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Integration of PMRI and Outdoor Learning in the Development of Math Trail: An Exploratory Study on Characteristics, Challenges, and Practical Contributions

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Abstract

The research investigates methods to enhance student learning experiences through authentic and relevant educational activities in modern mathematics classrooms. Outdoor learning serves as an educational approach that enables students to develop better physical and mental involvement in their learning activities. The Indonesian educational system faces multiple systemic barriers that prevent outdoor learning from becoming a standard practice in schools. Research to date focuses on the teaching methods that teachers use during math trail activities, but it does not fully connect these practices to the principles of Indonesian Realistic Mathematics Education (PMRI). The research investigates outdoor mathematics learning characteristics while identifying implementation obstacles and evaluating their effects on PMRI-based math trail development. The research design uses descriptive qualitative methods, which combine data from three sources through observation, interviews, and document analysis for triangulation purposes. The research shows that outdoor mathematics education contains real-world characteristics and participatory and exploratory elements and contextual grounding but fails to follow essential PMRI standards. The research provides practical recommendations that help developers create learning paths that adapt to specific learning environments. The research applies PMRI theory to outdoor learning environments, which creates new possibilities for using contextual learning to teach mathematics through environmental exploration in Indonesian schools.

Keywords: math trail, PMRI, outdoor learning, characteristics

INTRODUCTION

The main difficulty of mathematics education during the twenty-first century involves teaching students abstract concept through experiences which stay connected to their everyday world. Research conducted abroad shows students commonly view mathematics as an inflexible subject that appears difficult to understand and lacks connection to their everyday experiences.(Kurniawan, 2019; Mertoğlu & AKMAN, 2020; Ramadhanti, 2024). The research results demonstrate that educational methods need to become more informative and relevant to specific contexts because this approach will enhance student learning of mathematics while developing their mathematical literacy skills (Ratnasari et al., 2019; Tiengyoo et al., 2024). The Organisation for Economic Co-operation and Development (OECD) defines mathematical literacy in the 2018 PISA assessment as the capacity of people to create and use and understand mathematical ideas when dealing with actual problems in the world.

The education system for mathematics has experienced multiple attempts at reform during the previous few years. The programs have concentrated on creating educational activities which provide students with relevant learning experiences that build their confidence and understanding. Research conducted in recent times shows that teachers still use traditional teaching methods which focus on student reception instead of active participation while math education mostly focuses on rote memorization instead of developing problem-solving abilities (Walid et al., 2025). The existing gap between current educational standards and student performance levels leads to ongoing poor mathematical literacy results and restricted higher-order thinking development for students in primary and secondary education.

The Indonesian Realistic Mathematics Education (PMRI) uses the Dutch-origin Realistic Mathematics Education (RME) approach to establish authentic contexts as the fundamental element of mathematics teaching. The research conducted by (Agusta, 2023; Barutu et al., 2024; Yuliana & Fembriani, 2022; Zulkardi, 2002) demonstrates that PMRI helps students achieve better comprehension through their investigation of subjects which relate to their personal life experiences. The research conducted by (Clark et al., 2019; Ertando et al., 2019; Radulović et al., 2016) shows that outdoor learning experiences help students develop curiosity while motivating them through direct environmental interaction, as it engages them directly with real environments. Ludwig & Jablonski (2019) and Malalina et al. (2022) showed that students who learned mathematics by exploring their environment and physically investigating their surroundings developed better understanding of mathematical concepts.

Conversely, outdoor learning has been demonstrated to possess significant pedagogical potential in addressing the disconnection between mathematics and students' daily lives. However, this pedagogical approach has not yet been widely adopted in Indonesian schools. The practice of outdoor learning has been demonstrated to encourage exploration, observation, and problem-solving in real-world environments(Mardhiyah et al., 2023) . (Maynard & Waters, 2007; Nugraha et al., 2023) describe how learning experiences outside the classroom can enhance students' motivation, curiosity, and conceptual understanding. The curriculum is characterised by its densely packed learning outcomes, a feature that is particularly pronounced in the case of mathematics. This aspect of the curriculum necessitates that teachers address all the material with their students. Insufficient teacher understanding and readiness in implementing outdoor-based contextual learning presents a significant challenge in designing PMRI-oriented math trails. The research findings from (Koto & Susanta, 2019; Setiawan, 2020; Sofnidar et al., 2019) demonstrates that teachers maintain their focus on textbooks and traditional classroom teaching methods which do not effectively utilize environmental resources for students to practice mathematical learning.

The PMRI approach through its contextual learning principles faces multiple significant barriers which prevent its successful implementation in educational settings. The program faces three main obstacles which stem from its inflexible educational structure and teachers' lack of expertise in creating outdoor learning activities and insufficient resources and assessments that match local needs and the absence of documented successful outdoor mathematics teaching methods in Indonesia (Abdurrahman Wahid Pekalongan et al., 2024; Alfiany et al., 2024). The current educational problems require immediate solutions which must be both suitable for local contexts and easy to implement and directly related to students' current surroundings.

The problem requires a solution based on PMRI-based mathematics learning which provides an appropriate and relevant educational method. Students follow a math trail which leads them to different stations where they need to solve mathematical problems about the objects they find at each location (Cahyono et al., 2020; Nurin et al., 2024). The development of math trails based on PMRI principles leads to better student understanding of mathematical concepts while simultaneously teaching them about their natural environment and local cultural traditions.

(Barbosa & Vale, 2020; Laššová & Rumanová, 2023; Sie & Agyei, 2023; Sukestiyarno et al., 2023) state that integrating cultural contexts such as historical sites, city parks, or local artifacts into mathematics learning pathways can create learning experiences that resonate with students' identities and the communities in which they live.

This study aims to explore the characteristics of outdoor learning–based mathematics instruction, identify the challenges that arise within its implementation, and analyze the implications for developing a PMRI-oriented math trail. The focus of this analysis lies in the systematic design, adaptability, and integration of outdoor learning experiences with the students' immediate environment. So that it can have a positive impact on direct involvement by students and their understanding. More specifically, this research will answer questions about a fun and meaningful mathematics learning model, a math trail design that suits the characteristics of students and the context around students, and practical contextual learning and assessment tools for teachers.

A critical analysis of learning practices in the five schools that were the subjects of this study shows that the integration of PMRI, math trails, and outdoor learning has not been implemented systematically. The prevailing learning approach continues to be dominated by conventional methods, which are characterised by limitations in designing activities that are contextual, cross-spatial, and relevant to the students' environment. The present study addresses this lacuna by conducting an in-depth investigation of actual practices in the field, as opposed to merely synthesising literature.

The urgency of this research is reinforced by the results of a systematic review that has been carried out (Cahyono & Ludwig, 2019a)and it can be concluded that mathematics learning carried out outdoors is still rarely the focus of research and practice in Indonesian schools. Meanwhile, the place-based learning approach developed by (Higgins, 1997; Holden, 2016; Inharjanto & Lisnani, 2019; Wang, 2023)shows effectiveness in developing students' critical thinking, problem-solving and collaboration skills. In applied contexts, this methodology is adapted to correspond with the cultural intelligence and geographical characteristics unique to Indonesia.

The unique methodology of this investigation is characterized by its analysis of the convergence of PMRI, mathematical trails, and experiential learning in outdoor environments, employing a qualitative approach with genuine participants from five educational institutions. This research combines a theoretical framework with empirical data across disciplines, developing it at a key the connection between the development of PMRI theory and the pragmatic implementation of context-oriented education.

Data from the Ministry of Education and Culture of the Republic of Indonesia revealed that the average junior high school mathematics learning outcomes are still below the national minimum standards. The contributing factors are the lack of active involvement of students in the learning process, the dominance of teacher-centred teaching methods(Awofala et al., 2024; Lamichhane & Dahal, 2021). This shows the need for new strategies that are more participatory and based on real experiences.

This research is in line with UNESCO's Sustainable Development Goals (SDG) 4, which is to ensure inclusive and quality education that supports lifelong learning opportunities. The PMRI math trail design combines mathematical exploration and strengthening of local wisdom values expects students not only to develop in cognitive aspects but also in social and affective aspects (Laurens, 2018). Thus, this research expects to make theoretical and practical contributions to the development of contextualised mathematics learning models. Theoretically the results of this study will add to the literature on learning mathematics based on the environment and local wisdom. Practically, this research gives recommendations for the design of the PMRI mathematics pathway that may be adopted by teachers in Indonesian classrooms. Amidst the pressures for innovation and educational change, our initiative is a way to make learning mathematics more interesting, relevant, and innovative.

The research develops a system which enables the creation of PMRI-based mathematical trail activities that local educational institutions can implement through their specific educational settings (Mardia et al., 2025). The research method exists to connect academic teaching methods with their practical uses in actual educational settings (Mardhiyah et al., 2023; Walid et al., 2025). The learning environment for outdoor mathematics education should include an open space which enables students to explore while maintaining their motivation.

The main objective of this research investigates how students develop their mathematical understanding through outdoor math trail experiences. The research aims to demonstrate the actual obstacles which occur in this situation while establishing suitable design principles for creating mathematics learning paths which adapt to specific contexts.

METHOD

The research design uses descriptive qualitative evaluation to create an in-depth understanding of the events which take place in a particular setting. The research method uses this approach because it allows scientists to study how participants create their own meanings during their natural environment. The investigation of complex social and educational phenomena through qualitative methods proves suitable for studying how educators and learners experience contextual and open learning environments. The research design aimed to study these events through real-world observations which used various information sources. The research used purposive sampling to conduct its descriptive qualitative inquiry.

The research study selected participants through purposive sampling which involves choosing participants who possess characteristics that match the research goals. The research team chose five educational institutions because they had experience with outdoor learning since 2020 and they represented different locations across urban and district areas. The research participants consisted of teaching professionals who took part in designing and executing outdoor learning programs. The research methodology exists to achieve two main goals which include obtaining deep insights and meaningful results from the collected data. The research study used three data collection methods which included observation and in-depth interviews and documentation to identify essential field findings. The technique exists to develop a thorough understanding of outdoor learning characteristics together with its obstacles and educational effects which support the PMRI mathematical pathway. The research procedures follow all ethical guidelines which govern scientific studies. The researchers explained both the research objectives and advantages to participants through written materials and face-to-face communication. The research participants needed to provide their consent through a signed form before starting the data collection process.

The researchers used participant initials to protect their identity information while all collected data served only for scientific research. The researchers provided all study participants with complete information about data protection measures and their freedom to join the research and their ability to leave the study whenever they wanted. The research team used three data collection methods which included observations and in-depth interviews and document analysis. The research team collected data by observing fields and conducting interviews with knowledgeable sources and analyzing different written records. The document analysis included multiple types of documents which included files and reports and archival records. The data collection process included outdoor learning activities which used learning materials and test results and photographic documentation from the implementation period. The research team performed data analysis through multiple organized steps.First, data were compiled from observations, interviews, and documentation provided by the research participants. The steps of qualitative data analysis included:a) Conducting direct fieldwork, which involved collecting data and information from participants through interviews, observations, and documentation.After that, the data that was collected is written about. b) The next step is data reduction, which means summarizing, grouping, making notes, and choosing data. c) The last step is data presentation, which means writing about the research data collected during data collection in a story-like way and showing it in tables to make it easier to grasp.

The final stage is drawing conclusions. The following stages are involved in the process of checking the validity of data in research: 1) The triangulation technique is used to conduct credibility testing. The goal of using triangulation approaches is to combine several methods in one study, which will get the most information from observational studies, interviews, and documentation. Five math teachers (TW, YT, IM, NJ, and MR) who had already used outdoor learning in their classes were chosen for in-depth interviews. After these interviews, we directly observed how math trail activities were being used in the schools of

the participants, as well as supporting documents such as lesson plans, student worksheets, and photographs of activities. The member check was done to see how closely the data matched what the data providers had given, which would make sure that the data was reliable as well as accurate. Second, transferability is the ability to adapt and use research results as a basis for application to different things and persons that share similar traits to those seen in the original study. The researcher carefully describes the environment in which outdoor learning activities take place, the various phases involved, the challenges that come up, and how outdoor learning activities are carried out.

The third point to consider is the implementation of a reliability audit of the entire research process. At this stage, objectivity is paramount. The researcher must meticulously test the relationship between the research results and the research process in order to obtain accurate and appropriate data. Should there be a demonstrable consistency between the results and the research process, it can be concluded that the data obtained is accurate and appropriate.

RESULTS

The first stage in this research is reduction with the stages of initial data selection, category labelling, presentation of core data, drawing patterns and main themes, continuous reduction. At this stage, data collected through teacher interviews, field observations, and lesson plan documents were analysed to see information that was in accordance with the focus of the research. The results of data reduction taken from the field are as follows: (a) The characteristics of the implementation of outdoor learning at junior high schools in Jambi include learning outside the classroom around the school yard but these activities have not been systematically structured in mathematics lesson planning, (b) The challenges faced by teachers are time constraints, the absence of specific curriculum guidelines for outdoor activities, lack of training related to contextual learning, (c) Learning activities are still oriented towards procedural understanding, not contextual problem solving, (d) Implications for PMRI Math Trail design.

A. Characteristics of mathematics learning based on outdoor learning

The characteristics of outdoor learning-based mathematics learning are contextual, interactive and participatory, explorative, and observation and reflection. The first characteristic is contextual in that learning is carried out in a real environment such as the school environment or school yard, this is in accordance with the results of interviews with several teachers in 5 schools. The second characteristic is interactive and participatory between students in discussing solving problems and exploring objects and taking data directly on the object that has been determined. The third characteristic is the exploration carried out by students when taking the data needed on the object of the mathematical problem such as observing, calculating, and measuring objects directly in the field. The fourth characteristic is observation and reflection carried out by students and facilitated by the teacher.

Table 1. Characteristics of Outdoor Learning and its Implication to PMRI Math Trail

No	Characteristics	Description of Findings	Implication to Math Trail Design
1	Real Contextualisation	Students understand the material better when it is applied to the	Using location context (city park, city icon mosque, icon building, and cultural building)

		surrounding environment	
2	Spatial and Motion Learning	Physical activities support understanding of the concepts of space and shape	Designing problems that involve direct object data, distance, and direction.
3	Collaborative and Social	Students actively discuss and work together when solving problems	Design LKPD and reflection sheet

Outdoor learning in mathematics learning shows that the use of real contexts in the environment outside the classroom is an experience for students to know mathematics relevantly and directly. The figure below is an example of students directly applying mathematical concepts to problems in their school environment.

Figure 1. School students measuring a park bench

Figure 1 shows that students are measuring a bench with a tree in the middle, this bench is often used for students to sit when it is break time. Students measure the length and width of the bench and calculate how many students can sit on the bench. This integrates the area of flat shapes to solve the problems given in each post.

Figure 2. Hall in the school

Figure 2 shows the context of the math trail in the school which is designed with the context of the pendopo, an iconic building located in the school, so that students are very familiar with this pendopo. The PMRI-based Math Trail design with contextual characteristics implies that each post on the trail represents a real situation. The context used describes culture, iconic buildings, and public spaces around students. Math trail is not only a fun activity but also a bridge between local reality and formal mathematical structures. The PMRI approach focuses on reality as the beginning of learning, so the authentic context becomes the main foundation of the math trail design.

Embodied learning and spatial reasoning is the second characteristic where students' physical activity and movement become an integral part of the mathematical thinking process. Students who are asked to walk, count steps, observe angles from a particular place, or design trajectories, are developing spatial reasoning - the ability to visualise and manipulate objects in space. This stage sharpens the content aspects of building and space in the PISA framework and deepens the role of movement in knowledge construction.

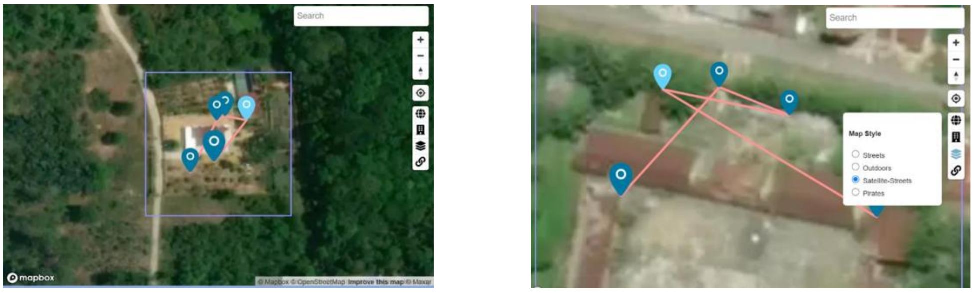

Figure 3. Plan of the maths trail activity

Figure 3 is the floor plan of the math trail in 2 different schools as an example, you can see in this floor plan the distance from post 1 to another post. So that students do physical activity and movement directly without realising it because they focus on the problems in each post and discuss for the solution of mathematical problems. When taking data to solve problems, students also perform physical activities such as counting footsteps to measure an object.

The implication for the PMRI math trail is that it is important to provide mathematical challenges that utilise student mobility such as cardinal points, distance, measurement using existing tools such as limbs, height comparisons. These activities not only activate the body but also reinforce the understanding of spatial relationships that are the basis of geometry. The design of the math trail needs to consider a meaningful spatial journey, not just a route to walk, but a journey of spatial thinking processes connected between posts.

Collaborative and social learning is the third character that is clearly seen in outdoor learning activities because of the strong social interaction in mathematics activities in the form of discussion, negotiation, and group work when finding solutions to the problems in each post. When students face real problems outside the classroom, they will tend to use collaborative strategies, such as dividing the task of measuring, cross-checking each other's results, or negotiating the interpretation of the data. This identifies that mathematics learning is not only individualistic, but also evolves and proceeds in a community of mind.

In the context of PMRI Math Trail design, this characteristic triggers the integration of group activities at each math trail post. The problem that arises demands simultaneous measurement, cross-data discussion, and estimation consensus formation to be an important part of the design. This activity is in line with the philosophy of the PMRI approach which positions students as subjects who think, dialogue, and build a uniform understanding not just to fill in answers.

B. Challenges when implementing outdoor learning in mathematics learning

The challenges during the implementation of outdoor learning in mathematics learning summarised from the observation of activities are limited time, the absence of structured modules, teacher resistance, weather and safety constraints, and lack of teacher workshops on how to design PMRI math trails. The implication on PMRI math trail design which is the purpose of this research is to design a PMRI math trail that can be a solution for outdoor learning activities in mathematics learning. The research findings that contribute to designing PMRI math trails are flexible design that can adjust to the location and conditions at school, student activities that are arranged gradually from concrete to abstract, integration of local wisdom using culturally meaningful locations, providing worksheets and guides that help teachers when implementing PMRI math trail activities, utilising MathCityMap technology which has superior navigation equipped with GPS and questions that are directly inputted on the application.

Table 2. Implementation Challenges and Solutions

No	Characteristics of	Description of Findings	Implications for Math Trail Design
1	Teacher Readiness	Lack of experience in designing learning outside the classroom	Organise a workshop for teachers on how to design PMRI math trail, create a guidebook to design PMRI math trail,
2	Outdoor location access	Not all schools have an open and safe environment	Design problems that involve direct object data, distance, and direction.
3	Assessment Difficulties	The assessment process is difficult to measure during outdoor activities.	Designing the LKPD and reflection sheet

Teachers' readiness and lack of experience in designing outdoor learning are the main challenges in the implementation of outdoor learning-based mathematics learning in the form of low teacher readiness in terms of theoretical and practical skills. Most teachers are accustomed to the indoor classification approach so that they still lack experience in designing learning that requires integrating real contexts, environmental exploration, and direct measurement of objects on site. This makes teachers feel that outdoor learning is difficult or incompatible with the curriculum. According to interviews with MR and NJ teachers at various schools, the most significant challenge in designing Math Trail questions was to ensure that the questions were genuinely contextual to the environment surrounding the objects and that they aligned with mathematical competencies and real-world conditions, such as the size, shape, and position of objects. A further challenge was ascertaining the appropriate level of difficulty for the questions, with the objective of aligning with the students' abilities.

Implications for the design of PMRI math trails need to be supported by a design that is easy to use and can be applied by teachers. Math trails should be designed with standardised flexible structures in mind, such as location plans, logistical instructions, time estimates, and adaptable sample problems. A companion module or guidebook for teachers is an important component for the dissemination and sustainability of this math trail activity.

Limited physical access and institutional support are challenges to outdoor learning activities. Access to learning locations that are safe, relevant and supportive of maths activities. Not all schools have access to city parks, cultural sites, and green open spaces that are safe for maths trail activities. Schools or institutions consider safety, liability and administrative permissions as barriers to conducting math trail activities.

In PMRI-based math trail design, it is necessary to identify and map the context in the student's environment that is easily accessible on foot or by public transport. The trail is designed in a location that is familiar with the students' daily environment either around the school or an area that is often visited by students. A trail that is familiar to students will be a mathematically meaningful trail for students. Support from the school principal, Education Office, Tourism Office, and local communities related to mathematics learning activities is a solution to the obstacles in the math trail activity.

Difficulties in assessment and documentation of outdoor activities are challenges in outdoor learning. The dynamic, spontaneous and experiential nature of outdoor learning makes it difficult for teachers to assess the process and outcomes of student learning. Math trail activities will not always get numerical answers that are directly assessed. Documentation of student work in the field, such as sketches, measurement results, and discussions are often not well documented.

Implications for math trail design include the integration of alternative assessment tools, such as observation sheets, group journals, photos of work, or supporting MathCityMap applications. Process-based assessment, collaboration, and problem-solving strategies are key components. The trail needs to be designed not only for exploratory activities, but also for authentic assessment media based on PMRI, with an emphasis on the process of thinking, interacting, and reflecting on students' mathematical experiences.

The results of the research findings on the characteristics and challenges of mathematics outdoor learning have important implications for the development of PMRI math trail. PMRI emphasises reality as the starting point of learning, social constructs, and contextualised mathematical models, which are relevant to be developed through math trail activities in green open spaces.

First, the Math trail needs to be designed with a contextual approach based on the culture and local environment around students. Such as the use of the Putri Pinang Masak Park tourist attraction as a task on the trail. This allows students to start from the reality that is around students. Each task on the trail presents a problem that not only requires calculation but also interpretation and mathematical exploration of the location. The PMRI principle that students form their own models is in accordance with the way students understand information from real spaces. Second, the design of the math trail accommodates physical activities and collaboration between students, including measurement activities, directional observations, recording observations on objects, and group discussions. Problems with multiple representations, such as field measurements translated into graphs, tables, or other visual forms, can improve the mathematical modelling process which is a key characteristic of PMRI. Third, the math trail needs to be accompanied by a structured and practical teacher's book,

Table 3. Mapping PMRI Principles with Outdoor Learning findings

No	PMRI Principles	Relevant Findings	Example of Application
1	Realistic Context	Students understand the application of mathematics through direct experience	Measuring area, pool volume, and stair height.
2	Guide Reinvention	Students build mathematical models independently from daily life experiences.	Develop a comparison formula from field observations
3	Interactivity	Students actively discuss and explore problem objects	Collaborative measurement problem discussion between groups
4	Intertwining	Mathematical concepts are integrated with students' surrounding environment	Problems about the geometric shape of regional icons or monuments
5	Progressive Formalisation	Students move from the tangible to the abstract directly	Measuring, sketching and comparing.

The potential for developing PMRI Math Trail is that the location of tourist attractions has good potential for integration in mathematics learning trajectories and appropriate activities such as measuring, classifying, and estimating are very suitable to be associated with realistic contexts. Drawing verification conclusions using data triangulation techniques between interview data, observation, and documentation, the conclusion is that outdoor learning-based mathematics learning in junior high schools has the characteristics of spontaneous and contextual activities around the school yard, but has not been designed as an integrated learning model, PMRI-based Math Trail PMRI design is very potential to be developed as a solution to present a mindful, meaningful, joyful learning, Deep learning is able to process visual, text, and sound data in real time, and solve various problems that are difficult to solve by other machine learning algorithms, the implications of the Math Trail PMRI design must consider the flexibility factor of time, curriculum integration, teacher readiness, and student safety in outdoor activities.

C. Learning activities are still orientated towards procedural understanding, not contextual problem solving.

The results show that there is still a lot of mathematics learning in junior high schools / MTs using a procedural approach. Teachers focus more on the ability to solve problems using certain formulas or algorithms without linking to real contexts. This can be seen in classroom learning activities that only focus on practice problems, memorising formulas, and solving daily problems presented in textbooks and national exam questions. The lack of contextual problem-solving activities will cause students to lack the ability to relate mathematics to the real world around students. Students only see mathematics as an abstract rule that is not relevant to their daily circumstances. This results in students lacking critical thinking skills and the ability to solve students' problems in real situations has not developed optimally. The results of interviews with 5 teachers can be concluded that the limited understanding of teachers to design questions that are contextual and stimulate students to think critically and solve real problems, the lack of mathematics learning guides or modules that support problem-based learning around students and local contexts, and the demands of completing material according to the curriculum and exam schedules that make teachers to pursue and focus on the material in the textbook in a fast and mechanical way. These findings are summarised in bold 4 and their implications.

Table 4. Findings of learning activities at school

No	Aspects observed	Field Findings	Implications
1	Teacher learning strategies	The dominance of lectures, practice questions, use of textbooks.	Learning that is still procedural
2	Types of problems given	Formula and algorithm based, not connected to the real world.	Students have difficulty in understanding the application of concepts
3	Student involvement in discussion	Lack of interaction with students, more students listen to the teacher's explanation.	Students are passive and do not develop critical thinking skills
4	Use of real context in problems	Almost none	There is no connection between concepts and real experiences.

D. Implications for PMRI Math Trail design.

The findings described above have important implications for the design of PMRI-based math trails, as shown in Table 5, problems in conventional learning and alternative designs in PMRI-based math trails. Firstly, focusing on contextual problems rather than mechanical procedures, the PMRI math trail design should present real situations and challenge students to think, reason and solve problems. The tasks in the math trail design should be related to the context around the students such as iconic buildings in tourist attractions, the size of parks, floors in tourist attractions, and patterns in a building, because this will make students explore an object to get the data needed instead of just memorising formulas and applying according to memorised algorithms.

The second is to facilitate the connection between mathematical concepts and the environment around students by making it a context such as green open parks, mosques, cultural heritage, city parks and markets. The activities on the math trail can bridge the formal understanding gained in the classroom with the reality of students' lives. This is in line with the PMRI principle that mathematics starts from the concrete to the abstract gradually (progressive formalisation). Third is the development of worksheets that encourage open thinking and reflection. In the math trail activity, the worksheet directs students to not only find the answer, but also to explain the thinking process, compare strategies, and reflect on the results. Such as "Is there any other way to measure the height of this pillar?" or "If you don't get into the pool, then how do you get the diameter of the pool?".

Fourth, it gives teachers room for flexibility and creativity in the design of the math trail which is open-ended, teachers can choose or adapt the context according to the location and characteristics of the students. This supports the implementation of PMRI which emphasises contextualisation and flexibility in learning. Fifth is the importance of teacher training in developing contextualised problems because one of the problems is the procedural dominance of teachers, so it is necessary to hold contextualised math trail training starting from finding locations looking at the safety of locations and problems that can be developed with existing contexts.

Table 5. Implication of findings to PMRI math trail design

No	Problems in conventional learning	Alternative Design on PMRI Math trail
1	Focus on memorising formulas and algorithms	Exploration activities outside the classroom such as measuring, estimating, comparing on objects around students
2	Lack of context in maths problems	Using contexts around students such as parks, markets, local buildings, and mosques.
3	Lack of interaction and discussion between students	Students worked in groups to solve the problems in the faithful post.
4	Closed-ended problems with one answer	Open-ended problems that allow for multiple approaches and discussion of solution strategies.
5	Teachers are not trained to create contextualised problems.	The PMRI math trail comes with worksheets, a teacher's manual and a PMRI math trail design workshop for outdoor learning.

DISCUSSION

The findings of the study suggest that the implementation of math trails by teachers in five schools has not been fully integrated with PMRI principles or contemporary outdoor learning theories. In the context of learning, conventional methods persist in their application. Specifically, mathematical trail activities are not being optimised to utilise the local context to its full potential, and students are not engaging in sufficient deep conceptual exploration.

The PMRI theory emphasises guided reinvention, realistic contexts, social interaction, and progress towards formalisation (Zulkardi, 2002), which are not yet dominant in the observed practices. The mathematics trails that have been devised place greater emphasis on the school environment. This finding is consistent with the conclusions of research(Pramudiani et al., 2022; Risdiyanti & Sulisworo, 2021) that the most significant challenge in implementing PMRI is teachers' capacity to develop contexts and activities that facilitate mathematical concept exploration.

The research by Mann et al. (2022) and Marchant et al. (2019), demonstrates that outdoor learning provides students with better motivation while creating more sensory experiences and improving their ability to connect concepts. The research has not yet investigated these benefits in detail The design of mathematics trail activities needs to create opportunities which enable students to interact with their environment through physical activities and mental processes and social interactions.

The data shows that students take part in mathematics trail activities at a significant rate. Their participation in the system focuses mainly on performing operational tasks. The research results show that students did not develop their conceptual knowledge through exploratory activities and reflective discourse which constructivist theory and PMRI recommend. Vygotsky demonstrates that social interactions between people serve as essential factors which help people develop their conceptual understanding. Students cannot develop their higher-order thinking abilities because there are no established methods for them to discuss mathematics.

The research uses outdoor learning theory together with PMRI as its theoretical framework. The method delivers essential knowledge which helps teachers and curriculum developers in their work. The research indicates that outdoor learning provides students with more than a new physical space because it enables them to develop their knowledge through direct environmental experiences.

The research findings demonstrate that mathematics trails fail to boost teacher involvement and student math competence because they lack proper design based on PMRI principles and outdoor learning principles. The research investigates whether taking students out of their classroom environment leads to meaningful learning achievements.

The process of adding outdoor learning activities to junior high school mathematics education faces significant obstacles. The program faces multiple obstacles which stem from teacher preparation levels and insufficient resources and weather limitations and class scheduling problems and requirements for effective classroom control. The readiness of teachers to conduct outdoor learning activities remains inconsistent. The research methods become most effective when they study student environments through contextual inquiries which connect to their educational context. The main concern stems from the lack of existing tools which support outdoor learning activities. The products in this category consist of portable equipment and tools which children can easily transport. Teachers need to be flexible with their time management and provide close supervision during outdoor learning activities because junior high school students tend to be disorganized. Educators who create outdoor learning activities need to consider weather conditions because these elements affect how well outdoor learning activities succeed. Environmental noise together with disturbances from people in the surrounding area and the introduction of unanticipated objects represent some examples of such interruptions. Research conducted by Munawar et al. (2024) shows that contextual learning requires both teacher readiness and systematic support to achieve its intended goals (Munawar et al., 2024).

The research results show that outdoor learning needs an adaptable teaching approach which works effectively under actual field conditions according to the PMRI-based math trail results. Students need to experience local culture and environmental elements throughout their regular school activities. The research suggests that teachers should receive training at workshops to create math trail activities which unite PMRI principles with outdoor learning methods. The GPS-enabled features of MathCityMap application provide essential tools which help users conduct math trail activities. The research shows that MathCityMap-based math trails function as an effective teaching tool because the application makes it easy for teachers to create mathematical activities and track student progress and monitor student activities during outdoor learning (Anaguna et al., 2024; Cahyono & Ludwig, 2019b; Nurin et al., 2024).

The PMRI Math Trail exists in a contextual relationship with Vertical Measurement Tools which form part of the PMRI technique. The problems stem from typical student experiences during their school day because students develop their models through direct observation of their environment before drawing conclusions based on classroom mathematical principles. The research project ends with a reflective exercise which helps students understand the formal mathematical concepts they learned in their classroom environment.

The PMRI Math Trail design will incorporate local cultural backgrounds to establish this feature as a distinguishing element. The goal becomes achievable through the combination of local sites which function as regional icons including specific buildings and parks and museums and educational programs throughout each section. The PMRI Math Trail design makes culture its core learning foundation which serves as the foundation for all educational activities. The research demonstrates that teaching mathematics through contextual methods which connect to students' everyday environment of Jambi tourism produces excellent results. The method has demonstrated its ability to improve student comprehension of mathematical subjects while creating deeper learning experiences. The digital era requires local context as an effective method to combat dehumanization and disconnected learning according to (Adha et al., 2024; Kamid & Ramalisa, 2019). Research shows that real-world mathematics education helps students develop personal and social connections between classroom knowledge and their everyday experiences.Students should apply their knowledge to real-world situations by studying length and width measurements and area and volume calculations and coordinate systems and basic statistical concepts.

Examples of relevant topics for contextualisation in students' surroundings include length, width, area, and volume measurement; coordinates and plane geometry; and fundamental statistics. For instance, the issue of perimeter and area of flat shapes can be taught through measurement activities of objects in an open green park or at a cultural heritage site, such as a temple (Fauziah et al., 2020). The features of acceptable content are such that it is multisensory, experience-based, and facilitates the development of higher-order thinking skills (HOTS) such as analysis and synthesis (Apino & Retnawati, 2017). Consequently, learning is not exclusively confined to formal classroom methods, but rather encompasses the widening of mathematical concepts to enhance their relevance and meaning in students' real-life circumstances. This is congruent with the notion of guide reinvention in PMRI and the meaningful learning approach in constructivist philosophy.

The following information is meant to provide a detailed overview of the subject topic. The practical limits of these findings are twofold. Firstly, the geographical scope is limited to five schools. Secondly, there is an absence of long-term impact measurements on learning achievement. It is advised that future research be devoted to the creation of an experimental design incorporating quantitative measurements of student learning outcomes. Such a design would permit the examination of learning paths based on age level and material complexity. Furthermore, future research could explore the integration of technology in the implementation of PMRI-based math trails across multiple geographical and social contexts.

CONCLUSION

The results of this study demonstrate that the implementation of math trail practice in five elementary schools in Jambi delivers a more dynamic and adventurous learning experience for kids, supported by direct engagement with real things in the surrounding environment. However, implementation that does not fully refer to PMRI principles results in low integration between outside activities and systematic and contextual mathematical meaning production. The findings indicate that, in the absence of a design built on guided reinvention, progressive formalisation, and consideration of the local cultural context, the full potential of outdoor learning cannot be effectively fulfilled. The theoretical contribution of this work is to highlight the urgency of integrating PMRI and place-based learning in the Indonesian context, emphasising the value of the local context as a reflective and interactive vehicle for understanding mathematical concepts. By examining real practices, this study addresses a gap in the literature about the difference between PMRI theory and its use in outdoor learning. Practically, this research advises building math-pathway-based learning aids that are relevant to the local context. Furthermore, this research advises building tiered learning pathways, student worksheets, and leveraging simple technologies like QR codes or augmented reality as interactive aids. Teachers need to acquire complete training in planning and facilitating exploration-based activities so they can help students shift from real-world circumstances to formal abstractions. This study provides a basis for curriculum developers and legislators to consider modifying the way mathematics is taught. The idea is to provide additional time for organized and meaningful exploration activities outside the classroom. In order to facilitate the allocation of time, contextual learning resources, and recognition of local environment-based learning models as part of the national curriculum, policy support is required. In order to facilitate further research in this area, it is essential to develop and evaluate PMRI-based math trail designs in a collaborative manner between teachers, lecturers and learning media developers. The objective of this collaborative effort is to produce replicable models of good practice, which have the potential to enhance students' mathematical literacy and thinking skills within a range of local contexts in Indonesia.

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