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Math trails in mathematics education: A systematic literature review on contextual learning, student engagement, and spatial reasoning (2013 – 2025)

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Abstract
Mathematics education has faced persistent challenges in student engagement, spatial reasoning, and real-world relevance. Among innovative approaches, math trails have emerged in the last decade to integrate contextual, spatial, and technology-enhanced learning experiences. This study presents a systematic review (2013–2025) examining how math trails contribute to contextual learning, enhance student engagement, and develop spatial reasoning skills. Following PRISMA 2020 guidelines, 50 relevant peer-reviewed studies were identified via Boolean searches in major databases (Scopus, ERIC, SpringerLink, MDPI, etc.) and analyzed using thematic synthesis. Three major themes were identified. First, math trails situate mathematics in authentic contexts, linking mathematical ideas to real environments and encouraging students to model real-world situations. Second, math trails promote active, collaborative learning that increases student interest and participation. Third, math trails improve spatial reasoning through tasks involving navigation, measurement, and visual-spatial problem-solving in outdoor settings. The literature goes on to say that using mobile apps and tasks that are relevant to students' cultures can improve math trails when they are used with clear learning goals and reflection. Overall, the findings suggest that math trails are a multidimensional pedagogical approach that bridges theory and practice, yielding both cognitive and affective benefits. Future research should investigate long-term impacts, cross-context adaptations, and scalable models for broader classroom adoption.
Keywords: Math trails; contextual learning; spatial reasoning; student engagement; mobile learning

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INTRODUCTION

Over the past two decades, contextual approaches to mathematics instruction have gained significant attention for their ability to connect conceptual understanding with real-life applications. One prominent strategy is the use of math trails, which are exploration routes through real-world environments incorporating mathematical tasks at physical locations. This approach supports experiential learning and fosters students' spatial literacy, aligning with the demands of 21st-century education that emphasize critical thinking, collaboration, and authentic problem-solving skills (Borba et al., 2016; Lloyd et al., 2018).

Findings from international tests like PISA further emphasize the significance of math trials. These reports reveal that students in Indonesia and many other developing countries continue to struggle with mathematical literacy, particularly in areas like spatial reasoning and applying knowledge to real-world contexts (Cui & Guo, 2022). Mathematics instruction that remains overly abstract and disconnected from everyday experience can hinder students' motivation and engagement (Mentari & Syarifuddin, 2020). Consequently, educational interventions that promote active participation and integrate place-based learning, including math trails, are becoming increasingly relevant in today's educational landscape.

Advancements in digital technology have also expanded the potential of math trails through mobile learning tools. Educational applications such as MathCityMap and MILAGE have enriched contextual learning by integrating digital maps, GPS functionality, and augmented reality features (Figueiredo et al., 2016; T.-H. Wang et al., 2021). These tools enhance students' cognitive and emotional engagement and help develop spatial abilities by enabling direct interaction with their surroundings (Larkin & Calder, 2016; Lowrie et al., 2018).

Despite the growing implementation of math trails and related technologies, current research remains fragmented. Much of the existing literature consists of isolated case studies and lacks a comprehensive, systematic examination of how math trails contribute to contextual learning, student engagement, and spatial development over an extended period (Medová et al., 2025; Schenck & Nathan, 2024). This highlights a substantial research gap in understanding the broader educational value of math trails within mathematics education. In response to this gap, the present study undertakes a Systematic Literature Review (SLR) of 50 peer-reviewed articles published between 2013 and 2025, sourced from Scopus and other academic databases. The main objectives of this review were to explore the ways in which math trails are utilized in contextual mathematics instruction, to evaluate their impact on student engagement and the development of spatial reasoning skills, and to examine the technological and pedagogical innovations that support their implementation. This article offers a theoretical contribution by proposing an integrative framework linking math trails with spatial literacy and student engagement in the context of contextualized learning. On a practical level, the findings may inform educators, curriculum developers, and policy makers in designing meaningful, inclusive, and locally relevant strategies for mathematics learning.

METHODS

This study employed a systematic literature review approach to comprehensively examine and synthesize research on the use of math trails in mathematics education, with specific attention to contextual learning, student engagement, and spatial abilities. The review was conducted in accordance with the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a widely recognized framework that ensures methodological transparency, rigor, and replicability in literature reviews (Page et al., 2021). Guided by this protocol, the review addressed three central research questions corresponding to the objectives stated in the Introduction, using a structured multi-step data selection process.

Data Search and Sources

The literature search was conducted across reputable academic databases and publisher platforms, including Scopus-indexed sources, ERIC, SpringerLink, ScienceDirect, Taylor & Francis Online, and MDPI. Boolean search strings were used to combine keywords and related terms, including: ("math trails" OR "place-based education" OR "contextual mathematics") AND ("spatial reasoning" OR "spatial ability") AND ("student engagement" OR "learning motivation") AND ("mobile learning" OR "digital math tools"). The review focused on studies published between 2013 and 2025, a period chosen to capture contemporary perspectives and recent trends in place-based and technology-integrated mathematics education. The search was conducted in two phases: an initial comprehensive search using the full Boolean string, followed by a targeted supplementary search on specific themes to ensure broader coverage.

Inclusion and Exclusion Criteria

Studies were included in this review if they met three main criteria. First, the article had to be published between 2013 and 2025 in a Scopus-indexed journal or another reputable peer-reviewed outlet. Second, the study needed to explicitly address math trails or closely related constructs, namely contextual learning, student engagement, or spatial ability, within the domain of mathematics education. Third, the review accepted empirical research using quantitative, qualitative, or mixed-methods designs, as well as relevant theoretical analyses or review papers that provided substantive contributions to the topic. Studies were excluded if they were non-scholarly works such as opinion pieces, editorials, or unpublished reports, if they focused on areas outside mathematics education, or if they only mentioned the relevant keywords superficially without meaningful discussion of math trails or the focal concepts. To improve transparency and replicability, the inclusion and exclusion criteria were defined as a priori and applied consistently during the screening process. The criteria are summarized in Table 1 to clarify the scope of the review and the operational decisions used to determine study eligibility.

Table 1. Inclusion and exclusion criteria for study selection

Criterion Type	Criteria	Operational Clarification
Inclusion	Publication outlet and period	Peer-reviewed articles in Scopus-indexed or other reputable journals, published 2013–2025
Inclusion	Topical relevance	Explicit focus on math trails and/or contextual learning, student engagement, or spatial ability in mathematics education
Inclusion	Study type	Empirical (quantitative, qualitative, mixed-methods) and relevant theoretical analyses/review papers
Exclusion	Non-scholarly source	Opinion pieces, editorials, unpublished reports
Exclusion	Out of scope	Studies not focused on mathematics education
Exclusion	Superficial mention	Keywords appear only in passing without substantive discussion of math trails or focal constructs

Selection and Screening Process

The selection process followed the PRISMA framework and comprised three main stages: (1) an initial identification of 145 articles across multiple databases; (2) a preliminary screening based on titles and abstracts, which narrowed the selection to 73 potentially relevant articles; and (3) a full-text eligibility assessment, resulting in 50 articles retained for final synthesis. All stages were conducted manually and supported by Mendeley reference management software to eliminate duplicates. To enhance methodological rigor, two independent reviewers conducted cross-checking to strengthen inter-rater reliability. The selected studies were then subjected to a thematic analysis aimed at identifying patterns of math trail implementation, their contribution to student engagement, and their role in enhancing spatial reasoning.

To further enhance methodological transparency, the selection process is illustrated in Figure 1, which presents a simplified PRISMA flow diagram. This visualization clearly depicts the number of records identified, screened, assessed for eligibility, and ultimately included in the synthesis, thereby reinforcing the validity and replicability of the review process.

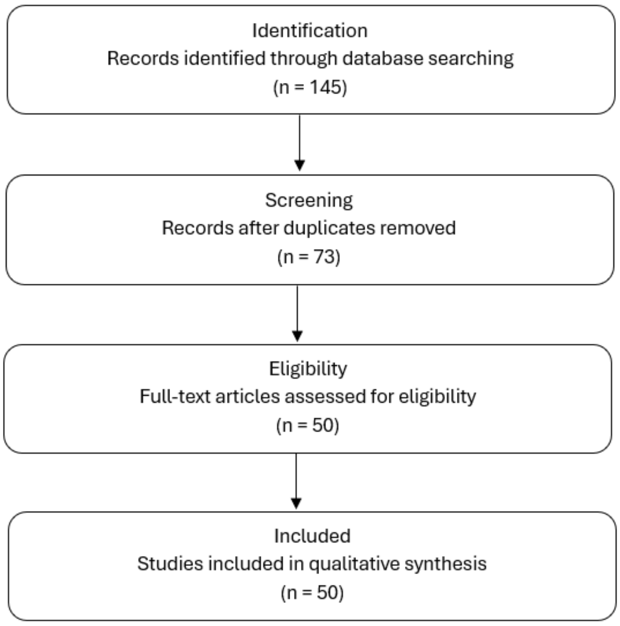

Figure 1. PRISMA Flow Diagram

From each included study, we extracted information on publication year, country or context, participants, study design, intervention or implementation characteristics, technology use, and reported outcomes linked to the three focal domains. A thematic synthesis was then conducted to identify recurring patterns and mechanisms across studies. Codes were iteratively developed and grouped into higher-order themes corresponding to contextual learning, engagement, and spatial reasoning.

RESULTS AND DISCUSSION

Results

The 50 included studies indicate a steady growth of math trail research, particularly after the mid-2010s, coinciding with increasing availability of mobile devices and location-based services. Studies span primary, secondary, and teacher education settings, with most implementations conducted as short interventions (one to three sessions) and fewer studies examining sustained integration over a semester or academic year. The corpus includes qualitative case studies, design-based research, quasi-experimental interventions, mixed-methods designs, and theoretical contributions. Outcome measures vary, including achievement tests, task-based performance assessments, spatial ability instruments, engagement surveys, observation rubrics, interviews, and artifact analyses. This heterogeneity suggests that effect claims should be interpreted in relation to design features, duration, and measurement quality.

This systematic review examined the contributions of math trails to mathematics education by analyzing 50 peer-reviewed articles published between 2013 and 2025. Collectively, these studies encompassed a broad range of research designs from experimental and quasi-experimental interventions to case studies, meta-analyses, and theoretical essays, and were conducted across diverse educational settings and geographic contexts (spanning North America, Europe, Asia, Africa, and Australia). Such diversity provided a robust basis for synthesis. Through a thematic analysis of the literature, three dominant themes emerged regarding the role and impact of math trails: (1) math trails as a contextual learning strategy; (2) math trails as a catalyst for student engagement and motivation; and (3) math trails as a means of developing spatial abilities. The distribution of studies among these thematic categories is illustrated in Figure 2.

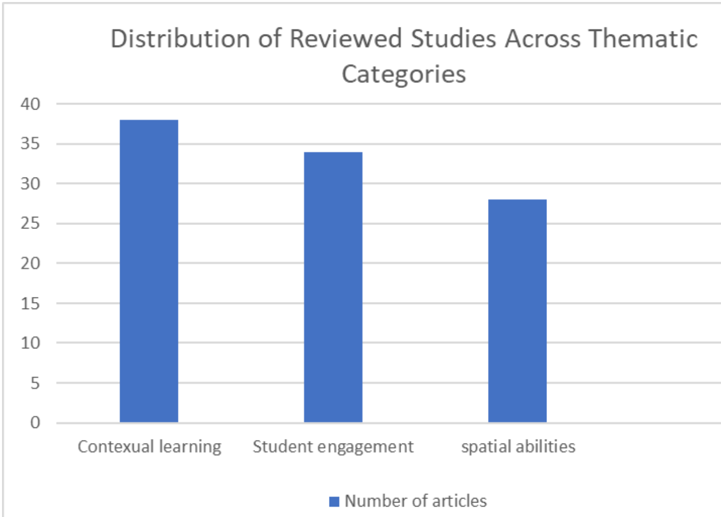

Figure 2. Distribution of reviewed studies across the three thematic categories

This bar chart shows the number of studies focusing on each theme: 38 studies (76%) addressed math trails in the context of contextualized learning, 34 studies (68%) examined student engagement and motivation through math trails, and 28 studies (56%) investigated spatial ability development. The chart highlights the prominence of contextual learning in literature, followed closely by engagement and spatial skills.

To complement the absolute counts, Figure 3 provides a proportional visualization of thematic coverage. Together, these figures make clear that math trail research is not limited to cognitive learning outcomes, but also significantly encompasses effective (engagement/ motivation) and psychomotor/spatial dimensions of mathematics education.

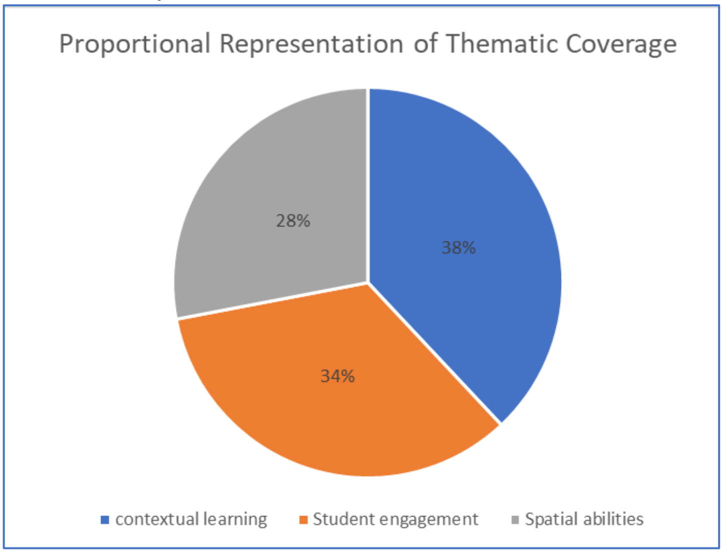

Figure 3. Proportional representation of thematic coverage

This pie chart illustrates the relative emphasis of each theme: contextual learning comprises 76% of the thematic references, student engagement 68%, and spatial abilities 56%. The visual comparison underscores that while contextual learning is the most frequently addressed aspect, engagement and spatial reasoning also represent substantial portions of the math trail research landscape.

The principal findings from the review are organized below according to the three thematic categories:

Math Trails as a Contextual Learning Strategy

Among the 50 articles reviewed, 76% (n = 38) highlighted math trails as an effective strategy for contextual learning, enabling students to connect mathematical concepts with real-world environments such as urban parks, public facilities, school grounds, and other local sites (Lloyd et al., 2018; Teise, 2025). Several studies combined math trails with established frameworks like Realistic Mathematics Education (RME) and ethnomathematics, emphasizing the integration of local cultural knowledge and values into mathematics instruction (Nurnaningsih et al., 2024; Putri et al., 2019). For example, Fesakis et al. (2018) demonstrated how mobile applications can be used to design location-based, interactive math trail activities aligned with realistic contexts. Similarly, Medová et al. (2025) underscored the importance of community and teacher collaboration in developing locally relevant, interdisciplinary trail activities. These findings suggest that math trails provide a tangible means of situating mathematical learning in students lived experiences, thereby making abstract concepts more meaningful and accessible.

Student Engagement and Motivation in Math Trails

Approximately 68% of the articles (n = 34) reported that math trails significantly enhance student engagement, often increasing motivation and interest through active exploration, teamwork, and the use of digital tools. The studies documented engagement on multiple levels: cognitive (improved concentration and problem-solving), affective (higher enthusiasm and interest in math), and behavioral (more on-task behavior and participation) (Kearney & Maher, 2013; Mentari & Syarifuddin, 2020). For instance, Lowrie et al. (2018) provided evidence that student engagement was elevated using the MathCityMap and MILAGE apps, which support map-based learning tasks and augmented reality features during math trails. Students in these studies were often more invested and interactive than in traditional classroom settings. In general, the literature suggests that the collaborative and exploratory nature of math trails, often akin to a scavenger hunt or geocaching experience, fosters greater enjoyment and involvement in learning mathematics.

Enhancing Spatial Ability through Math Trails

A total of 56% of the reviewed studies (n = 28) linked participation in math trails with improvements in spatial skills such as directional orientation, mental rotation, map-reading, and geometric visualization (Cui & Guo, 2022). Field-based math trail activities typically require students to interpret visual information, estimate distances, navigate physical space, and engage in hands-on measurement, all of which contribute to developing spatial reasoning and representation. Several studies also explored how technology-enhanced tools can deepen spatial understanding by supporting visualization and interactive representations. For example, Kurtulus and Uygan (2010) reported that Google SketchUp-based geometry activities improved pre-service mathematics teachers' spatial visualization performance. Likewise, Velázquez and Méndez (2021) showed that augmented reality applications could provide immersive visual experiences on a math trail, further reinforcing spatial conceptualization. These findings suggest that math trails, particularly when complemented by appropriate digital tools, offer a practical pathway to strengthening spatial cognition alongside mathematical content learning.

Digital and Technological Designs in Math Trails

Task design varies widely, but common mathematical domains include measurement, geometry, proportional reasoning, algebraic thinking, and data interpretation. High-quality trails typically combine three phases: (1) noticing and posing, where students identify quantitative features of objects or spaces; (2) modeling and mathematizing, where they construct representations, perform calculations, and test assumptions; and (3) reflection and consolidation, where discussion connects outdoor solutions to formal concepts. Several studies highlight the value of culturally grounded tasks where landmarks and local practices provide authentic contexts and improve relevance. In contexts with limited instructional time, on-campus trails aligned to current topics are frequently reported as a feasible entry point before expanding to community-based routes.

According to the reviewed studies, technology served four recurring instructional functions. First, navigation and orchestration features used GPS, maps, QR codes, or checkpoints to structure student movement and task sequences. Second, scaffolding and feedback provide hints, automated checking, or adaptive progression to support competence development. Third, representation tools enable learners to capture data (photos, measurements), visualize relationships, and connect physical observations to symbolic representations. Fourth, engagement features drew on game-like elements such as points, badges, or time challenges. Studies focusing on MathCityMap and similar platforms emphasize that effective implementation depends on balancing screen-based guidance with attention to the physical environment, so that technology amplifies rather than replaces embodied exploration.

Comparison with Previous Research

Overall, the results of this SLR reaffirm earlier literature asserting that contextual, real-world learning experiences can improve students' understanding and engagement in mathematics. At the same time, this review offers several novel perspectives that extend beyond prior studies. Unlike previous reviews that tended to focus on isolated dimensions of math education (such as spatial cognition or mobile learning in the classroom), our synthesis interweaves contextual, affective, and spatial dimensions within the single framework of math trails. In doing so, it explicitly links math trail activities with the development of spatial reasoning (a connection that was often only implied in earlier work) and examines the synergistic integration of place-based learning with mobile/digital tools,an area that remains underexplored in existing reviews. Furthermore, this review highlights the socio-cultural relevance of math trail pedagogy, particularly through the incorporation of ethnomathematics and culturally responsive teaching practices, which adds a new layer to the discourse on place-based mathematics education. These contributions mark a departure from prior literature and set the stage for a more holistic understanding of how math trails function as a multifaceted educational strategy

Discussion

Summary of Evidence and Mechanisms. Synthesizing across designs, the evidence indicates that math trails influence learning through mechanisms that link activity, motivation, and representation. Contextual learning gains are most consistently reported when tasks require learners to identify relevant quantities in situ and translate them into mathematical models that can be discussed and refined. Engagement benefits are strongest when trails include collaborative roles, clear task goals, timely feedback, and opportunities for choice, which support SDT needs. Spatial reasoning benefits appear when learners coordinate viewpoints, navigate routes, interpret maps, and connect physical space to diagrams, coordinate systems, and symbolic expressions. These mechanisms are interdependent because engagement increases persistence, which supports deeper mathematization and richer spatial reasoning practice.

The systematic analysis of 50 studies confirms that math trails are not merely an educational novelty, but a holistic pedagogical framework that effectively blends local context, spatial exploration, and technological integration. This interpretation aligns with contemporary situated learning perspectives that frame learning as active exploration of real-world problems in authentic contexts, supported by appropriate scaffolding and learning resources (M. Wang et al., 2025). Within outdoor mathematics, math trails are conceptualized as location-based routes where learners engage with mathematical tasks grounded in real objects and situations, often supported by digital systems such as MathCityMap to provide navigation, feedback, and opportunities for collaboration (Cahyono et al., 2023; Taranto et al., 2021). In the wider place-based education literature, learning is similarly described as being strengthened when it is meaningfully connected to local environments and community contexts, which helps explain why math trails can serve as a productive bridge between mathematical ideas and students lived spaces (Yemini et al., 2025). In this section, we discuss the implications of our results considering these perspectives, consider factors influencing implementation, and identify directions for future research.

Math Trails Considering Learning Theories

Math trails create an experiential learning environment where students actively construct mathematical knowledge through direct engagement with real-world objects and spaces. This aligns closely with principles of Realistic Mathematics Education (RME) as proposed by Freudenthal, wherein learners develop mathematical understanding grounded in everyday experience (Putri et al., 2019). By solving problems in authentic settings (measuring a real statue or analyzing patterns on a building), students move from abstract concepts to concrete understanding, reflecting constructivist ideals.

Moreover, the incorporation of place-based education in math trail design deepens students' cultural and environmental awareness while strengthening their social and ecological connections to the community (Smith, 2002; Teise, 2025). Through math trails, learning becomes situated in local significance, mathematics is not taught in isolation but emerges from exploring one's immediate environment. This contextualization reinforces situated learning theory, which holds that knowledge is more meaningful when tied to the context in which it will be used.

The use of mobile learning applications (such as MathCityMap, MILAGE, and other augmented reality tools) further enhances the adaptability of math trails to modern educational landscapes. These digital aids increase accessibility and relevance in a digitally mediated generation, and they align with theories of connectivism and experiential learning, where technology facilitates interactive, self-directed exploration (Figueiredo et al., 2016; T.-H. Wang et al., 2021). In summary, math trails embody a convergence of constructivist, situated, and experiential learning theories by emphasizing authentic, place-based engagement and leveraging technology to enrich the learning experience.

Contributions to Student Engagement and Spatial Reasoning

One of the most salient benefits of math trails evident from this review is the heightened level of student engagement they foster. By moving beyond passive classroom instruction, math trail activities promote exploration, collaboration, and even gamified learning experiences. Students become active participants in their own learning journeys, a dynamic that reinforces theories of learner agency and intrinsic motivation (Lowrie et al., 2018; Mentari & Syarifuddin, 2020). Activities such as measuring real objects, navigating outdoor locations, solving location-based puzzles, and overcoming physical challenges cultivate a sense of excitement, autonomy, and ownership in the learning process. This corresponds with Self-Determination Theory, which posits that supporting students' needs for autonomy, competence, and relatedness leads to higher motivation. Math trails inherently provide autonomy (students choose paths or strategies), build competence (applying math to solve tangible problems), and foster relatedness (working in teams in real contexts).

In terms of cognitive outcomes, math trails offer a natural platform for developing essential spatial skills. Spatial reasoning has been well-documented as a predictor of success in STEM disciplines, and our findings indicate that math trails can play a role in cultivating this skill set (Cui & Guo, 2022; Uttal et al., 2013). Many math trail tasks require students to interpret maps, visualize geometric features in the environment, estimate distances or angles, and mentally transform objects, practices that support the documented relationship between spatial skills and mathematical performance (Tam et al., 2019). When these tasks are paired with digital visualizations, such as interactive app-based constructions or immersive overlays, they can further strengthen spatial orientation and wayfinding processes that underpin spatial reasoning (Carbonell-Carrera & Saorin, 2018). Thus, math trails contribute not only to engagement and contextual understanding, but also to the development of cognitive tools that are foundational for advanced mathematical and scientific thinking.

Overall, our integrated analysis underscores that math trails constitute multidimensional learning experience bridging contextual learning, spatial reasoning, and engagement. The predominance of studies focusing on contextualization is in harmony with RME and experiential learning theory, emphasizing that grounding math in real-world experiences improves understanding. Meanwhile, the strong evidence for increased engagement aligns with motivational theories and suggests math trails meet students' psychological needs in learning. Lastly, the evidence for improved spatial ability highlights an often-underemphasized outcome of contextual math activities, an outcome that could have long-term benefits given the importance of spatial skills in STEM.

Enabling Factors and Implementation Challenges

The literature reviewed identifies several enabling factors critical to the successful implementation of math trails. A key factor is the availability and effective use of mobile and digital technology. Tablets or smartphones with GPS, mapping software, or AR capabilities can greatly enrich a math trail by guiding students, providing instant feedback or hints, and connecting outdoor observations with mathematical data. However, technological readiness varies widely; unequal access to devices or internet connectivity, especially in under-resourced schools, can pose a significant challenge (Medová et al., 2025). This suggests a need for adaptable implementations of math trails that can work with low-tech resources when necessary (using printed maps or physical compasses).

Another enabling factor is teacher support and training. Teachers play a crucial role in designing and facilitating math trails that align with curriculum goals. Several studies noted that when teachers receive professional development on outdoor mathematics activities and have time to co-design trail tasks suited to their local context, math trails are more effective and sustainable. Conversely, a lack of teacher confidence or experience in conducting outdoor learning can limit the integration of math trails into regular practice. Thus, capacity-building for teachers is essential so they can navigate logistical issues (like managing a class outside the classroom, ensuring safety, and connecting trail activities back to classroom lessons).

Logistical considerations are a practical challenge highlighted across multiple studies. Time constraints within the school schedule, concerns about student safety or supervision outdoors, and the effort required to plan a high-quality trail are commonly cited hurdles. Additionally, tailoring math trails to various socioeconomic and geographic contexts requires flexibility; what works in an urban setting (with many landmarks and public spaces) might differ from a rural setting (where distances are greater and resources fewer). Rather than seeing these challenges as deterring factors, researchers emphasize that they highlight the need for adaptable models of math trails. For example, some schools have implemented on-campus math trails (utilizing the school grounds) as an initial step before more complex community-based trails. Others have sought partnerships with local museums or community organizations to provide safe venues and additional supervision for math trail excursions.

Despite these limitations, the studies consistently suggest that such obstacles do not diminish the educational potential of math trails. Instead, they underscore the importance of institutional support: school leadership can encourage outdoor and contextual learning by allocating time (special project days), resources (devices or transport), and curricular space for math trails. Policy-level recognition, such as incorporating math trails or outdoor math modules into official curricula or guidelines, could greatly legitimize and facilitate their use. In summary, successful implementation of math trails calls for attention to equity in technology access, investment in teacher training, thoughtful logistical planning, and supportive educational policies that value experiential, place-based learning

Directions for Future Research

Building on the current findings, several directions for future research are recommended to strengthen both the evidence base and practical implementation of math trails in mathematics education. First, longitudinal experimental or quasi-experimental studies are needed to examine whether the positive effects reported in existing research, such as improved engagement, mathematical achievement, and spatial competence, are sustained over time and persist as students' progress through different grade levels. Second, future work should develop integrated assessment frameworks capable of capturing the multidimensional impact of math trails by combining cognitive outcomes (conceptual understanding and problem solving) with affective outcomes (engagement and attitudes toward mathematics) and behavioral outcomes (participation and collaboration). Third, cross-cultural and comparative studies are essential because math trails are inherently context-dependent; such studies can investigate how math trails are adapted across cultural settings and compare implementations in urban versus rural environments to identify both generalizable principles and context-specific design strategies, including the integration of local history and indigenous knowledge. Fourth, research should continue exploring technology integration and innovation, including emerging tools such as virtual reality and advanced location-based applications, while also examining the optimal balance between screen-based guidance and direct real-world exploration.

Finally, scalability and policy-oriented research is required to understand how math trails can be implemented beyond single classrooms or schools, including how they might be embedded into curriculum standards, what teacher training and resources are necessary, and what systemic barriers must be addressed. Collectively, these directions can deepen theoretical understanding of why and how math trails work and provide actionable guidance for maximizing their impact across diverse educational contexts.

CONCLUSION

This systematic literature review synthesized evidence from 50 scholarly studies to clarify the multidimensional value of math trails in mathematics education. The findings indicate that math trails are more than just supplementary activities; rather, they function as integrated learning environments that combine contextualized tasks, spatial reasoning challenges, and (often) digital support to create meaningful mathematical experiences. Across the reviewed literature, math trails consistently position students as active problem solvers who engage with authentic real-world settings and translate their observations into mathematical representations.

The review also shows that math trails align with constructivist and situated learning perspectives and with the principles of Realistic Mathematics Education by emphasizing learning by doing activities that are rich in context. In practice, math trails tend to strengthen student engagement and autonomy through exploratory and collaborative tasks that satisfy key motivational conditions for learning. They also contribute to the development of spatial abilities through students' engagement in navigation, measurement, visualization, and interpretation of spatial relationships, which are increasingly recognized as foundational skills for STEM learning. Although implementation of math trails may involve logistical constraints, the evidence suggests that supportive conditions (such as teacher readiness, adaptable local environments, and appropriate use of mobile tools) can facilitate their integration across a variety of school contexts.

Taken together, these results reinforce the conclusion that math trails represent a context-sensitive and potentially technology-enhanced strategy for connecting theoretical principles with classroom practice. To strengthen this field, future research should prioritize longitudinal studies and scalable models that can be adapted to diverse settings, and teacher education programs and curriculum developers should provide systematic support for designing, facilitating, and assessing math trail activities. With stronger evidence and sustained capacity-building, math trails can evolve from isolated innovative projects into a more established approach for fostering mathematics learning that is engaging, embodied, and grounded in students lived environments.

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