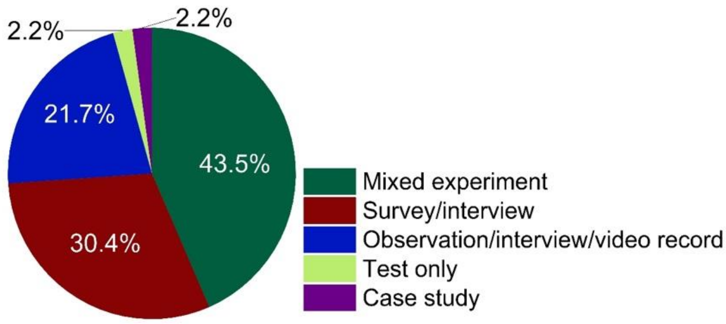


Table 2

Summary of the main research method groups in the reviewed studies

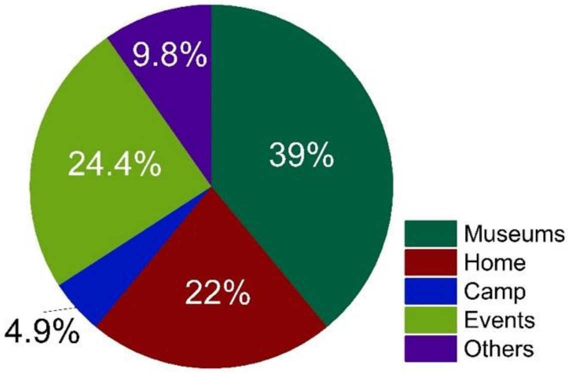
Method	Description	N
Mixed Methods	A combination of multiple techniques, including naturalistic observation, video recording, conversation analysis, WH-question scaffolding, hands-on activities, questionnaire administration, and game-based learning using digital devices.	20
Survey/Interview	Semi-structured interviews and/or surveys with parents, children, and experts, followed by qualitative or quantitative data analysis.	14
Observation/Interview/ Video	Video recordings of participant activities and conversations; parent-child interviews; transcription and coding of interactional data.	10
Case Study	In-depth examination using interviews, surveys, and video documentation within a specific setting or participant group.	1
Test Only	Focused on experimental design involving STEM-based games or robotics with integrated software platforms.	1

Learning Environments

Museums were the most frequently studied settings (n = 16, ~40%), followed by homes (n = 9, 22%) and community events (n = 10, 24.4%). Other contexts included camps (n = 2), botanical gardens (n = 1), and zoos or aquariums (n = 3). Several studies adopted multi-site approaches, integrating venues such as homes, clubs, and historic buildings. The proportional distribution of these environments is presented in Figure 5 (Table S1, Supplementary Data).

Figure 5

Distribution of STEM venues in the reviewed articles



Types of Activities

Across all environments, informal STEM learning involved a variety of activities (Table 3). Parent-child conversations (n = 27) were the most frequent, often centering on inquiry and causal explanations. Play-based and digital games (n = 22), including robotics and interactive tools, promoted problem-solving and active engagement. Hands-on engineering and design activities, such as toy-making and building tasks, were also common. In addition, community-based events provided opportunities for exploration and collaboration.

Table 3

Summary of research themes, informal STEM activities, and reported outcomes.

Theme	Main Activities	Key Outcomes
1. Family Support (n = 28)	- Parent-child conversations (n = 27) - Play-based activities (n = 22) - Parental questioning (n = 23)	- Strong parental role (n = 20) - Positive child attitudes (n = 19) - No negative responses reported
2. STEM at Home (n = 9)	- Daily routines (cooking, hygiene) (n = 2) - STEM games (n = 4) - Family investigations (n = 6)	- Positive attitudes (n = 9) - Skill development (n = 7) - Some neutral effects (n = 1)
3. STEM in Museums (n = 16)	- Building, hands-on tasks (n = 6) - Exhibits, surveys (n = 9)	- Passion for science (n = 14) - Skill gains (n = 10) - Career interest (n = 3)
4. Other Informal Settings (n = 16)	- Community events, camps, zoos, libraries (n = 16) - Games, inquiry (n = 12)	- Science interest (n = 11) - Skill development (n = 10) - Some neutral effects (n = 9)

Cognitive, Affective, and Behavioral Outcomes

Across settings and activity types, informal STEM experiences were associated with multiple outcomes for primary school-aged children (Table 3). On the cognitive level, studies reported improved problem-solving skills, enhanced scientific reasoning, and gains in subject-specific knowledge, particularly in mathematics and science/engineering. Affective outcomes included heightened curiosity, positive attitudes toward STEM subjects, and the development of a science identity linked to early career aspirations.

RQ2-Findings: Parental Mediation, Gender, and Age

Parental Mediation

Across 24 studies, parents were found to play a critical role in mediating children's engagement, competence, and interest in informal STEM learning. Figure 6 illustrates the connections between different groups of parent-child communication and their effects on children's STEM learning, highlighting that questioning and conversational strategies are most frequently associated with cognitive growth and learning support. Parents supported learning through games, storytelling, questioning, explanations, and scaffolding strategies such as guided conversation cards or preparatory content. Open-ended "wh-questions" and technical vocabulary were consistently linked to higher levels of reasoning, problem-solving, and STEM-related talk. Everyday routines, book reading, and museum visits also provided opportunities for parental mediation that enhanced children's vocabulary, causal reasoning, and inquiry behaviors. Table 4 summarizes the main groups of parent-child communication forms in STEM, outlining their specific practices and the associated effects on children's cognitive, motivational, and skill development.

Figure 6

Links between parent-child communication groups and their positive impacts on STEM learning outcomes

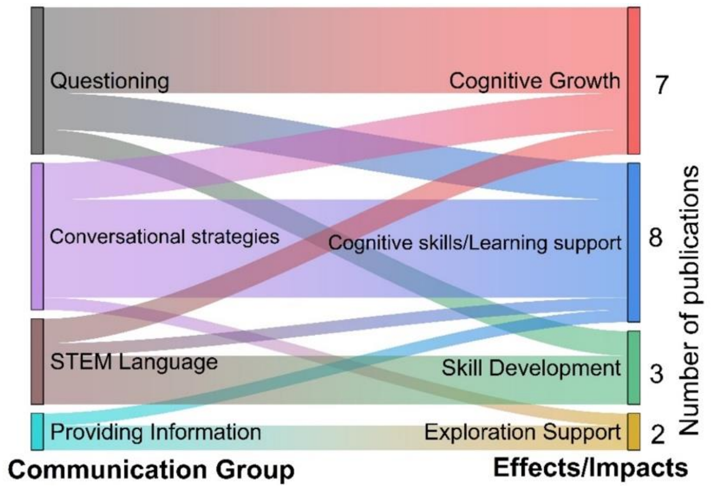


Table 4

Groups of parent-child communication forms in STEM and their impacts

Communication Group	Specific Forms	Effects/Impacts	References
Questioning	- Open-ended questions (wh-questions) - Critical thinking questions	(Cognitive Growth) Enhance scientific understanding, develop thinking and dialogue skills, and make positive predictions about STEM learning outcomes.	(Short-Meyerson et al., 2024; Haden et al., 2014;Ornstein et al., 2004;Callanan et al., 2017; Benjamin et al., 2010;;So et al., 2018)
Conversational Strategies	- Observations, explanations, instructions - Conversation tactics - Book-reading conversations	Cognitive skills/Learning support) Help children remember and deeply understand events, develop vocabulary, causal reasoning, and an interest in science.	(Short-Meyerson et al., 2024;Haden et al., 2014; Ornstein et al., 2004; De Leon and Westerlund, 2021; Eberbach and Crowley, 2017; Willard et al., 2019; Shirefley et al., 2020; Joy et al., 2021)

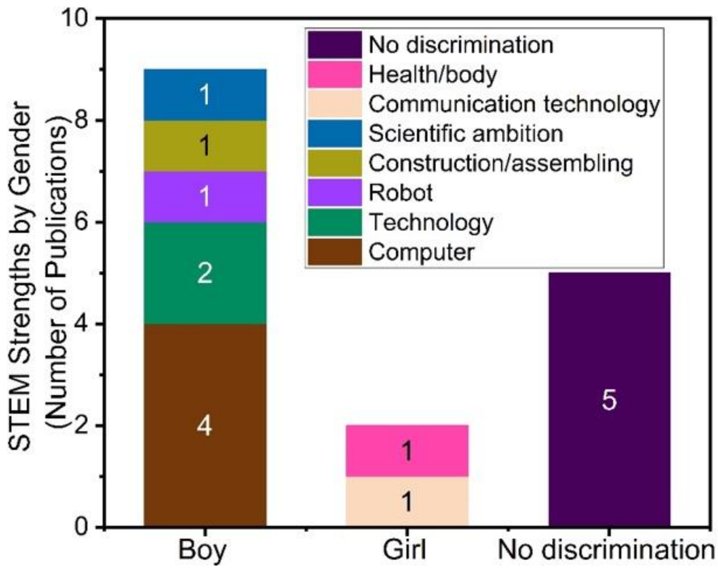
Providing Information & Support	- Using conversation cards in museums - Providing scientific information before activities	(Exploration Support) Encourage exploration, increase STEM talk, and improve knowledge transfer	(Willard et al., 2019); (Marcus et al., 2018)
STEM Language & Content	- Use of technical terms (angle, brace, crossbeam, etc.) - Discussion of 21st-century skills	(Skill Development) Improve technical skills, foster long-term motivation for STEM learning, and provide stronger problem-solving support for younger children	(Anand and Dogan, 2021; Short-Meyerson et al., 2024); Gentner et al., 2016)

Gender Influences

Findings indicate gender-based differences in STEM engagement and competence (Figure 7). Boys generally showed higher proficiency and interest in technology, robotics, and engineering, while girls expressed stronger interest in health- and human-related topics. Parents often rated boys as more knowledgeable in hands-on construction and directed more technical explanations to them, whereas girls more frequently received attention-guidance strategies and general explanations. Nonetheless, several studies reported minimal gender differences in STEM talk, suggesting that parental mediation and activity context can mitigate disparities.

Figure 7

Gender-based differences in children's STEM strengths

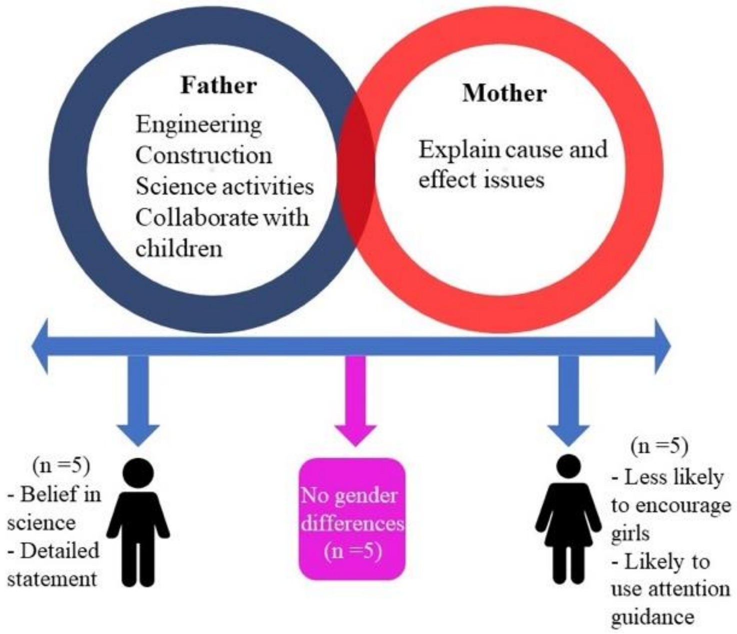


Parent-Child Conversations by Gender

Mothers tended to provide more questions and causal explanations, while fathers more often engaged in hands-on construction or technology tasks (Figure 8). Gendered conversational patterns were evident: 61% of girls received at least one parental explanation, compared to 38% of boys, but boys more often received in-depth technical guidance (Tõugu, 2021).

Figure 8

Gender-based differences in parental and child attitudes and conversational tendencies



Age Influences

Children's age shaped both parental mediation and engagement. Younger children typically received more scaffolding and verbal guidance, whereas older children engaged more independently, used technical vocabulary, and participated more in post-activity reflections. Age also influenced preferences for interactive versus static exhibits. However, multiple studies reported no significant differences in parental STEM talk across age groups. Digital access further intersected with age, with children aged 5-8 showing high levels of mobile device use, thereby expanding opportunities for self-directed STEM exploration.

RQ3-Findings: Parental Education, Income, and Children's STEM Engagement

Parental education consistently influenced children's informal STEM engagement, with higher education associated with more scientific explanations, content-rich conversations, and facilitation of diverse STEM activities. At the same time, some studies noted collaborative inquiry styles among less-educated parents, while others found no significant differences. By contrast, income showed limited direct effects; its role was mainly indirect through access to STEM resources and technologies. These patterns are summarized in Table 5, which highlights the differential effects of parental education and income on children's informal STEM engagement and learning outcomes.

Table 5

Summary of findings on parental education and income

Factor	Main Findings	References
Parental Education	Parents with advanced education or prior science experience tend to provide more scientific explanations during museum visits and exhibit-based learning.	(Siegel et al., 2007; Szechter and Carey, 2009; Tenenbaum and Callanan, 2008; Tenenbaum et al., 2002)
	Gendered engagement (sons > daughters) at moderate levels; equity increases with higher education.	(Tenenbaum and Leaper, 2003)

	Highly educated parents introduced new ideas and gave richer responses.	(Tõugu, 2021; Eberbach and Crowley, 2017)
	Collaborative, inquiry-based styles are sometimes stronger among lower-educated parents.	(Solis and Callanan, 2021)
	No significant differences in some cases.	(Fivush et al., 2006; Sobel et al., 2021)
Parental Income	No direct association with STEM conversations.	(Acosta and Haden, 2022; Sobel and Stricker, 2022)
	Indirect effects via access to digital technologies and STEM resources.	(Bonnette et al., 2019)

Discussion

RQ1-Discussion: What types of informal STEM activities and settings are most studied, and how do they influence the cognitive, affective, and behavioral development of primary school children?

The synthesis of the reviewed studies highlights that informal STEM learning has emerged as a highly interdisciplinary field that intersects psychology, education, and the learning sciences. The predominance of mixed-methods approaches (43.5%) underscores the need to capture both micro-level interactional processes and macro-level participation patterns (Figure 4; Table 2). While observational and video-based methods have proven especially effective in unpacking inquiry processes (Marcus et al., 2018; Callanan et al., 2021; Marcus et al., 2021; Doering, 2004), survey and interview-based designs (30.4%) remain central for assessing attitudinal and sociocultural dimensions (Allen et al., 2019; Burušić et al., 2021). However, the limited use of standardized measures and longitudinal case studies (2.2% each) suggests that evidence for long-term developmental outcomes remains underdeveloped, representing a crucial area for future research.

In terms of settings, the dominance of museums (~40%) reflects their semi-structured capacity to balance autonomy with scaffolded guidance (Marcus et al., 2018; Callanan et al., 2021; Marcus et al., 2021; Doering, 2004). At the same time, the growing proportion of home-based (e.g., cooking, handwashing) (22%) and community-based events (24.4%) signals a shift toward recognizing the educational value of everyday and socially embedded environments (Morris et al., 2023; Burušić et al., 2021; Sobel & Stricker, 2022; De Leon & Westerlund, 2021; Relkin et al., 2020; So et al., 2018). Multi-site approaches, extending to clubs, historic buildings, zoos, and libraries (Rushton & King, 2020; Allen et al., 2019; McGuire et al., 2020), further expand the scope of what counts as an informal STEM environment (Figure 5; Table S1).

This diversity of settings is mirrored in the range of activities studied, with parent-child conversations, play-based engagements, and hands-on design tasks functioning as critical vehicles for inquiry, problem-solving, and collaborative exploration (De Leon & Westerlund, 2021; So et al., 2018). The mapping of activities and their associated outcomes emphasizes how these experiences contribute to children's cognitive, affective, and behavioral development in complementary ways (Table 3). Importantly, parental involvement consistently emerges as a magnifier of learning processes, strengthening both engagement and knowledge transfer across home, museum, and community contexts (Marcus et al., 2018; Callanan et al., 2021; Marcus et al., 2021; Doering, 2004).

Overall, the evidence (Figures 4 and 5; Tables 2 and 3) demonstrates that informal STEM learning is not peripheral but integral to children's STEM trajectories, supporting reasoning, identity formation, and sustained interest. However, what remains insufficiently addressed is how diverse environments and activities interact longitudinally to foster cumulative STEM identities. This gap highlights the need for more systematic and comparative designs to trace developmental pathways across time.

RQ2-Discussion: How do parents mediate and facilitate children's engagement, perceived competence, and interest in informal STEM learning, and how do child gender and age influence these parental interactions?

The evidence from 28 studies highlights that parental mediation is a decisive mechanism in children's informal STEM learning, shaping engagement, competence, and interest through both structured and everyday interactions. Rather than being neutral facilitators, parents actively regulate learning trajectories by deploying strategies ranging from guided questioning to motivational support. The significance of such mediation is illustrated in Short-Meyerson et al. (2024), who found that directive yet supportive interactions facilitated comprehension and problem-solving, reinforcing earlier work linking parental talk with durable STEM learning outcomes (Haden et al., 2014; Ornstein et al., 2004). Importantly, the high proportion of Latinx parents willing to engage with STEM activities suggests that cultural expectations and community norms can amplify parents' mediating role (De Leon & Westerlund, 2021).

A critical implication emerging from the literature is that the quality of parent-child dialogue, rather than frequency alone, determines the depth of learning. Open-ended "wh-questions" and prompts for critical reasoning are repeatedly shown to stimulate scientific thinking (Haden et al., 2014; Short-Meyerson et al., 2024; Callanan et al., 2017; Benjamin et al., 2010; Anand and Dogan, 2021; Short-Meyerson et al., 2024). At the same time, interventions that provide parents with scaffolding tools, such as conversation cards (Willard et al., 2019) or preparatory explanations (Marcus et al., 2018), broaden STEM-related discourse and facilitate greater knowledge transfer during hands-on building activities. However, these benefits are counterbalanced by risks of over-scaffolding: studies in museum and aquarium contexts indicate that excessive parental commentary can reduce opportunities for children to construct and articulate their own explanations (Willard et al., 2019; Joy et al., 2021). Thus, effective parental mediation requires a balance between structuring engagement and preserving children's autonomy in inquiry processes.

Gender consistently emerges as a structuring influence on both children's STEM experiences and the ways parents interact with them. Boys are more frequently associated with engagement in engineering and technology (Walan & Gericke, 2021; Cooper, 2006; McKenney & Voogt, 2010; Mantzicopoulos et al., 2008), a pattern reinforced by home-based digital activities (Burušić et al., 2021) and parental perceptions of competence (Benjamin et al., 2010). These gendered trajectories are often linked to stereotypes internalized at an early age, whereby girls perceive robotics and programming as male domains (Master et al., 2017). Parents' conversational styles mirror such expectations: boys are provided more technical explanations (Crowley et al., 2001; Tenenbaum & Leaper, 2003; Tenenbaum et al., 2005; Tõugu, 2021), while girls often receive broader attention-guidance strategies or fewer detailed explanations preferences (Shirefley et al., 2020; Luce et al., 2013; Siegel et al., 2007). At the same time, counterevidence indicates that when parents adopt equitable mediation strategies, gender gaps in participation and STEM talk are substantially reduced (Haden et al., 2014; Ma et al., 2016; Acosta & Haden, 2022; Sobel & Stricker, 2022; Callanan et al., 2021; Ocular et al., 2022). This suggests that parental discourse can either perpetuate or counterbalance gender disparities in early STEM learning.

Child age constitutes another key determinant, shaping both the nature of mediation and the child's role in STEM exploration. Parents of younger children provide more directive and explanatory support, reflecting responsiveness to early developmental capacities (Marcus et al., 2018; Geerdts et al., 2015; Crowley et al., 2001; Tenenbaum & Leaper, 2003). Older children, in contrast, exhibit greater independence, more technical dialogue, and enhanced reflective articulation (Sobel et al., 2021; Acosta et al., 2021), consistent with developmental gains in cognitive and communicative abilities. However, findings remain mixed: some studies observe no significant differences in explanatory or scaffolding behavior across age groups, indicating that parental strategies may be more context-dependent than strictly age-driven (Acosta et al., 2021; Callanan et al., 2017; Sobel & Stricker, 2022; Ocular et al., 2022;

Marcus et al., 2018). Moreover, the widespread availability of digital devices highlights that technological access intersects with age, creating new forms of mediated STEM engagement that transcend traditional developmental boundaries (Master et al., 2017).

Taken together, the synthesis demonstrates that parental mediation is a complex, dynamic process shaped by cultural values, gender norms, and developmental trajectories. Parents can either reinforce existing disparities by privileging boys in technical domains or by dominating explanatory space, or act as agents of equity by employing questioning, scaffolding, and motivational strategies that foster curiosity and competence in all children. As illustrated in Figure 6, the combined effects of parental regulation, scaffolding, and encouragement significantly determine the quality and inclusivity of children’s informal STEM experiences.

RQ3-Discussion: How do parental education and income influence children’s engagement and learning outcomes in informal STEM activities?

The reviewed literature indicates that parental education exerts a more consistent and direct influence on children’s informal STEM learning compared with income. Higher educational attainment is repeatedly associated with content-rich interactions, explanatory talk, and facilitation of diverse STEM activities (Siegel et al., 2007; Szechter & Carey, 2009; Tenenbaum & Callanan, 2008; Tenenbaum et al., 2002). These effects extend across museum-based contexts (Franse et al., 2020), mathematics-related problem solving (Marcus et al., 2018), and structured engineering programs (Pagano et al., 2020), suggesting that educational background enhances both the quality and adaptability of parental scaffolding. Importantly, education also shapes the gendered distribution of STEM engagement, with evidence that conversational biases observed among moderately educated parents diminish at higher levels of attainment (Tenenbaum & Leaper, 2003; Eberbach & Crowley, 2017; Tõugu, 2021).

At the same time, findings are not uniform. Some studies highlight that less-educated parents adopt collaborative and inquiry-oriented strategies that stimulate children’s conceptual questioning (Solis & Callanan, 2021), while others report no systematic relationship between education and STEM engagement (Fivush et al., 2006; Sobel et al., 2021). These discrepancies underscore the need to account for cultural and contextual variations, as parental practices are embedded within broader sociocultural frameworks that may offset or even invert expected education effects.

By contrast, the role of income is less direct. Evidence suggests minimal correlations between family income and conversational depth during STEM activities (Acosta & Haden, 2022; Sobel & Stricker, 2022). Instead, income appears to function primarily through resource availability, shaping children’s opportunities to access digital technologies or extracurricular learning environments (Bonnette et al., 2019). Interventions designed to mitigate such disparities, including staggered instruction and media modeling, have been proposed as inclusive strategies to support low-income families in sustaining engagement (Raynal et al., 2022).

Taken together, the comparative evidence (Table 5) suggests that education consistently enhances explanatory and facilitative capacities, while income primarily influences structural access to learning opportunities. This distinction highlights the necessity of separating the cognitive and interactional mechanisms of education from the material affordances of income. Future research would benefit from designs that disentangle these dimensions, attending not only to the direct influence of parental background but also to the ways cultural practices and economic resources jointly mediate children’s STEM trajectories.

Practical Implications

The synthesis of reviewed studies underscores several actionable implications for practice in informal STEM education. First, parents play a decisive role in mediating children’s experiences, suggesting the need for targeted resources and training programs that enhance parents’ ability to engage in rich, inquiry-based conversations across home, museum, and community contexts (Marcus et al., 2021; Sobel & Stricker, 2022). Practical strategies such as media modeling, scaffolded questioning, and accessible STEM toolkits can empower families from diverse backgrounds to support children's learning, particularly for those with limited prior exposure to science (Raynal et al., 2022).

Second, institutions such as museums and community organizations should design flexible programs that bridge structured and unstructured engagement, enabling children to explore STEM concepts while accommodating diverse cultural and linguistic backgrounds (Allen et al., 2019; De Leon & Westerlund, 2021). Outreach initiatives in community spaces and at-home interventions may be particularly effective in expanding access to STEM for underrepresented groups who do not regularly participate in traditional cultural institutions.

Finally, practitioners in formal education can leverage findings from informal settings to enrich classroom practices. For example, encouraging design-based learning, collaborative play, and family-inclusive projects can create continuity between school and out-of-school learning, ultimately strengthening children's STEM identities and aspirations (Morris et al., 2023; Burušić et al., 2021).

Future Research Directions

Despite the breadth of evidence, several critical gaps remain that warrant systematic investigation. First, the field would benefit from longitudinal and experimental research designs that track the sustained impact of informal STEM participation over time. Current reliance on cross-sectional and observational studies limits our ability to conclude causal mechanisms or long-term identity formation (Callanan et al., 2021; Marcus et al., 2018).

Second, future work should examine cross-cultural and socio-economic diversity in greater depth. Existing studies are disproportionately concentrated in the United States and Europe, with limited representation from Asia, Africa, and Latin America (Allen et al., 2019; Relkin et al., 2020). Comparative research across different cultural contexts would not only reveal variations in parental involvement and learning practices but also expand the generalizability of current frameworks.

Third, research should focus on understudied activity types and environments, such as outdoor science camps, maker spaces, and digital hybrid learning platforms, which remain marginal in current literature but have the potential to enrich children's inquiry and problem-solving skills (McGuire et al., 2020). Exploring how these contexts interact with parental education, income, and cultural capital could further illuminate pathways to equitable participation.

Finally, advancing methodological diversity remains an urgent priority. The limited use of standardized assessments, experimental interventions, or mixed-methods triangulation limits the robustness of the findings. Greater integration of learning analytics, video ethnography, and design-based research would provide richer evidence to substantiate claims about the cognitive, affective, and behavioral outcomes of informal STEM learning.

Together, these future directions point to the need for an expanded and more inclusive research agenda, ensuring that informal STEM education is understood not only as an individual or family endeavor but as a dynamic ecosystem of interrelated influences.

Limitations

This review has several limitations that should be acknowledged. First, only studies published in English were included, which may have excluded relevant research conducted in other languages and limited the global representativeness of the findings. Second, although extensive, the selection of databases may have omitted studies available in other repositories, leading to potential database exclusion bias. These constraints suggest that the observed patterns, such as the predominance of studies from the United States and the relative scarcity of research in Asian contexts, should be interpreted with caution. Future systematic reviews could expand language inclusion criteria and search additional databases to capture a more comprehensive and culturally diverse set of studies, thereby enhancing the generalizability and robustness of conclusions.

Conclusions

This systematic review of 53 peer-reviewed studies (2010-2024) highlights the pivotal role of parents in shaping primary school children's informal STEM learning. Parental education and active facilitation consistently enriched children's engagement, while gender dynamics sometimes reinforced traditional stereotypes, signaling the need for equitable strategies to support both boys and girls. Informal STEM experiences across homes, museums, and community settings fostered cognitive, affective, and behavioral outcomes, yet these benefits were highly context-dependent, influenced by socioeconomic and cultural factors.

In practice, the findings call for stronger school-family-community partnerships and targeted resources to ensure equitable access to STEM opportunities. For future research, longitudinal, cross-cultural, and experimental designs are essential to uncover developmental pathways and address the overrepresentation of U.S. and English-language studies. Taken together, this review positions informal STEM education as a critical and complementary pathway for strengthening STEM competence, identity, and lifelong engagement among children.

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