A Systematic Analysis of Effective Math Trail Characteristics in Mathematics Learning: A Literature Review

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Abstrak

Math trails dan pembelajaran di luar ruangan menawarkan matematika dengan konteks, namun karakteristik efektifnya belum dibahas. Systematic Literature Review mensintesis efektifitas dan dukungan digital. Menggunakan PRISMA, jurnal yang terindeks Scopus (2019–2025) kata "math trails" dan "outdoor learning", menghasilkan 312 artikel dan 50 artikel yang memenuhi kriteria inklusi. Analisis deskriptif dan tematik menjawab tiga pertanyaan. Efektivitas sejalan dengan desain tugas yang kontekstual, terstruktur, dan kolaboratif; dukungan digital yang proporsional, yang mendukung eksplorasi kontekstual tanpa mendominasi pengalaman belajar (umpan balik/validasi berbasis perangkat, geolokasi/GPS, dasbord pemantauan, realitas tertambah); dan koordinasi yang disengaja oleh peneliti di seluruh fase briefing pra-lapangan, petunjuk di pos dan refleksi pasca-aktivitas. Hasil dilaporkan secara konsisten mencakup peningkatan pemahaman konseptual, pemecahan masalah, motivasi dan sikap, literasi spasial, dan keterampilan sosial. Efektivitas meningkat ketika konteks budaya lokal diintegrasikan dengan scaffolding eksplisit dan teknologi yang sesuai. Batasan intervensi yang singkat dan akses teknologi yang tidak merata di sekolah. Temuan ini menawarkan kerangka kerja praktis desain kurikulum dan pengembangan pelatihan.
Kata Kunci: *efektif; karakterisitk; math trail; PMRI; SLR.*

Abstract

Math trails and outdoor learning offer context-rich mathematics, yet effective characteristics remain scattered. This review synthesizes effective features, digital supports, and key outcomes. Using PRISMA, we searched Scopus-indexed journals (2019–2025) with "math trails" and "outdoor learning," yielding 312 records; 50 met inclusion criteria. Descriptive and thematic analyses addressed three questions. Effectiveness aligned with contextualized, scaffolded, collaborative task design; proportional digital supports contextual exploration without dominating the learning experience (device-based feedback/validation, geolocation/GPS, monitoring dashboards, augmented reality); and deliberate teacher/researcher orchestration across phases pre-field briefing, on-site prompts and hints at each post, and post-activity reflection. Reported outcomes consistently included gains in conceptual understanding, problem solving, motivation and attitudes, spatial literacy, and social skills. Effectiveness strengthened when local cultural contexts were integrated with explicit scaffolding and appropriate technologies. Limitations involved short intervention windows and uneven school access to technology. Findings offer a practical framework for curriculum design and teacher professional development.
Keywords: Effective; Charateristics; Math trail; PMRI; SLR.

I. INTRODUCTION

A math trail is an outdoor learning activity in which participants explore points in public spaces to observe mathematical objects, model them, and solve mathematical problems designed for each object. Recent studies show that math trails combine group work, mathematical communication, and contextual problem solving, thereby bridging concepts with the real world (Nilimaa, 2023). The Realistic Mathematics Education (RME) framework focuses on using context to facilitate the reinvention of informal models into formal representations, which is in line with the philosophy of math trails. In Indonesia, the adaptation of RME is known as Indonesian Realistic Mathematics Education (PMRI), which emphasizes authentic phenomena and local cultural connections as the starting point for mathematization, which is a relevant foundation for math trails at tourist attractions (Afriansyah et al., 2023; Hamidah et al., 2024). The development of mobile devices makes it possible to provide real-time feedback and validation of students' answers outdoors, which will strengthen the potential of modeling on math trails. (Ludwig & Jablonski, 2019) is in line with research based on mathematical walks in informal spaces documenting how participants ask critical mathematical questions about the built environment, while linking concepts to design.

Math trails are also used to develop specific skills, such as spatial and modeling skills, and are reported to provide an enjoyable learning experience that increases student engagement. In the Indonesian context, research on design--based learning shows that mobile/augmented math trails can facilitate meaningful modeling activities through contextual tasks designed in real locations. Math trails are at the intersection of place-based learning, mathematical modeling, and realistic pedagogy, with technology serving as a lever for effectiveness (Toolin & Blouin, 2025).

Research outside Indonesia on math trails has evolved from paper trails to digital solutions that provide automatic feedback, interval-based validation, and verification-elaboration flows that trigger student reasoning. (Jablonski, 2023) theme-based mobile math trail designs propose design principles such as thematic coherence, scaffolding questions, and orchestrating technology to foster early algebraic reasoning and rich learning experiences. In line with research (Barbosa & Vale, 2020) that studies of math trails show how facilitators and adolescents together view the context of mathematics in open spaces, focusing on the importance of open-ended questions and the position of participants as co-inquirers. In research (Marchant et al., 2019) in Europe, several studies highlight group problem solving on trails and its connection to other STEM disciplines, expanding the claim of benefits beyond just a leisurely walk.

In the Indonesian context, research on AR/mobile math trails demonstrates the potential for integrating modeling, field measurement, and digital visualization at the junior high school level, revealing a mature ecosystem for large-scale development (Cahyono et al., 2020; Nugraha et al., 2023). Research (Cahyono et al., 2020) on teacher training in

MathCityMap shows that synchronous-asynchronous training design and field practice can strengthen competencies in designing math trail tasks and implementing them in different regions. Recent research explores digital feedback on MathCityMap and its relationship with the process of verifying student elaboration, marking a shift in focus from outdoor activities to a precise cognitive support architecture (Jablonski, 2022).

Evidence from math trail activities still defines the effectiveness and reporting characteristics of trail tasks, such as context type, scaffolding structure, the role of technology, and assessment forms, which tend to be heterogeneous, making it difficult to compare across studies (Barbosa & Vale, 2021). Math trail research is often small-scale and diverse in context, which limits generalization and obscures which design components contribute most to learning outcomes (Jackson & Stenger, 2024). Although there are indications of benefits in spatial abilities or engagement, the linkage to measurable learning outcomes and the validity of assessments have not been standardized, requiring a systematic synthesis that maps design features to outcomes (Laššová & Rumanová, 2023).

The purpose of this systematic literature review is to analyze the effective characteristics of math trails in mathematics learning, including task attributes, technological support for feedback or validation, pedagogical strategies such as PMRI, and assessment practices, as well as to map how these characteristics correlate with reported outcomes (Sharma, 2024). Following the PRISMA guidelines to ensure transparency in the identification, selection, and synthesis processes, this review collected studies from Scopus and Sinta to capture both global contributions and the rich context of Indonesian practices (Hoover et al., 2023). The SLR article specifically links international findings on mobile/digital math trails with local evidence to produce a framework of effective characteristics that can guide the design of trails in tourist/community spaces (Jablonski, 2023). The expected contributions are a taxonomy of task and support characteristics (content, context, scaffolding, technology, assessment), a map of the relationship between characteristics and outcomes, and a research agenda that addresses gaps in reporting and assessment standards in math trail studies.

The research question of this study is what characteristics of math trails or outdoor learning tasks (type of context, sequence of stations, level of scaffolding, measurement tools) are consistent with improving mathematics learning outcomes, what digital support features such as feedback, answer validation, geolocation, teacher dashboards, and what teacher orchestration practices have been proven to strengthen the learning process in the field. What indicators and assessment instruments are used to measure the impact and what is the direction/measure of the effect at various levels and topics, how do factors such as place/culture, accessibility and safety, teacher readiness or training, and logistical constraints

moderate the effectiveness and sustainability of math trail implementation.

Within the framework of Programme for International Student Assessment (PISA) mathematical literacy is conceptualized as students' capacity to formulate, employ, and interpret mathematics in a variety of real-world context (Masfufah & Afriansyah, 2021; Ulkhaq, 2023; Sarumaha, Khairiani, & Amirah, 2025). Math trails align closely with this framework by situating mathematical activity within authentic environments, thereby enabling learners to engage in all three PISA processes in an integrated manner. Through context-rich task embedded in real settings, students are required to mathematize situation, apply appropriate concepts and procedures, and interpret solutions in relation to the original context (Afriansyah, 2022; Nursyahidah, et al., 2025). From a theoretical perspective, math trails practice in which mathematical reasoning, representation, and communication are inherently connected to contextual meaning-making.

II. METHOD

The stages of this research, in accordance with the Systematic Literature Review (SLR) method, are Source Identification, Selection and Exclusion, Data Analysis and Synthesis. The literature sources in this study were obtained from Google Scholar, ERIC, DOAJ, and Scopus. The keywords used in the search were "Math Trail" and "Outdoor Learning." The inclusion criteria were peer-reviewed articles published between 2015 and 2025, written in Indonesian and English, and focusing on the application and analysis of

Math Trail activities in mathematics learning. Selection and exclusion were carried out on 12,000 articles found and selected into 50 articles that were relevant to the keywords searched after duplicating and reading the abstracts and contents as a whole. The next stage was data analysis and synthesis. The articles reviewed used thematic coding techniques to find characteristics that appeared repeatedly and significantly.

The systematic literature review in this study uses the Preferred Reporting for Systematic Review and Meta-Analysis (PRISMA) guidelines. This method will review Math Trail, Outdoor Learning, and Contextual Learning. This technique will obtain information relevant to subjects that meet predetermined eligibility criteria (Mengist, 2020). The PRISMA method uses a uniform approach and is evaluated by experts to review and report the results (Conde et al., 2020). The PRISMA method is in line with the systematic review process that can be carried out accurately and reliably (Mohere et al., 2010). The stages of PRISMA are identification, screening, eligibility, and inclusion (Mohamed et al., 2025).

Data identification and retrieval were conducted in ERIC, Scholar, and Scopus from 2019 to 2025. The results obtained were 312 documents using the keywords "Math Trail" and "Outdoor Learning." After screening, 262 documents did not meet the criteria for inclusion in the study because they were not related to the requested keywords. A total of 50 documents passed the screening stage. The articles included for analysis were those that met the inclusion criteria, namely,

they were registered in ERIC, Scholar, and Scopus, discussed math trails in Indonesia, and were available in open access format.

Presentation of data using descriptive statistics for data that has undergone extraction and tabulation. Findings related to the research questions are presented in a narrative summary. The following is a flowchart of the selection stages as a source of article reviews that are in accordance with the stages for Systematic Literature Review as shown in Figure 1.
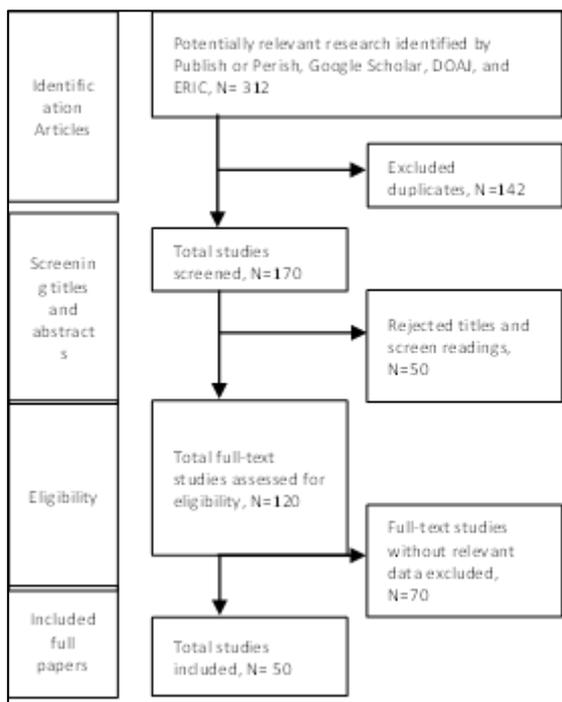

Figure 1. PRISMA Stage.

Data analysis in this study involves analyzing articles that meet the inclusion criteria using a qualitative descriptive analysis approach. There are four steps in descriptive analysis: understanding each article to be reviewed in order to obtain an overview of math trails and outdoor learning and their relevance to educational research; summarizing the findings in each article, focusing on how math trails and

outdoor learning are implemented and the effects of such implementation on learning; relating the findings in each article to answer the questions posed in this article, and drawing conclusions based on the synthesis of findings regarding the contribution of math trails and outdoor learning to student abilities.

III. RESULT AND DISCUSSION

A systematic review was conducted to analyze 50 articles published in reputable Scopus international journals from 2019 to 2025, focusing on math trails in mathematics learning. The analysis was conducted with reference to three main research questions, namely: what are the characteristics of effective math trails task designs in supporting mathematics learning; what digital support features have been proven to strengthen the effectiveness of math trails; and what learning outcomes are consistently associated with the implementation of math trails. These three aspects were chosen because they describe the key dimensions of the study title, namely the effective characteristics of outdoor learning and math trails in mathematics education.

Table 1.
Review Result Math Trails

Author	Name of Journal	Results
(Weinhandl et al., 2021)	EURASIA Journal of Mathematics and Science Teaching Education	Math trails involve real-world mathematical experiences that students explore through activities in their environment.
(Murphy et al., 2023)	Educational Studies in Mathematics	Math trails involve engaging parents in supporting their children's

Author	Name of Journal	Results
		mathematics learning through experiential and contextual activities outside the traditional classroom environment.
(Roos, 2023)	Educational Studies in Mathematics	Math trails involve students engaging with mathematics in real-world contexts, promoting participation and inclusion in mathematics education.
(Meaney et al., 2021)	Educational Studies in Mathematics	Math trails can be developed using conversational prompts that challenge traditional views of mathematics and promote inclusive discussions around social justice in education.
(Maaß et al., 2021)	International Journal of Science and Mathematics Education	Math trails connect mathematics education to real-life, socio-scientific issues, promoting active citizenship through student-centered learning.
(L. Huang et al., 2020)	International Journal of Science and Mathematics Education	Math trails can enhance inquiry-based learning by encouraging experiential and constructive engagement in mathematics.
(Beccuti, 2024)	Educational Studies in Mathematics	Math trails emphasize the exploration of mathematical concepts in real-world contexts, linking learning to practical experience.

A. Characteristics of math trails and outdoor learning mathematics activities

Consistent characteristics improve learning outcomes. A review of the summarized articles reveals that the characteristics found in math trails and outdoor learning are context type, post sequence, scaffolding level, and assessment tools. The type of context is authenticity and the direct relevance of mathematics to real life, such as the local environmental context in the research (Beccuti, 2024; Weinhandl et al., 2021), which used objects such as buildings, markets, city parks, signs, and transportation in its research. These objects encouraged mathematical exploration in math trail activities. Socio-scientific and community contexts, such as energy, water, waste, and city accessibility issues, link mathematics to real problems and decision-making, which is in line with research (Bloom & Fuentes, 2019; Gibbs & Park, 2022). Participatory and inclusive contexts, such as disability access and disability facilities in urban spaces, are included in the research (Roos, 2023) and (Meaney et al., 2021).The family or community context in this trail involves parents before/after the trail, which is useful for motivation, support, and learning transfer, as per research (Murphy et al., 2023).The inquiry context, such as findings or investigations rather than merely executing problems in research (Huang et al., 2020), is in line with research (Kollosche, 2021), which also focuses on reasoning and problem-solving. It is concluded that good location or issue

selection materials for math trails are authentic and measurable, culturally relevant, open to inquiry and discussion, and allow for variations in real data such as distance, time, frequency, and density.

Second is the sequence of stations in the math trail activity, with a gradual sequence of levels in accordance with cognitive demands, namely orientation and warm-up, which include quick observation, object classification, and preliminary estimation to build confidence in the early stages (Roos, 2023). Measurement and representation such as length, area, slope, data collection, maps, and sketches. Patterns and models that create or adjust models such as linear, proportional, and geometric models that are useful for several representations. Arguments and decisions in math trail activities, namely justification of choices, comparison of alternatives, and connection to issues or fairness (Meaney et al., 2021). Reflection and connection are posts that connect to curriculum concepts and family or community contexts. The posts are designed to have 5-7 posts containing cognitive components appropriate to the level of each post, and at the end of each post there is always a synthesis or argument task.

The scaffolding level consists of supports and fading, namely pre-trail, on-trail, differentiation and inclusion, and post-trail. Pre-trail is a brief introduction to the context and vocabulary worked on in groups and the determination of each group member's tasks (Huang et al., 2020). On trail in math trail activities, each post will have hints, namely the first hint is a general clue, the second hint is a specific clue question, and the third hint is procedural/visual, where researchers or teachers encourage reasoning and justification (Kollosche, 2021). Differentiation and inclusion are alternative representations such as sketches, maps, and photos, as well as a choice of tools at each station, such as measuring tapes, AR applications, compasses, and other items. Post-trail activities include whole-class discussions, model comparisons, linking to issues (Murphy et al., 2023), and brief written reflections.

The most noticeable improvement in learning outcomes occurs when assessments are aligned with objectives such as reasoning, problem solving, modeling, contextual relevance, and triangulation. Use short standardized pre- and post-tests aligned with topics such as propositions, geometry, and data modeling, employing a variety of question types such as multiple choice and short essays to capture reasoning (Kollosche, 2021). The performance rubric for artifacts and final assignments (4 levels) includes accuracy of measurement and data, modeling or representation, reasoning and justification, contextual relevance and community impact, and collaboration and participation in groups (Meaney et al., 2021; Roos, 2023).

B. Support features for math trail activities and outdoor learning mathematics

Digital features that support math trail activities include geolocation and navigation, structured feedback, automatic

answer validation, teacher dashboards, gamification, and task wizards (Debeş, 2018; Kalimullina & Ибрагимов, 2021). Geolocation and navigation are designed by researchers to determine locations on the MathCityMap web portal, then run via the application. MathCityMap already supports navigation tools to ensure the location of objects that have been designed and display images of objects in tasks (S., Jablonski & Ludwig, 2020).Hints are designed on the web portal and can be displayed on smartphone applications during math trail activities. Answers are validated automatically during math trails, and the solution format is in the form of intervals to tolerate measurement deviations. This is very relevant for field activities and automatic validators in the application to check students' answers. The teacher dashboard is used to monitor the progress of each group of students directly and to send support messages via chat in real time. Gamification and task wizards can be enriched with points or narratives, and task wizards also provide a general task bank as a reference for designed tasks. The technological functions for math trail activities include assessment, teacher-student communication, and a teacher dashboard on the web portal for designing tasks. This technology makes it easier for teachers or researchers to design tasks and organize activities when they begin.

The latest innovation reported in five articles from 2022 to 2025 is the use of Augmented Reality (AR) (Arvola et al., 2021; Jabar et al., 2022; Sirakaya & Alsancak Sirakaya, 2018). With AR, students can see mathematical overlays on real objects, such as symmetrical lines that can be visualized directly on buildings or function graphs that appear above roads. This technology has great potential to deepen abstract concepts through immersive visuals.

The synthesis of the reviewed studies suggests that the presence of technology in math trail activities does not automatically enhance learning. In several cases, digital tools were found to draw students' attention away from the mathematical ideas toward the devices themselves. When the use of tools such as smartphones or augmented reality is not carefully managed, students tend to rush through the tasks—moving quickly from one station to the next to complete activities procedurally—while opportunities for deeper mathematical sense-making become limited. This pattern highlights that excessive or poorly structured technology use can shift students' focus from contextual exploration and mathematical reasoning to merely operating digital features.

In contrast, studies that reported positive learning outcomes consistently emphasized the role of proportionate digital support. In these implementations, technology functioned as pedagogical scaffolding-for instance, providing answer validation, supporting navigation, or offering limited visual enhancement-without replacing physical engagement, direct observation, or peer interaction. From this perspective, technology appears to be most effective when it is used selectively and purposefully rather than continuously, allowing a balance to be maintained between embodied activity in real environments and digital interaction.

Discussion of these findings highlights the risk of over-reliance on technology. Several studies warn that too much digital interaction can actually reduce the quality of direct exploration of the real environment, which is at the heart of math trails and outdoor learning. Therefore, the balance between real exploration and digital support must be a primary concern in the development of technology-based math trails.

C. Consistent learning outcomes in the application of math trails and outdoor learning mathematics

This study summarizes the consistent learning outcomes of math trails/outdoor learning: conceptual understanding, problem solving, motivation, spatial literacy, collaboration, and positive attitudes in Table 2.

Table 2.
Review Result Consistent Learning Outcomes

Author	Name of Journal	Results
(Hammad et al., 2021)	EURASIA Journal of Mathematics and Science Teaching Education	A strong foundation in concept mapping works repeatedly, systematically, and dialogically.
(H.-M. E. Huang, 2016)	International Journal of Science and Mahtematics Education	The results show that conceptual, problem-solving, motivation, spatial, and social skills improve when tasks are contextual, multi-level, collaborative, and supported by appropriate technology.
(Nugraha et al., 2023)	International Journal on Emerging Mathematics	The designed Hypothetical Learning Trajectory (HLT) are in

Author	Name of Journal	Results
	Education	accordance with student learning activities in the teaching experiment
(Pambudi et al., 2022)D	Mathematics Eduaction Journal	The application of collaborative RME learning inside and outside the classroom makes students more active, both physically, socially, and mentally.
(Iqbal et al., 2017)	Educational Studies in Mathematics	The result revealed that there is a difference between classroom learning and AR learning. AR experiences have positive effect on students learning. Furthermore, students' confidence and motivation towards learning are achieved.

A synthesis of 50 articles published between 2019 and 2025 that explicitly used the terms "math trails" and "outdoor learning" in mathematics education. Although these two terms have different emphases, with math trails focusing on location-based task trails and outdoor learning covering a broader spectrum of field activities, both have similarities in placing authentic experiences in real environments as activities in the mathematics learning process.

The main findings were cognitive, with strong convergence seen in cognitive achievement. Most studies reported an increase in conceptual understanding, especially in geometry, measurement, and

proportion content, as well as problem-solving skills after out-of-class interventions (Hammad et al., 2021; Huang, 2016). In math trails studies, this improvement was seen in a series of graded tasks at each station, namely observation, estimation, calculation, and validation. In non-trail outdoor learning, improvement often occurs through phenomenon-based investigations, such as measurements in city parks or tourist attractions. The learning mechanism pattern is similar, namely contextualization reduces the cognitive load of abstraction, embodied and situated cognition enriches representation, and transfer to formal concepts is facilitated during reflection sessions after outdoor activities.

Affective and dispositional findings in math trails and outdoor learning show positive affective impacts, namely increased motivation, curiosity, and attitudes toward mathematics (Chiu et al., 2022; Shahali et al., 2016). Outdoor activities that require independent exploration foster students' agency and perception of the relevance of mathematics to life. The varied challenges at each station in math trails can strengthen a sense of accomplishment, while in broader outdoor learning, choice and voice (freedom to choose objects or phenomena) often drive engagement in solving problems at each station.

Spatial literacy and representation. Improvements in spatial literacy were a consistent finding in both keywords, particularly in 2D and 3D visualization, spatial orientation, and object-based geometric reasoning (Iqbal et al., 2017; Nindiasari et al., 2024). Studies that combine digital support such as AR and GPS report strengthening in cross-representation translation, such as from real objects to map sketches and symbols, although a balance with physical exploration remains crucial so as not to shift the focus from the environment to gadgets (Cahyono & Ludwig, 2019).

Collaborative social skills. Outdoor learning requires collaboration such as role sharing in the field, strategy negotiation, and mathematical communication to validate answers (Shiue & Hsu, 2017; Siller & Ahmad, 2024; Wakhata et al., 2023). In math trails, the structure of the stations facilitates coordination of steps, while in non-trail outdoor learning, collaboration depends on the design of the investigation, such as group work when collecting data on objects at each station. Although many qualitative reports support this improvement, quantitative instruments are still diverse and rarely standardized.

Moderators and conditions for success. The effectiveness of outcomes in review studies is the quality of task design, which includes clarity of mathematical objectives, scaffolding, and relevance to the curriculum, teacher orchestration practices in the form of pre-field briefings, hints during activities, and structured reflection, proportional digital support such as feedback, geolocation, teacher dashboards or monitoring, or AR as a visual enhancer, as well as duration and frequency, which includes multi-session interventions, tend to produce more stable impacts than a single visit (Cahyono et al., 2015; Ludwig & Jesberg, 2015).

limitations and research agenda. There are three prominent aspects, namely the

dominance of short-term designs, resulting in limited testing of long-term retention and transfer; the lack of uniformity in instruments for measuring spatial literacy, attitudes, and collaboration; and the need for equity and access evaluations in contexts such as rural or urban areas and schools with limited resources. Future research is important to test the dosage of interventions, experimentally compare forms of outdoor learning (trail and non-trail), and validate cross-context learning outcome instruments.

Overall, research evidence from 2019 to 2025 shows that math trails and outdoor learning produce similar outcomes, such as cognitive outcomes (concept reinforcement and problem solving), affective outcomes (motivation and positive attitudes), spatial outcomes (visualization and spatial orientation), and collaborative social outcomes (communication and team coordination). The difference between the two is the form of orchestration, such as trails with more freedom to investigate phenomena, but the mechanism for success in both is found in a combination of real contextualization, scaffolding, and reflection, which when combined with digital support will produce consistent improvements in learning outcomes.

One of the most consistent and critical findings of this review concerns the role of debriefing or post-activity reflection. Numerous studies report that math trail activities often fail to foster conceptual understanding when the learning experience ends immediately after students complete the outdoor tasks. In such cases, students may have *engaged in* mathematical activity, yet they have not had sufficient opportunities to reflect on their actions, generalize their findings, or connect their field experiences with more formal mathematical concepts.

This is where the notion of deliberate coordination becomes central. Effective studies demonstrate that teachers or researchers intentionally structure the entire sequence of the math trail, beginning with a pre-activity briefing that clarifies mathematical goals and focal ideas, continuing with guided prompts at each station, and culminating in a reflective discussion after the activity. The debriefing phase enables students to slow down their learning process, compare strategies, discuss errors, and relate their outdoor findings to more formal mathematical ideas. Without such deliberate coordination, math trails risk being reduced to engaging physical activities that offer limited mathematical meaning.
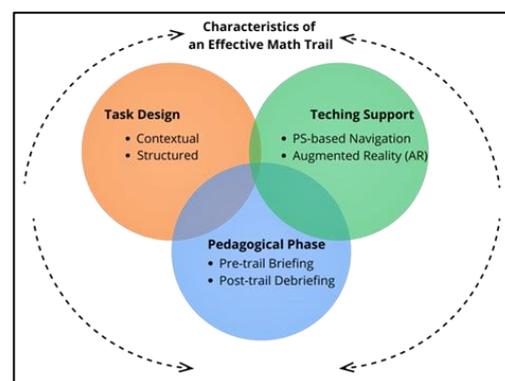

Figure 2. **Conceptual Framework of Effective Math Trail Characteristics**.

The synthesis of the research data culminates in a conceptual framework titled the Effective Math Trail Framework, as illustrated in Figure 2. This framework

posits that a successful math trail is not merely an outdoor learning, but a synergistic interaction between three core pillars: task design, teaching support, and the pedagogical phase.

First, task design ensures that mathematical problems are both econtextual, utilizing the unique physical attributes of the environment, and structured to provide appropriate scaffolding for students. Second, teaching support acts as a cognitive tool; the integration of GPS ensures seamless navigation, while Augmented Reality (AR) bridges the gap between abstract geometric concepts and real-world objects. Finally, the pedagogical phase frames the entire experience, where the pre-traill briefing sets the objective and the post-trial debriefing facilitates deep reflection and formalization of the mathematical discoveries made in the field. The intersection of three domains creates a robust learning environment that fosters both engagement and conceptual understanding.

IV. CONCLUSION

The Systematic Literature Review (SLR) research synthesized 50 Scopus-indexed articles from 2019 to 2025 on math trails and outdoor learning in mathematics education. The findings from this study indicate that effectiveness is determined by three mutually reinforcing aspects, namely contextual task design, scaffolding, and collaboration, proportional digital support including feedback or device-based validation, geolocation using GPS tools, and teacher dashboards to monitor math trail activities, and structured learning

management by researchers or teachers in the pre-field phase, during the activity, and post-activity reflection. Consistent implementation resulted in multidimensional improvements such as conceptual understanding and problem solving, motivation and positive attitudes, spatial literacy, and collaborative social skills. However, the evidence is still dominated by short-term studies, measurement instruments vary, and the issue of equitable access to technology is still inadequate. The practical implication is that teachers or researchers need to link the local cultural context to the curriculum, design a sequence of posts or investigations with explicit scaffolding, prepare monitoring protocols, and limit technology to only reinforcing real exploration. The agenda for further research includes longitudinal design, testing costs and benefits, direct comparisons between math trails and non-trail outdoor learning, and standardization of indicators of cognitive, affective, spatial, and social learning outcomes.

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