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Mathematical literacy learning environment for inclusive education teachers: A framework

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Abstract

The Program for International Student Assessment (PISA) 2022 study revealed low mathematical literacy scores among students, including those in inclusive education settings. A significant factor contributing to this issue is the inadequate capacity of teachers to effectively teach mathematical literacy. In response, this study aimed to design a mathematical literacy learning environment framework to enhance teachers' theoretical and practical understanding of teaching mathematical literacy in schools. The research employed a design research methodology, specifically the development study type, which involved preliminary research, prototype development, and evaluation stages. This paper focuses on the preliminary research phase, where data were collected through literature reviews and focus group discussions (FGDs) with teachers from inclusive schools. The collected data were analyzed qualitatively and descriptively. The study successfully developed a framework for a mathematical literacy learning environment that integrates courses, social media, and community engagement. This framework is intended to serve as a comprehensive reference for improving teachers' capacity to teach and assess students' mathematical literacy in a more holistic manner.

Keywords: Design Research, Framework, Inclusive Education Teachers, Learning Environment, Mathematical Literacy, PMRI

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The findings from the Program for International Student Assessment (PISA) 2022 study, published in late 2023, indicate a concerning decline in the mathematical literacy skills of Indonesian students, with performance levels continuing to deteriorate over successive assessments (OECD, 2023a). This study assessed not only the mathematical literacy of the general student population but also evaluated the abilities of students with special needs (Gamazo et al., 2019). These results present a significant challenge for the Indonesian education system, particularly for teachers in inclusive schools, who are tasked with enhancing the literacy skills of students with varying characteristics and needs (Djam'an et al., 2023). As a result, the PISA 2022 study highlights a troubling decline in mathematical literacy among Indonesian students, with ongoing deterioration observed in successive assessments, and underscores a significant challenge for the Indonesian education system, especially for teachers in inclusive schools who must address the diverse needs of students.

Teachers in inclusive schools frequently encounter challenges in delivering effective learning support to students with special needs, as they are primarily trained to educate regular students (Hornby, 2014; Ní Bhroin & King, 2020). Moreover, these teachers often struggle to design appropriate instructional strategies aimed at enhancing mathematical literacy within an inclusive classroom setting (Carty & Farrell, 2019). Consequently, these challenges hinder the optimal development of literacy skills among students in inclusive schools.

The challenges faced by teachers in developing students' mathematical literacy in inclusive schools' stem from their limited understanding of mathematical literacy frameworks, as well as a lack of familiarity with effective approaches, technologies, and assessment methods for enhancing students' mathematical literacy (Kurniastuti et al., 2023; Muhaimin et al., 2024). Additionally, teachers often lack the necessary knowledge to effectively support students with diverse characteristics and abilities. Stacey (2011) and Wijaya et al. (2024) further argue that the widespread difficulty among Indonesian teachers in fostering students' mathematical literacy is largely due to the absence of targeted programs aimed at enhancing teacher competencies in this area, unlike the initiatives implemented in other Organisation for Economic Co-operation and Development (OECD) countries.

Previous research on mathematical literacy has predominantly focused on analyzing students' abilities to answer PISA questions and the development of related questions, media, and learning models (Zulkardi & Kohar, 2018; Nusantara et al., 2021; Amir et al., 2019; Ozkale & Erdogan, 2022). Although the study by Gustiningsi et al. (2023) successfully created a Learning Management System (LMS)-based mathematical literacy environment, classroom, and community, it primarily targeted teacher engagement rather than directly addressing the enhancement of teacher competencies. Notably, there is a lack of research specifically aimed at developing the competencies of teachers in inclusive schools to effectively teach mathematics and foster students' mathematical literacy. Consequently, this study aims to bridge this gap by enhancing the competencies of teachers in inclusive schools through the development of a comprehensive mathematical literacy learning environment. Within this environment, teachers will engage with mathematical literacy frameworks, assessments, and effective teaching approaches and technologies tailored to improving students' mathematical literacy in inclusive school settings.

One effective approach for developing the mathematical literacy skills of students with diverse characteristics and needs is the Indonesian version of Realistic Mathematics Education approach called 'Pendidikan Matematika Realistik Indonesia' (PMRI) (Stacey et al., 2015; Jannah & Prahmana, 2019; Zulkardi et al., 2020; Wardani & Prahmana, 2021). PMRI emphasizes the integration of real-life contexts into mathematics instruction while carefully considering students' cognitive levels (Zulkardi & Putri, 2019; Prahmana et al., 2020; Risdiyanti et al., 2024). In inclusive school settings, it is crucial for teachers to align their instruction with students' levels of thinking, enabling them to identify appropriate starting points and learning trajectories that facilitate a deeper understanding of mathematics for all students, including those with special needs (Wardani & Prahmana, 2021). By adapting starting points and learning trajectories, teachers can enhance student engagement and motivation, improve learning outcomes, and support cognitive development in alignment with each student's developmental stage (Risdiyanti & Prahmana, 2021). Within the learning environment developed in this study, PMRI serves as one of the key approaches that teachers will explore to cultivate mathematical literacy among students.

The PISA 2022 mathematics framework highlights the importance of incorporating technology to enhance students' mathematical literacy (OECD, 2022). Technology is pivotal in facilitating both the understanding and application of mathematical literacy (Magnusson, 2023). Furthermore, Letwinsky (2017) noted that in the current digital era, individuals increasingly seek knowledge through social media,

including mathematical concepts. As such, social media can be leveraged as an effective educational tool to create a dynamic mathematical literacy learning environment (Mansah & Safitri, 2022). To effectively integrate technology into the development of mathematical literacy, it is crucial for teachers to become proficient in utilizing these tools for instructional purposes. This study proposes the creation of a learning environment that incorporates social media technology, thereby familiarizing teachers with the use of technology in teaching and learning to support the advancement of mathematical literacy.

Conversely, Graham (2007) asserts that teacher professional development is most effectively achieved through learning communities, where educators can exchange pedagogical knowledge and skills with their peers. Learning communities foster a sense of connection and motivation among teachers, empowering them to tackle teaching challenges, including enhancing mathematical literacy to address the demands of 21st-century students (Saavedra & Opfer, 2012). By engaging in discussions and collaborative efforts, teachers can disseminate innovative practices and techniques, thereby facilitating continuous professional growth. Such collaboration within learning communities also drives innovation, enabling educators to better understand and address the diverse needs of their students (Nel, 2012). Consequently, this study includes the development of a community to complement course-based learning environments and the use of social media, enhancing the overall support for teachers.

This research aims to make a substantial contribution to enhancing the competencies of teachers in inclusive schools, addressing the challenges of mathematical literacy faced by students with diverse characteristics and abilities. In light of the PISA 2022 findings, which indicate a decline in mathematical literacy in Indonesia and underscore the additional difficulties encountered by teachers in inclusive settings, this study focuses on developing course-based learning environments, utilizing social media, and fostering professional communities. These elements are designed to facilitate the sharing of experiences, innovative techniques, and motivational support among educators, thereby promoting continuous professional development. Furthermore, this research is anticipated to facilitate advancements in mathematics education within inclusive schools and align with the demands of 21st-century education in Indonesia.

METHODS

This study employed design research with a validation studies approach to develop a framework for a mathematical literacy learning environment tailored for inclusive education teachers. Design research, particularly the validation studies type, is aimed at addressing educational challenges through the application of pertinent theoretical knowledge (Plomp, 2013; Zulkardi, 2002). This methodology is deemed effective for addressing the study's problem formulation, as it aligns with the research objective of enhancing mathematical literacy instruction. By focusing on the development of a learning environment that integrates courses, social media, and professional communities, this approach seeks to provide a practical solution to the challenges faced in teaching mathematical literacy in inclusive schools.

The design research method of the development study type consists of three distinct stages. The preliminary research stage involves reviewing relevant literature and developing a framework for the mathematical literacy learning environment. The prototype stage follows, where the framework is finalized into a working prototype and subjected to testing and evaluation (Plomp, 2013). The final stage, evaluation, assesses the potential impact and effectiveness of the developed learning environment (Zulkardi, 2002).

This research is focused on the preliminary research stage. Specifically, it involved a literature

review conducted by researchers on several key areas, including the PISA, mathematical literacy, the PMRI approach, mathematics content, social media, learning environments, and inclusive education. The insights from this literature review were utilized to develop a framework for the learning environment. This development process included organizing a Forum Group Discussion (FGD) with teachers to address issues and needs related to mathematics literacy in schools, and to collaboratively design the learning environment. The research also involved creating mathematics literacy materials and modules for teachers, as well as designing a social media platform and community for mathematical literacy. Data were collected through the literature review and discussions with teachers in inclusive schools at the junior high school level in Yogyakarta and were subsequently analyzed qualitatively and descriptively.

RESULTS AND DISCUSSION

In this study, researchers designed a framework for a mathematical literacy learning environment, beginning with an analysis of the problems associated with mathematical literacy in Indonesia. The analysis revealed that students' mathematical literacy skills in Indonesia are notably low, with scores declining over the past two years (OECD, 2023a; OECD, 2023b; Wijaya et al., 2024). A contributing factor is the lack of emphasis on enhancing the competence and quality of teachers in fostering mathematical literacy among Indonesian students (Stacey, 2011). Consequently, many teachers have limited capacity to develop students' mathematical literacy skills. They often lack understanding of the mathematical literacy framework and its assessment, struggle with selecting appropriate learning approaches, and face challenges in utilizing technology to support mathematical literacy development (Wijaya et al., 2024; Lestari et al., 2018). Additionally, teachers frequently encounter difficulties in instructing students to solve PISA questions and in connecting mathematical content to real-world contexts relevant to the students (Umbara et al., 2019; Saefudin et al., 2023).

Previous studies on mathematical literacy have primarily focused on developing additional PISA questions, learning models, and analyzing students' abilities to address PISA questions, rather than enhancing teachers' capacity to cultivate students' mathematical literacy skills (Zulkardi et al., 2020; Nusantara et al., 2021; Amir et al., 2019; Ozkale & Erdogan, 2022). Research on teacher capacity building often centers exclusively on developing teachers' abilities to create PISA questions, rather than offering a comprehensive and thorough understanding of mathematical literacy (Saefudin et al., 2023). In contrast, OECD countries such as Singapore, Finland, Japan, Hong Kong, and the Netherlands have achieved success in PISA mathematical literacy assessments due to their education systems' emphasis on extensive teacher training and capacity building for teaching mathematical literacy (Stacey, 2011; Jäppinen, 2005; Andrews et al., 2014).

Previous research has largely overlooked the study of mathematical literacy within the context of inclusive schools. This gap is significant, as teachers in inclusive settings face greater challenges than those in regular classrooms. They must not only understand mathematical literacy but also tailor their teaching to accommodate students with diverse characteristics and abilities (Kurniastuti et al., 2023). Teachers in inclusive schools often struggle to provide effective learning support and face difficulties in designing lessons that effectively enhance the mathematical literacy of students with special needs (Kurniastuti, 2023; Tomėnienė, 2014). Addressing these challenges is crucial, as students with special needs are expected to encounter the same demands and complexities of 21st-century life as their peers (Genc & Erbas, 2019; Bolstad, 2020).

The OECD has made the PISA framework for mathematical literacy accessible through both a website and a downloadable file (OECD, 2022). However, merely providing access to this framework is unlikely to address the complexities involved in enhancing mathematical literacy, particularly in the context of inclusive education. This study posits that a more comprehensive learning environment is required—one where teachers can not only delve deeply into the mathematical literacy framework but also acquire the skills necessary to design effective learning trajectories and develop assessment questions tailored to evaluate students' mathematical literacy. Through a thorough problem analysis, an extensive literature review, and a FGD with teachers in inclusive schools, the researchers were able to conceptualize a framework for a mathematical literacy learning environment specifically designed for educators in inclusive settings.

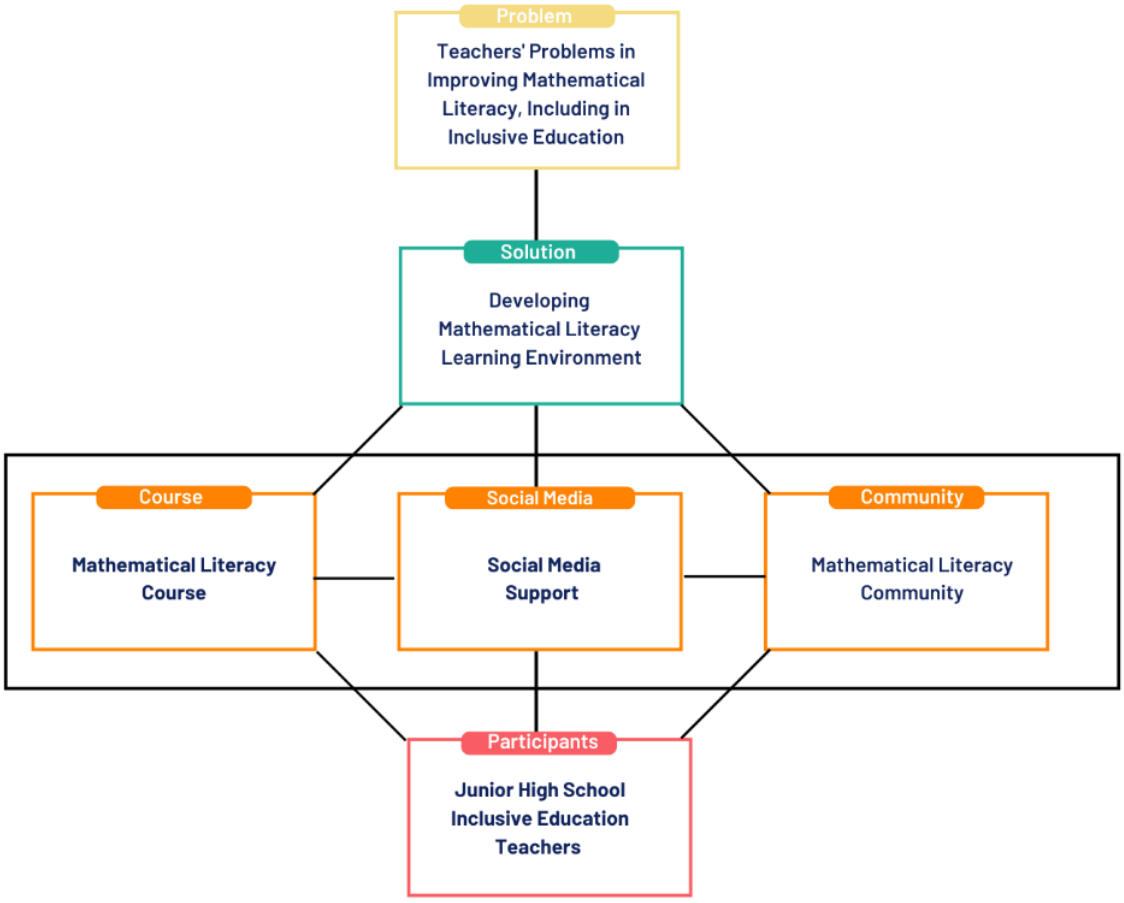

Figure 1. Conceptual framework of the mathematics literacy learning environment

Figure 1 illustrates a conceptual framework for a mathematics literacy learning environment, adapted from Zulkardi (2002). The framework begins with an analysis of the existing problems related to mathematics literacy in Indonesia, particularly within the context of inclusive education. These challenges, as discussed earlier, highlight the need for a targeted approach to enhance teachers' competencies in this area.

In response to these challenges, the researcher proposes an alternative solution: the development of a mathematics literacy learning environment. This environment is structured around three key components—course-based learning, social media engagement, and community interaction—all

designed to improve the ability of teachers in inclusive schools to teach and assess mathematical literacy effectively.

Once teachers have gained a comprehensive understanding of mathematical literacy through this structured environment, they are equipped to apply the learning trajectories and assessment questions they have developed directly in their classroom practice. This approach not only addresses the immediate needs of teachers but also ensures a sustainable improvement in the quality of mathematics education in inclusive schools, ultimately benefiting students with diverse characteristics and abilities.

This framework is designed to enhance teachers' understanding and practical skills in teaching mathematical literacy, particularly within the context of inclusive education. It integrates three key components—courses, social media, and community interactions—to create a comprehensive learning environment for teachers. The course component provides a structured approach that combines theoretical knowledge with practical applications, aimed at improving teachers' competence in delivering mathematical literacy instruction. By blending theoretical foundations with hands-on practice, the course equips teachers with the necessary tools and strategies to effectively teach mathematical concepts to students with diverse needs.

Social media platforms play a crucial role in this framework by facilitating effective information sharing and promoting collaborative learning among teachers. Interactive features such as polls, quizzes, and discussion forums are utilized to foster creativity, engagement, and the exchange of innovative teaching practices. This collaborative approach allows teachers to continuously refine their skills and stay updated with the latest educational trends and techniques.

Additionally, the community aspect of the framework supports ongoing discussions and collaboration, enabling teachers to deepen their understanding and application of mathematical concepts in real classroom settings. Through sustained professional development and peer interaction, teachers can better address the challenges of teaching mathematical literacy, especially in inclusive educational environments. Overall, this framework underscores the significance of continuous professional development and the creation of collaborative learning environments in improving the quality of mathematics education, with a particular focus on enhancing mathematical literacy in inclusive schools.

Mathematical Literacy Learning Environment based on Course

Learning mathematical literacy is inherently complex, requiring teachers to not only grasp theoretical concepts but also engage in practical applications (Schoenfeld, 2022). To effectively develop students' mathematical literacy, especially in inclusive education settings, teachers need access to a learning environment that offers both theoretical knowledge and opportunities for hands-on practice (Zagona et al., 2021; Ali & Wardat, 2024). Such an environment should enable teachers to design lessons using effective approaches, manage inclusive classrooms, address diverse student needs, assess students' mathematical literacy, and guide students in solving mathematical literacy problems (Gustiningsi et al., 2023; Bansilal et al., 2015).

Given these demands, it is crucial to provide course-based learning environments specifically focused on mathematical literacy. These courses can significantly enhance teachers' ability to cultivate students' mathematical literacy skills, equipping them with the tools and strategies necessary to succeed in diverse and inclusive educational contexts. By combining theoretical instruction with practical exercises, these courses empower teachers to meet the challenges of fostering mathematical literacy among all students, regardless of their individual characteristics and needs.

The mathematical literacy course developed in this study is structured into seven comprehensive sessions, each designed to build on the previous one, ensuring a thorough understanding and practical application of mathematical literacy concepts. The sessions cover a broad range of topics, from foundational knowledge of mathematical literacy to the application of the PMRI approach and the integration of technology and social media as teaching aids. The sessions are as follows:

1. Introduction to Mathematical Literacy
   This session focuses on providing a solid understanding of what mathematical literacy entails, its importance in education, and how it aligns with current educational standards like PISA. The objective is to ensure that teachers have a foundational understanding of mathematical literacy.
2. Introduction to Social Media for Supporting Mathematical Literacy
   Teachers are introduced to various social media platforms and tools that can enhance their understanding and teaching of mathematical literacy. This session aims to familiarize teachers with the digital tools that can be integrated into their teaching practices.
3. Effective PMRI Approaches for Developing Students' Mathematical Literacy
   This session delves into the PMRI approach, emphasizing its effectiveness in fostering mathematical literacy. Teachers learn how to apply the PMRI approach in their classrooms to enhance students' mathematical understanding.
4. Teaching Mathematical Literacy in Inclusive Schools
   This session addresses the unique challenges of teaching mathematical literacy in inclusive settings. It provides strategies for adapting lessons to meet the diverse needs of students with varying abilities.
5. Assessment of Mathematical Literacy
   Teachers are trained in assessing students' mathematical literacy, including how to develop and use assessment tools that align with PISA standards and other relevant frameworks.
6. Practice in Designing Lessons using the PMRI Approach
   This practical session allows teachers to create lesson plans that incorporate the PMRI approach, focusing on developing students' mathematical literacy. It provides hands-on experience in lesson planning and instructional design.
7. Practice in Developing PISA Questions and Implementing Lesson Plans
   The final session involves the creation and implementation of PISA-style questions, and the practical application of the lesson plans developed in previous sessions. Teachers engage in peer review and feedback to refine their teaching practices.

Each session is designed with specific objectives, activities, and durations, ensuring that teachers gain both theoretical knowledge and practical skills. The detailed framework of this course, including session components, objectives, activities, and duration, is outlined in Table 1. This structured approach aims to equip teachers with the necessary tools to effectively teach and assess mathematical literacy in inclusive education settings.

The training program outlined in the Table 1 is designed to enhance teachers' understanding and application of mathematical literacy, with a focus on integrating the PISA framework and the PMRI approach. This comprehensive program consists of ten sessions, each with specific goals, activities, and time allocations to address different aspects of mathematical literacy and inclusive education. It begins with Session 1, which provides a foundational overview of PISA and mathematical literacy. In this 60-minute session, teachers engage in discussions about PISA's objectives and review the 2022 results for

Indonesian students. This initial session sets the stage by familiarizing teachers with international standards of mathematical literacy and their implications for educational practice.

Table 1. Framework design of mathematical literacy course

Session	Course Component	Goals	Activities	Time
1	Overview PISA and Mathematical Literacy	Teachers gain an understanding of PISA and mathematical literacy	1. Discuss an overview of PISA and mathematical literacy 2. Review the results of the 2022 mathematical literacy study of Indonesian students	60 minutes
2	Introduction Mathematical Literacy via Social Media	Teachers recognize and utilize social media resources to enhance understanding of mathematical literacy	1. Access mathematical literacy resources on social media 2. Utilize these resources to gather information about mathematical literacy	60 minutes
3	Four Aspects Mathematical Literacy	Teachers comprehend the four aspects of mathematical literacy: Mathematical Reasoning, Problem Solving, Content, and Context	1. Discuss the four aspects of mathematical literacy: mathematical reasoning, problem solving, content, and context 2. Examine how content and context relevant to students can be integrated into mathematics instruction to enhance mathematical literacy skills	60 minutes
4	Introduction to PMRI as a Learning Approach for Developing Mathematical Literacy in Inclusive Education	Teachers understand PMRI (Philosophy, Principles, and Characteristics) and learn to design mathematics instruction with the PMRI approach to develop mathematical literacy	1. Explore the PMRI approach for developing mathematical literacy 2. Review an example of a mathematics learning trajectory using the PMRI approach within the context of Yogyakarta cultural tourism 3. Design a mathematics learning trajectory incorporating the PMRI approach	120 minutes
5	Teaching Mathematical Literacy in Inclusive Education	Teachers learn effective methods for teaching mathematical literacy in inclusive settings	Discuss strategies for teaching mathematical literacy to students in inclusive schools	120 minutes
6	Mathematical Literacy Assessment	Teachers acquire knowledge on assessing mathematical literacy	1. Review methods for assessing mathematical literacy 2. Develop questions for assessing mathematical literacy	120 minutes

7	Designing Learning Trajectory using PMRI Approach to Enhance Mathematical Literacy	Teachers develop a learning trajectory for mathematics instruction using the PMRI approach to improve mathematical literacy in inclusive schools	Practice creating mathematics learning trajectories that enhance students' mathematical literacy skills	2 weeks
8	Developing Mathematical Assessment	Teachers create PISA-style questions to assess students' mathematical literacy skills	Develop PISA-style questions to measure students' mathematical literacy	2 weeks
9	Implementation of Learning Trajectory Design and Mathematical Literacy Assessment	Teachers implement learning trajectory designs and mathematical literacy assessments in their schools	Implement the designed learning trajectories and assessment questions in mathematics instruction at their schools	2 weeks
10	Reflection	Teachers reflect on their experiences following the mathematics literacy course	1. Present outcomes from the implementation of learning trajectory designs and mathematical literacy assessments 2. Reflect on the overall learning experience from the course	120 minutes

Following this, Session 2 focuses on utilizing social media to support mathematical literacy. Teachers are guided to access and leverage social media resources, which are increasingly becoming valuable tools in education. This 60-minute session highlights the importance of integrating modern digital resources into teaching practices, allowing educators to stay updated with the latest trends and information relevant to mathematical literacy.

Session 3 provides a comprehensive examination of the four key aspects of mathematical literacy: mathematical reasoning, problem-solving, content, and context. Over the course of 60 minutes, teachers participate in discussions and activities that explore these aspects in depth. This session aims to deepen teachers' understanding of how these components interact and can be integrated into mathematics instruction to enhance students' literacy skills.

Session 4 introduces the PMRI approach, focusing on its philosophy, principles, and practical application. In a 120-minute session, teachers explore the PMRI approach, review examples related to Yogyakarta cultural tourism and design their own mathematics learning trajectories using this approach. This session emphasizes the development of culturally relevant and effective teaching strategies, providing teachers with the tools to create meaningful and inclusive learning experiences.

The program then transitions to practical application with Session 5, where teachers learn effective methods for teaching mathematical literacy in inclusive settings. This 120-minute session discusses strategies for addressing diverse student needs and promoting inclusivity in mathematics instruction. By focusing on inclusive education, this session aims to equip teachers with the skills necessary to cater to all students, regardless of their individual learning requirements.

The final sessions, Session 6 through Session 10, focus on assessment, implementation, and reflection. Teachers review assessment methods in Session 6 and develop PISA-style questions in Session 8, ensuring their ability to evaluate mathematical literacy effectively. Sessions 7 and 9 are dedicated to the practical application of learning trajectories and assessments, where teachers implement and refine their designs in real classroom settings over two weeks. The program concludes with Session 10, a reflection session where teachers present their outcomes and discuss their experiences. This reflective component allows for evaluation of the training's impact and provides a platform for continuous professional growth.

Overall, the training program offers a structured and comprehensive approach to improving teachers' capabilities in mathematical literacy, blending theoretical knowledge with practical application and reflection. By focusing on both international standards and culturally relevant approaches, the program aims to enhance the quality of mathematics education and support inclusive teaching practices.

Furthermore, the course was also designed to equip teachers in inclusive schools with both in-depth understanding and practical skills in teaching mathematics to enhance students' mathematical literacy. To support this, each participant received a comprehensive mathematical literacy handbook. This handbook serves as a vital resource, providing detailed guidance on various aspects of mathematical literacy education. It includes chapters on an overview of PISA and its relevance to mathematical literacy, the concept of mathematical literacy itself, the PMRI approach for developing students' mathematical literacy, designing learning trajectories using the PMRI approach, teaching mathematical literacy in inclusive educational settings, utilizing social media to support the development of mathematical literacy, assessing mathematical literacy, developing, and implementing mathematical literacy questions.

An example of the mathematical literacy handbook developed in this study is depicted in Figure 2. This handbook is intended to be a practical guide for teachers, helping them understand and apply concepts of mathematical literacy effectively in their teaching practices.

Figure 2. Mathematical literacy handbook

In addition to the handbook, teachers were provided with a mathematics literacy working module designed to facilitate their understanding and application of mathematical literacy concepts. The number of modules corresponds to the various components of the prototype mathematics literacy learning environment developed in this study. Each module is tailored to specific aspects of the course, providing practical guidance and exercises aligned with the course components.

An example of the mathematics literacy working module developed in this study is illustrated in Figure 3. This module serves as a practical tool for teachers, offering structured activities and resources to support their learning and implementation of mathematical literacy strategies in their classrooms.

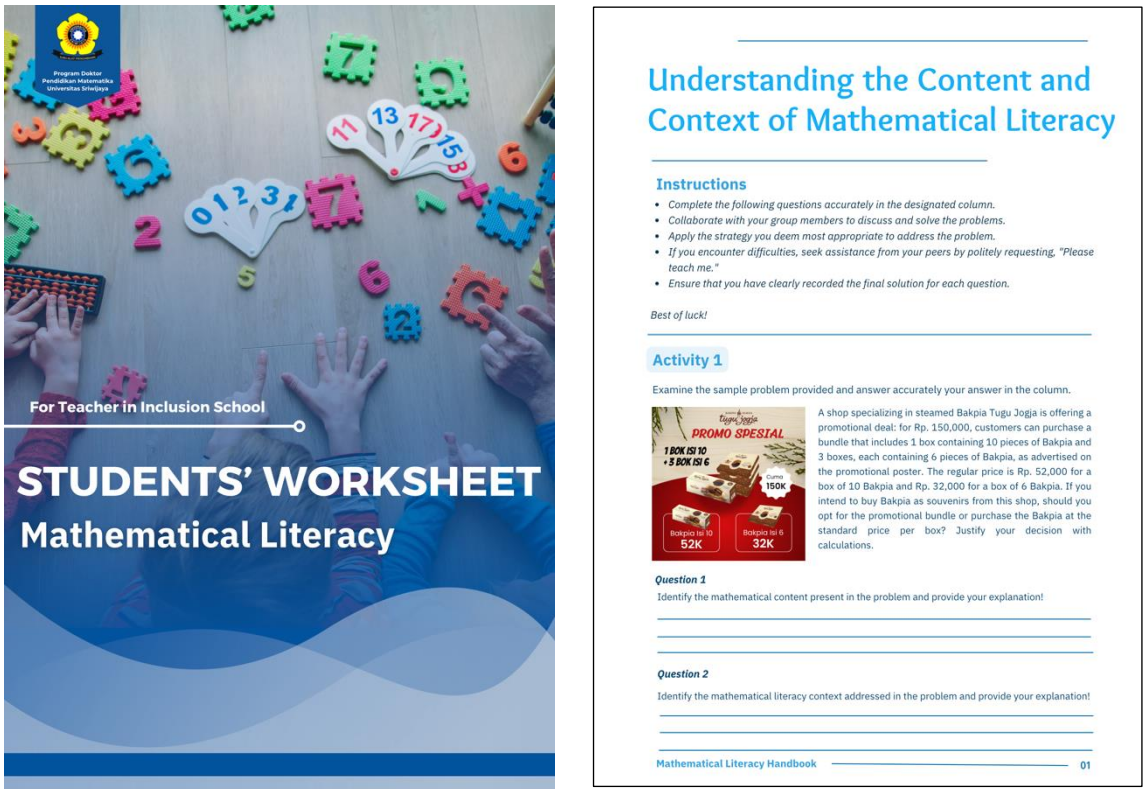

Figure 3. Mathematical literacy workbook

The workbooks were designed with a case study approach to provide a structured and practical guide for teachers in understanding and applying mathematical literacy concepts. Each workbook is carefully crafted to present clear, step-by-step instructions that help teachers navigate through the complexities of mathematical literacy.

A key feature of the workbooks is their emphasis on collaborative learning. Teachers are encouraged to engage in group discussions as a central part of the course. The modules guide teachers to work together, share ideas, and collaboratively solve problems, fostering a community of practice. This approach not only enhances individual understanding but also promotes collective problem-solving and knowledge sharing among teachers. By incorporating group discussions and collaborative activities, the workbooks aim to create an interactive learning environment that supports teachers in developing effective strategies for teaching mathematical literacy, ultimately benefiting their students in inclusive educational settings.

Mathematical Literacy Learning Environment based on Social Media

This research also developed a virtual-based mathematics literacy learning environment through social media support. In the current era of advanced digital technology, social media has become a vital tool for obtaining information and sharing ideas and experiences. Ansari and Khan (2020) emphasize that social media significantly impacts education by allowing individuals, groups, and institutions to create and disseminate knowledge through the Internet. Additionally, social media platforms enable active participation, collaboration, and interaction, fostering communities where creativity, ideas, and experiences can be shared and learned from (Gaceri et al., 2022).

The development of a social media-based mathematics literacy learning environment in this study aimed to create a flexible and accessible platform for teachers. This environment was designed to facilitate active participation, collaboration, and the exchange of ideas, creativity, and experiences related to mathematics literacy. Researchers utilized various social media channels, including Instagram, Facebook, and X, to reach teachers and provide valuable resources.

The content shared on these social media platforms covered topics such as the PISA, mathematical literacy, the PMRI approach, and PISA-type questions. Table 2 outlines the design and structure of the mathematics literacy social media content, illustrating how these platforms were used to support and enhance teachers' understanding and practice of mathematical literacy.

Table 2. Social media content design for mathematics literacy

No	Topic	Post	Content	Content Description
1	PISA	Post 1	What is PISA?	Provides a brief explanation of the PISA
		Post 2	PISA Objectives	Explains the objectives of PISA and its benefits to educational systems and student outcomes
		Post 3	PISA Contribution	Describes how PISA contributes to educational policy and practice
		Post 4	PISA Assessment Domain	Provides an overview of the three assessment domains of PISA: mathematical literacy, science literacy, and reading literacy
		Post 5	Literacy Assessment in PISA	Explains the technical methods employed by PISA to assess students' literacy skills
2	Mathematical Literacy	Post 6	What is Mathematical Literacy?	Defines mathematical literacy and its significance
		Post 7	Mathematics Literacy Assessment	Describes the four aspects of mathematical literacy assessed in PISA: Mathematical Reasoning, Problem Solving, Content, and Context
		Post 8	Definition of Mathematical Reasoning	Provides a brief explanation of mathematical reasoning as outlined in the PISA 2022 Framework
		Post 9	Importance of Mathematical Reasoning	Discusses the importance of mathematical reasoning in practical life

		Post 10	Difference Between Mathematical Reasoning and Mathematical Thinking	Explains the distinction between mathematical reasoning and mathematical thinking with practical examples
		Post 11	Indicators of Mathematical Reasoning in Students	Describes conditions under which students demonstrate mathematical reasoning skills
		Post 12	Types of Mathematical Reasoning	Outlines various types of mathematical reasoning
		Post 13	Six Keys to Mathematical Reasoning	Discusses six essential components of mathematical reasoning
3	PMRI's Approach	Post 14	What is PMRI?	Provides a definition and brief history of the PMRI approach
		Post 15	Philosophy of PMRI	Explains the underlying philosophy of the PMRI approach
		Post 16	Realistic Concepts in PMRI	Describes the concept of realism within the PMRI approach
		Post 17	PMRI Principles	Outlines the core principles of the PMRI approach
		Post 18	Advantages of PMRI for Developing Mathematical Literacy	Explains why PMRI is advantageous for developing students' mathematical literacy skills
		Post 19	PMRI Learning Design	Provides an example of a learning design using the PMRI approach to enhance students' mathematical literacy skills
4	Teaching Mathematical Literacy in Inclusive Education	Post 20	Teaching Mathematical Literacy in Inclusive Education	Explains methods for teaching mathematical literacy in inclusive educational settings
5	PISA-Type Questions	Post 21	What are PISA Type Questions?	Defines PISA-type questions
		Post 22	Characteristics of PISA-Type Questions	Describes the characteristics of PISA-type questions and their role in assessing students' literacy skills
		Post 23	Examples of PISA-Type Questions	Provides examples of PISA-type questions

Overall, the social media literacy content developed in this study offers a comprehensive resource to guide teachers in understanding and teaching mathematical literacy. Beyond the static content uploaded to the feed, the study also leveraged various interactive social media features such as questions, polls, quizzes, links, reels, retweets, and threads. These features were strategically used to create a more dynamic, participatory, and collaborative learning environment, enriching the classroom

experience and engaging teachers in meaningful ways. An example of the social media design created in this research is illustrated in Figure 4. This example highlights the use of these tools to foster an interactive educational community centered around mathematical literacy.

Figure 4 showcases examples of mathematical literacy social media content on Instagram, Facebook, and X, which have been systematically designed following the content structure developed in this study. Each post, ranging from explanations of PISA to detailed PISA-style questions, is crafted to offer deep insights into critical topics within mathematical literacy. The primary goal of these posts is to disseminate valuable and relevant information to educators, students, and parents, thereby enhancing their understanding of key aspects of mathematical literacy. Through these platforms, the content aims to foster greater awareness and knowledge of mathematical literacy concepts, ultimately supporting improved educational outcomes.

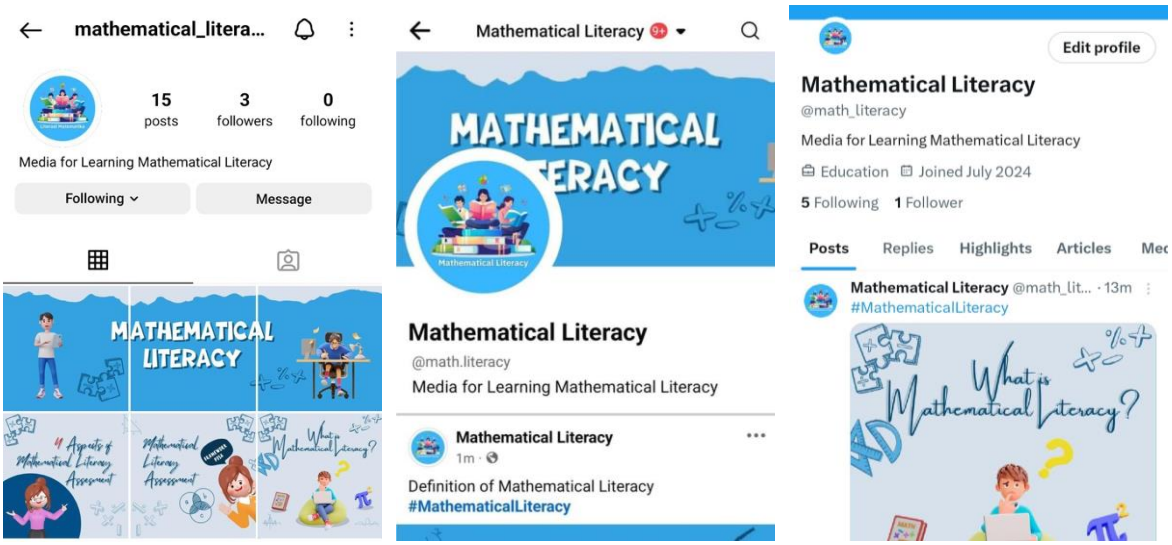

Figure 4. Social media of mathematical literacy on Instagram, Facebook, and X

Mathematical Literacy Learning Environment based on Community

The community-based mathematical literacy learning environment developed in this study is designed to promote collaboration, reflection, and growth among participants. A community, as defined by Hord (2009), refers to a gathering of individuals in a social setting united by a common purpose, mutual respect, and a commitment to integrity and shared goals. In this context, the community formed is a professional learning community focused on enhancing mathematical literacy.

This professional community is built upon three fundamental dimensions:

1. Inquiry Dimension
   This dimension emphasizes the community's focus on a specific topic, in this case, mathematical literacy. It encourages participants to explore and investigate various aspects of mathematical literacy deeply.
2. Practice Dimension
   Here, the community engages in activities that foster the development of shared practices. These activities are designed to help members collaboratively design learning trajectories, develop PISA-type questions, and implement these strategies in real classroom settings.

3. Community Dimension
   This dimension underscores the importance of meaningful collective learning, characterized by trust, reciprocity, engagement, and shared roles. It is within this dimension that members of the community come together to share experiences, discuss challenges, and support one another in their professional growth.

The community-based learning environment is centered around these dimensions and is structured to include activities such as gathering, discussing, collaborating, sharing, and recognizing achievements. These activities are strategically organized to build networks, address challenges, and develop effective teaching and assessment tools. The integrity and commitment of the community members are established at the outset, and the success of the community is acknowledged at the conclusion of the activities. Through this collaborative approach, the community-based learning environment aims to enhance the mathematical literacy of both teachers and students, fostering a supportive and effective educational experience.

Table 3. Framework design of mathematical literacy community

No	Activities		Activity description	Activity Objectives
1.	Gathering	Community gathering	Informal meetings among community members to exchange information, experiences, and ideas related to mathematical literacy	Build networks, share experiences, and enhance mutual understanding of mathematical literacy
2.	Discussion	Discussion of problems in teaching mathematics and developing students' mathematical literacy in inclusion schools	Examination of challenges in teaching mathematics and developing mathematical literacy in inclusive schools	Identify issues, share solutions, and develop strategies to improve mathematics teaching and literacy in inclusive settings
3.	Collaboration	Collaboration to explore content and the context of students' mathematical literacy	Cooperation to explore and understand the content and context of students' mathematical literacy	Enhance understanding of mathematical literacy content and context to create more effective learning materials
4.	Discussion	Discussion of the results of content exploration and the context of students' mathematical literacy	Review findings from the exploration of mathematical literacy content and context	Discuss findings and receive feedback to refine the explored content and context
5.	Collaboration	Collaboration in designing mathematics learning tracks with the PMRI approach	Joint effort in designing a mathematics learning trajectory using the PMRI approach	Develop a relevant and effective mathematics learning trajectory based on the PMRI approach

6.	Discussion	Discussion on the results of designing a mathematical literacy learning track with the PMRI approach	Review the design outcomes of the mathematics literacy learning trajectory using the PMRI approach	Assess and improve the learning trajectory design based on feedback received during the discussion
7.	Observation	Observing the implementation of the design of the mathematical literacy learning trajectory carried out by community members	Monitor the implementation of the designed mathematics literacy learning trajectory by community members	Evaluate the effectiveness and quality of the implemented learning trajectory design
8.	Sharing	Sharing the results and challenges of implementing the design of learning mathematics literacy with the PMRI approach	Exchange experiences and challenges encountered in implementing the mathematics literacy design with the PMRI approach	Provide a platform for discussing implementation results and challenges, and collaboratively find solutions
9.	Collaboration	Collaboration in the development of PISA type questions to measure students' mathematical literacy skills	Joint development of PISA-type questions to assess students' mathematical literacy skills	Create PISA-standard questions to effectively measure students' mathematical literacy skills
10.	Discussion	Discussion of the results of the development of PISA type questions to measure students' mathematical literacy skills	Evaluate the development and application of PISA-type questions for measuring students' mathematical literacy	Assess the quality and effectiveness of the PISA-type questions in evaluating students' mathematical literacy
11.	Observation	Observing the implementation of PISA type question development carried out by community members	Monitor the application of PISA-type questions developed by community members	Evaluate the successes and challenges in using PISA-type questions in practical contexts
12.	Sharing	Sharing the results and challenges of implementing the	Discuss experiences and challenges related to the implementation of PISA-type questions	Review implementation results and address challenges encountered with PISA-type questions

		development of PISA type questions		
13.	Appreciation	Appreciation for the success of the mathematics literacy learning community	Event to acknowledge the successes and achievements of the mathematics literacy community	Recognize community achievements and boost motivation and enthusiasm for continued efforts

Table 3 outlines the series of activities within the mathematical literacy community, each strategically designed to enhance members' understanding and skills in mathematics education. These activities—gathering, discussing, collaborating, sharing, and appreciating—form the core structure of the community's engagement with explanation as follows.

1. Gathering
   This informal activity serves as the foundation for community building. During gatherings, members meet to exchange information, share experiences, and discuss ideas related to mathematical literacy. The primary goal is to foster networking among members, facilitating the sharing of knowledge and experiences that contribute to a deeper collective understanding of mathematical literacy.
2. Discussing
   These sessions involve focused, in-depth discussions on various topics pertinent to mathematical literacy. Topics may include challenges in teaching mathematics, strategies for developing mathematical literacy in inclusive schools, and evaluating the effectiveness of mathematics learning designs. The objective of these discussions is to identify and address problems, exchange solutions, and receive constructive feedback for improvement.
3. Collaborating
   Collaboration among community members is central to the practical application of mathematical literacy concepts. Members work together to explore and understand the content and context of mathematical literacy, design learning trajectories using the PMRI approach and develop PISA-type questions. The purpose of this collaborative effort is to strengthen cooperation within the community, enhance understanding, and create effective learning and assessment tools.
4. Sharing
   This activity provides a platform for members to present the results and challenges they have encountered in implementing learning designs and developing PISA-type assessments. By sharing their experiences, community members can collectively analyze outcomes, address difficulties, and collaboratively develop solutions to improve their practices.
5. Appreciating
   The community concludes its activities with appreciation sessions, where members' contributions and successes are recognized and celebrated. This activity aims to boost motivation and enthusiasm by acknowledging the achievements of the community, thereby fostering a positive and supportive environment for ongoing professional development.

These activities are systematically organized to build a strong, collaborative community dedicated to advancing mathematical literacy education. By participating in these activities, members not only enhance their individual skills but also contribute to the collective growth and success of the community.

Discussion

The findings of this study highlighted significant challenges and opportunities in the development of mathematical literacy learning environments within inclusive education settings. One of the primary challenges identified is the insufficient emphasis on enhancing the capacity of teachers, particularly those in inclusive schools, to foster students' mathematical literacy (Stacey, 2011). The study reveals that many teachers lack a deep understanding of mathematical literacy, underscoring the critical need for developing specialized mathematical literacy learning environments tailored for teachers in inclusive schools (Vodičková et al., 2023). Furthermore, in the context of inclusive education, teachers encounter additional complexities, as they must address the needs of a diverse student population. This diversity requires the implementation of effective teaching approaches and the integration of relevant technological support to facilitate the development of students' mathematical literacy (Kurniastuti et al., 2023).

This study successfully developed a framework for a mathematical literacy learning environment that integrates courses, social media, and community-based approaches, offering teachers comprehensive opportunities to deepen their understanding of mathematical literacy development. Course-based learning environments have been shown to boost teachers' confidence in teaching mathematical literacy to students (Boldstad, 2020). When these environments are designed in a structured and systematic manner, they provide a holistic teacher training model that encompasses theory, practice, and reflection. This approach enables teachers to gain a foundational understanding of mathematical literacy, while also equipping them with practical skills for designing learning trajectories and developing assessments that align with mathematical literacy goals (Bansilal et al., 2015).

In this study, the course was meticulously designed to strike a balance between theoretical knowledge and practical application, ensuring that teachers could effectively enhance their understanding and skills in fostering students' mathematical literacy. Additionally, the course-based learning environment was aimed at reinforcing collaboration and support among educators, creating a shared learning space where different experiences and practices could be exchanged to address common challenges (Fransman, 2010). This comprehensive framework not only supports individual teacher development but also promotes a collaborative culture within the educational community, contributing to the broader goal of improving mathematical literacy in inclusive education settings.

The integration of social media as a foundational component of the learning environment developed in this study offers a dynamic platform for teachers to effectively share information, ideas, and creative practices. Social media's inherent characteristics—such as accessibility, permanence, reach, recency, and usability—make it an ideal tool for fostering academic interaction and collaboration (Bosman & Zagenczyk, 2011; Agarwal, 2011). These features enable educators to easily disseminate ideas, participate in discussions, collaborate, and interact with others in the academic community, thereby enhancing the overall learning experience.

Moreover, the diverse functionalities provided by social media platforms, including polls, quizzes, stories, live sessions, reels, and more, significantly contribute to the creation of innovative and participatory learning environments. These tools not only facilitate creativity but also encourage active collaboration among students and teachers, making the learning process more engaging and effective (Sobaih et al., 2020). By leveraging these features, the study's social media-based learning environment supports the development of a more interactive and collaborative educational experience, which is particularly beneficial in enhancing mathematical literacy.

The establishment of a community-based learning environment fosters a dynamic space for discussion, collaboration, and continuous knowledge development, as emphasized by Johnson et al. (2021). Within this framework, activities are strategically designed to enhance skills and deepen the understanding and practice of mathematical literacy. The collaborative nature of these communities is crucial for integrating mathematical concepts into practical applications, thereby facilitating the exchange of knowledge across educational settings. This collaborative effort not only promotes a deeper understanding of mathematical literacy but also leads to more meaningful learning experiences (Gustiningsih et al., 2023; Smith et al., 2017).

Furthermore, the community-based learning environment developed in this study offers teachers ample opportunities to practice, apply, reflect, and evaluate their learning outcomes. This iterative process ensures that the theoretical knowledge acquired is effectively translated into practical applications in real-world educational settings. By engaging in this reflective practice, teachers can refine their approaches, leading to improved teaching strategies and more effective integration of mathematical literacy into their curricula (Feldman & Fataar, 2014). This approach not only strengthens the teachers' pedagogical skills but also contributes to the overall enhancement of mathematical literacy education.

This research serves as a valuable reference for designing course-based, social media, and community-based mathematical literacy learning environments, specifically aimed at enhancing teachers' capacity in inclusive education settings. The primary contribution of this study lies in its comprehensive approach to strengthening teachers' understanding of mathematical literacy and their practical skills in lesson planning and assessment design. By focusing on continuous professional development and providing holistic support, this research addresses the unique challenges of teaching mathematics in inclusive schools.

Equipping teachers with the necessary knowledge and skills, while also offering platforms for collaboration and reflection, is crucial for improving the quality of mathematics education. The learning environments developed in this study not only foster a deeper understanding of mathematical literacy but also promote effective teaching practices that can enhance students' mathematical literacy, particularly in inclusive settings. This approach has the potential to significantly elevate the standards of mathematics teaching, ensuring that all students, regardless of their learning needs, receive a quality education that prepares them for future academic and life challenges.

CONCLUSION

This study successfully developed a comprehensive mathematical literacy learning environment framework, integrating course-based instruction, social media platforms, and community engagement, aimed at enhancing teachers' capacity to teach mathematical literacy in inclusive school settings. The environment was meticulously designed to provide teachers with a deep understanding of both the theoretical and practical aspects of teaching and assessing mathematical literacy. The findings indicate that such an integrated approach has the potential to significantly improve teachers' skills and confidence in delivering mathematics education tailored to diverse student needs.

Despite the promising outcomes, this study has certain limitations. The designed learning environment, while robust in its framework, requires further exploration and practical implementation to fully understand its impact. The study did not extensively measure long-term outcomes or the scalability of the environment across various educational contexts. Moreover, the research was primarily conducted in a specific setting, limiting the generalizability of the results. These factors suggest that additional

studies are needed to validate the effectiveness of this learning environment and to refine its components for broader application.

Future research should focus on the continued evaluation and refinement of this mathematical literacy learning environment in diverse educational contexts. Investigating its implementation in different types of schools and varying educational settings will be crucial to identifying the factors that contribute to or hinder its success. Additionally, longitudinal studies are recommended to assess the sustained impact of this approach on both teachers' instructional practices and students' mathematical literacy over time. Such research will provide deeper insights into the adaptability and effectiveness of the learning environment, ultimately contributing to the development of more tailored and impactful educational strategies for inclusive mathematics education.

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Declarations

Author Contribution	:	IR: Conceptualization, Writing - Original Draft, Editing, Formal analysis, Methodology, and Visualization. Z: Writing - Review & Editing, Methodology, Validation, and Supervision. RIIP: Writing - Review & Editing, Formal analysis, Validation, and Supervision RCIP: Writing - Review & Editing, Formal analysis, Validation, and Supervision.
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