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Developing a Set of Learning Tools Based on Realistic Mathematics Education for Sequences and Series Assisted by MathCityMap in Islamic Boarding School

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***Abstract*:**
Mathematics learning is essential for strengthening students' logical reasoning and numeracy skills, particularly in abstract topics such as sequences and series; however, instructional practices in Islamic boarding schools often remain procedural and insufficiently contextualized, creating a gap between theoretical recommendations of meaningful learning and classroom reality. This study aims to develop and evaluate RME-based learning tools for sequences and series assisted by MathCityMap to determine their validity, practicality, and effectiveness in a pesantren context. The research employed a 4D development model consisting of Define, Design, Develop, and Disseminate stages. Implementation involving an experimental class and a control class, each comprising 34 students. Data were collected through expert validation sheets, observation instruments, questionnaires, interviews, and numeracy pretest-posttest assessments. The results show that all learning tools achieved valid criteria, with average expert scores above 3.75 on a four-point scale. Practicality was confirmed by 95% implementation fidelity, 84.9% active student participation, and highly positive teacher and student responses. Effectiveness testing revealed a moderate N-gain score of 0.65 in the experimental class compared to 0.54 in the control class, with an independent samples t-test indicating a significant difference (Sig. = 0.049 < 0.05). These findings demonstrate that integrating Realistic Mathematics Education with MathCityMap enhances conceptual understanding, engagement, and numeracy achievement in sequences and series learning within Islamic boarding schools.

Keywords: MathCityMap; Numeracy Skills; Realistic Mathematics Education; Sequences and Series.

Introduction

The swift current of digital transformation is reshaping mathematics education, compelling schools to prepare learners for the intricate demands of a technology-driven society (Tăng et al., 2023). International benchmarks such as the Trends in International Mathematics and Science Study underscore the urgency of curriculum reform to sustain global competitiveness (Octaviani et al., 2019). Indonesia has responded by strengthening mathematics instruction in pursuit of standards demonstrated by high-performing Asian systems (Yuanita et al., 2018). Contemporary reforms prioritize student-centered and competency-based learning, recognizing that literacy and numeracy alone no longer suffice in a dynamic global economy (Cahyono et al., 2021; Putri et al., 2022). Consequently, the creation of an innovative set of learning tools has become a strategic imperative (Nuswantari et al., 2020). Yet classroom realities frequently remain teacher-dominated, emphasizing procedural fluency over conceptual understanding and authentic application (Dinglasan et al., 2023; Pambudi, 2021). This persistent gap has stimulated interest in constructivist paradigms such as Realistic Mathematics Education, or PMRI, which situates mathematics as a human activity emerging from meaningful contexts (Abdi et al., 2023; Diponegoro et al., 2024; Lumbantoruan & Ditasona, 2021; Minarni & Napitupulu, 2020).

Within Indonesia's educational mosaic, Islamic boarding schools or pesantrens hold a distinctive and strategic role as institutions that weave religious heritage with academic advancement (Asror et al., 2023; Lanya et al., 2024). Policy initiatives have sought to elevate their quality through curricular reform and structural support (Firdaus & Mardiana, 2024). Modern pesantrens increasingly integrate mathematics and general sciences alongside classical Islamic texts such as the kitab kuning, reflecting their transformation into comprehensive learning communities (Pujiastuti & Haryadi, 2023). These institutions emphasize both intellectual development ('aqliyah) and spiritual growth, making the integration of mathematics and Islamic values essential for meaningful learning (Imamuddin et al., 2020; Rochmat et al., 2022). Therefore, teachers require instructional tools that can connect abstract mathematical concepts with students' religious and daily experiences (Choirudin et al., 2020). Moreover, many students perceive mathematics as abstract and detached from religious meaning, diminishing motivation and engagement (Inganah et al., 2023; Ni'mah, 2020; Sah et al., 2023). Integrating Islamic values within mathematics instruction therefore becomes essential to nurture holistic understanding and unify rational inquiry with spiritual consciousness (Fitrah & Kusnadi, 2022; Lateh, 2023; Setiawan et al., 2025).

Among secondary mathematics topics, sequences and series present persistent learning obstacles (Magfiroh et al., 2024; Rachma et al., 2022). Students frequently struggle with ontogenical, didactical, and epistemological barriers that constrain conceptual growth. It is common to mix up arithmetic and geometric patterns, not recognize patterns correctly, and use formulas incorrectly (Hartati, 2021; Maharani et al., 2020). Limited opportunities for active knowledge construction often produce fragmented understanding, which can hinder students' ability to connect different mathematical concepts and apply them effectively in problem-solving situations. Given that sequences and series underpin advanced mathematical reasoning and scientific modeling, carefully structured learning trajectories are indispensable to guide learners from contextual observation toward formal abstraction (Jia & Zhu, 2025; Markle & McGarvey, 2025; Yanrizawati et al., 2023). Realistic Mathematics Education offers a coherent theoretical foundation by encouraging horizontal and vertical mathematization grounded in real contexts, thereby improving accessibility and cognitive achievement, including in pesantren environments (Gee et al., 2018; Johar et al., 2025; Tamur et al., 2021; Winarso & Wahid, 2020; Zulkardi et al., 2019).

Digital technology further enriches RME by extending learning beyond classroom walls (Darmanova et al., 2025). Mobile learning, characterized by accessibility and flexibility, enables students to explore concepts anytime and anywhere (Bano et al., 2018; Wang et al., 2025). Contemporary devices provide visualization tools, immediate feedback, and adaptive guidance that strengthen mathematical comprehension (AÇIKGÜL & Şad, 2020; Nurfadilah et al., 2021). Research confirms that mobile technologies enhance achievement, attitudes, and social interaction while aligning instruction with modern societal demands (Fabian et al., 2018; Soboleva et al., 2020; Tăng et al., 2023; Wulandari et al., 2023).

MathCityMap exemplifies this synergy between pedagogy and technology through structured math trails that merge authentic modeling with GPS-supported tasks (Ariosto et al., 2021; Psycharis et al., 2020). By solving contextual problems in real environments, students bridge lived experience and formal mathematics (Nugraha et al., 2023; Zender & Ludwig, 2019). Instant feedback and guided hints sustain engagement and correct misconceptions in real time (Ludwig et al., 2020). Empirical findings indicate improvements in achievement, motivation, collaboration, and critical thinking (Bočková, 2024; Gurjanow et al., 2019; Jablonski, 2025; Nurin et al., 2024; Poçan et al., 2022; Pulido et al., 2025). Nevertheless, research integrating RME, MathCityMap, sequences and series, and Islamic educational contexts remains scarce (Buchori & Puspitasari, 2023; Hasbi et al., 2025; Lanya et al., 2024).

The urgency of this study lies in addressing that gap. Theoretically, it advances structured modeling that connects abstraction with lived reality (Bilgili & Çiltaş, 2025; Kohen & Orenstein, 2021). Practically, it responds to teacher-centered practices that limit reasoning and communication (Magfiroh et al., 2024; Yusuf, 2023). While cultivating engagement through technology-supported math trails (A'la & Arnawa, 2023; Greefrath & Siller, 2024; Nurin et al., 2024; Thomsen et al., 2020). By integrating Islamic values into contextual tasks (Fitrah & Kusnadi, 2022; Hasbi et al., 2025). The study specifically aims to describe the process of developing RME-based learning tools for sequences and series assisted by MathCityMap to enhance numeracy skills and to present the results of this development in terms of validity, practicality, and effectiveness, with the goal of improving numeracy skills in Islamic boarding schools, particularly in the topics of sequences and series.

Research Methods

The type of research used includes various research methods and approaches. In terminological terms, development research refers to a systematic scientific activity conducted within an academic framework, encompassing the processes of designing, implementing, evaluating, and refining a particular product or activity (Nur & Wahyu, 2020). The development model employed in this study is the Thiagarajan, Semmel, and Semmel (4-D) model. This model is selected due to its structured and systematic procedures, as well as its suitability for developing comprehensive and valid instructional instruments. The 4-D model consists of four sequential stages, namely define, design, develop, and disseminate. In this research, the learning tools developed comprise a complete set of learning tools, including mathematics lesson plans, student worksheets, teaching materials, numeracy test items, user manuals, and MathCityMap-based learning media. These components are designed to support effective learning, particularly in the topic of sequences and series.

The subjects of this study are eleventh-grade students of SMA Nuris Jember. The research was conducted during the odd semester of the 2025/2026 academic year at SMA Nuris Jember. Furthermore, the design and development of the Realistic Mathematics Education (RME)-based learning tools assisted by MathCityMap in an Islamic boarding school context follow the 4-D model framework. According to Thiagarajan, Semmel, and Semmel, the Four-D model consists of four main stages: defining, designing, developing, and disseminating. The selection of this model is based on several considerations, particularly its systematic development procedures and its incorporation of expert validation prior to field testing. The developed learning tools are evaluated by experts, revised accordingly, and subsequently tested on students to ensure their validity, practicality, and effectiveness.

The research procedures based on the 4-D model are outlined as follows.

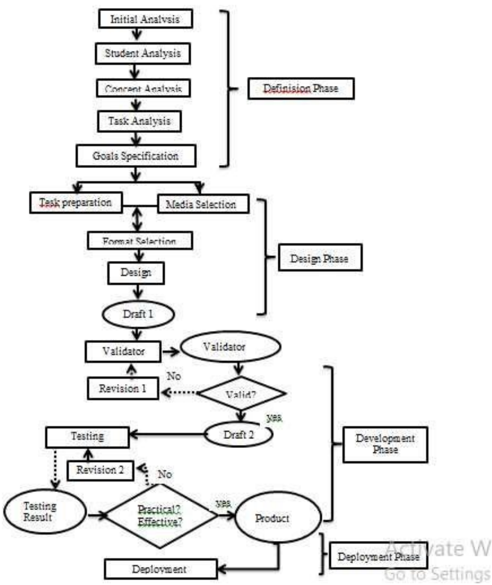

Figure 1. Design of 4D-Model

In the Define phase, preliminary analysis was conducted at Nuris Senior High School in Jember to examine curriculum alignment, student characteristics, and difficulties in learning sequences and series within the pesantren context. Data was collected through interviews, classroom observations, and a pretest. During the design phase, RME-based learning tools assisted by MathCityMap were constructed, including lesson plans, student worksheets, and assessment instruments aligned with numeracy indicators integrated into Islamic boarding school activities. In the Develop phase, content and construct validity were evaluated by three experts, while readability and practicality were assessed by three mathematics teachers. A limited development class trial was conducted prior to experimental implementation to refine the product. Quantitative data was analyzed using descriptive statistics and validity indices, while effectiveness was tested using an independent samples t-test. In the Disseminate phase, the revised tools were implemented in an experimental class and compared with a control class to determine validity, practicality, and effectiveness. The control and experiment class trial schemes are presented in Table 1

Tabel 1. Experimental and Control Class Trial Scheme

Class	Pretest	Treatment	Posttest
Experiment	Y_1	X_1	Y_3
Control	Y_2	X_2	Y_4

Description:
Y_1 Y_2 : numeracy pretest results
X_1 : Learning with RME integrated with MathCityMap
X_2 : Learning with a teacher-centered learning
Y_3 Y_4 : numeracy posttest results

Data analysis employed descriptive and inferential statistical procedures. Validity was determined using a four-point Likert scale, with a minimum criterion score of 3.00 indicating acceptable validity. Practicality was evaluated based on implementation fidelity ≥75%, observed student activity ≥80%, and ≥80% positive responses from teachers and students. Effectiveness was measured using the normalized gain (N-Gain) formula as proposed by Richard Hake, with N-Gain ≥ 0.3 categorized as moderate effectiveness. Additionally, an independent samples t-test was conducted to compare the mean posttest numeracy scores between experimental and control classes at a significance level of 0.05. Statistical procedures followed standard educational research guidelines as outlined by John W. Creswell. All statistical analyses were performed to ensure that measurement results reported in the Results section were transparently derived from the described procedures.

Results and Discussions

Define Stage

The Define stage functioned as the intellectual compass of this development journey. A preliminary study conducted at the Islamic boarding school revealed that students experienced persistent difficulties in distinguishing arithmetic and geometric sequences, identifying patterns, and translating contextual situations into algebraic representations. Classroom observations showed a dominance of teacher centered instruction and limited use of contextual exploration, resulting in passive learning behavior. Diagnostic test results confirmed low numeracy performance, particularly in tasks requiring reasoning and interpretation of sequences in real situations. Interviews with teachers further indicated a lack of interactive and context sensitive learning tools aligned with pesantren culture. These findings justified the need to design RME based learning tools supported by digital outdoor exploration. The Define stage therefore crystallized three essential needs: contextualization of sequences and series, integration of Islamic boarding school environments, and technology supported modeling activities using MathCityMap.

Design Stage

The Design stage translated these identified needs into a structured instructional blueprint (Sutarni et al., 2024). Learning objectives were formulated to emphasize conceptual understanding, problem solving, and mathematical communication. The selected model was Realistic Mathematics Education, which encourages students to construct knowledge from meaningful contexts (Revina & Leung, 2018; Heuvel Panhuizen & Drijvers, 2020). Learning tools developed at this stage included lesson plans, student worksheets (LKPD), teacher guides, and assessment instruments (Pambudi et al., 2025). Tasks were embedded in authentic boarding school settings such as dormitory arrangements, mosque architecture patterns, and daily activity schedules. The MathCityMap application was integrated to facilitate math trails where students explored numerical patterns through GPS based tasks and immediate feedback. Vertical mathematization principles were embedded so that students gradually formalized informal strategies into algebraic formulas for sequences and series (Lumbantoruan & Ditasona, 2021). Prototype 1 was produced as the initial tangible outcome of this phase.

Develop Stage

The Develop stage focused on validation, revision, and limited testing to ensure feasibility and effectiveness (Sutarni et al., 2024). Prototype 1 was validated by two Mathematics Education lecturers and one experienced mathematics teacher. They evaluated content accuracy, construct alignment, linguistic clarity, and pedagogical coherence (Alves et al., 2023; Cassiano et al., 2020). The average validation score reached the "valid" category, although revisions were recommended for improving contextual clarity and strengthening instructions for MathCityMap tasks.

A readability test involving three teachers and selected students from Class XI C indicated that instructions were understandable and tasks were engaging. Before conducting classroom trials, a homogeneity test of students' prior mathematical ability was administered, confirming comparable group characteristics (Sianturi, 2022). A limited development class trial was then implemented to evaluate practicality. Observations showed high student engagement during outdoor math trails, active discussion, and collaborative reasoning. Minor revisions were made to optimize time allocation and clarify GPS navigation guidance. Prototype 2 was subsequently revalidated and achieved improved validity scores, confirming readiness for broader testing (Pambudi et al., 2025). The test results showed that the readability level was good, and the product was declared valid, as shown in Table 2.

Table 2. Expert Review Results

Product	Content Score	Construct Score	Avarage Score	Criteria
Teaching Tools				
Teaching module	3.71	3.83	3.77	Valid
LKPD	3.83	3.78	3.81	Valid
Numeracy test	3.78	3.91	3.84	Valid
Instruction manual	3.87	3.87	3.87	Valid
Research Instrument				
Learning implementation observation	4	3.83	3.92	Valid
Student observation	3.78	3.79	3.785	Valid
Student response questionnaire	3.67	3.83	3.75	Valid
Teacher response questionnaire	3.67	3.83	3.75	Valid
Interview guideline	3.67	3.67	3.67	Valid

Table 3. shows that the tools and instruments have surpassed the minimum scores for both criteria, making them valid in terms of both construct and content. This indicates that the developed tools and instruments have met the criteria for use in measuring according to the development objectives (Wulandari et al., 2023). Figure 2 below provides an example of the results of compiling learning tools that have been declared valid.

Experimental design involving two classes: XI C as the experimental group and XI A as the control group, each consisting of 34 students (Pambudi et al., 2025). Both groups completed a numeracy pretest to measure initial equivalence. Results indicated no significant difference in prior ability. The experimental class received instruction using the RME based learning tools assisted by MathCityMap for three sessions, while the control class used conventional materials. Four observers documented implementation fidelity and student participation. Posttest analysis using an independent samples t test revealed a statistically significant difference in favor of the experimental class, indicating higher achievement in understanding sequences and series. Student response questionnaires demonstrated positive perceptions regarding engagement, clarity, and relevance of contextual tasks. Teacher interviews confirmed that the tools were practical and aligned with pesantren values. These findings indicate that integrating RME with MathCityMap not only enhances conceptual understanding but also transforms the boarding school environment into a living laboratory of mathematics. A detailed summary of these practicality assessments is shown in Table 3.

Table 3. Practicality Assessment

Assessment Aspects	Percentage(%)	Criteria
Observations of learning implementation	95	Very good
Observations of student activities	84.9	Active
Student response questionnaires	95.48	Positive
Teacher response questionnaires	100	Positive

Table 3. indicates that all measured aspects meet the minimum standards for practicality. Implementation observations showed effective learning with active student engagement, aligning with findings that the RME approach enhances motivation and participation (Pambudi et al., 2022, 2023). Student and teacher responses were positive, supported by interviews indicating improved interactivity and numeracy skills. Thus, the tools met practicality criteria (Habibi et al., 2024).

The effectiveness of the learning tools was assessed based on two key indicators: the average N-gain score in the experimental group and a comparison of posttest numeracy scores between the experimental and control classes. Evaluation of these criteria began with calculating the N-gain scores, which reflect the improvement in students' numeracy skills. A detailed summary of the test results from both groups is presented in Table 4.

Table 4. Numeracy Skill Test Results

Experiment Class			Control Class	
	Pretest	Posttest	Pretest	Posttest
Participants	31	31	31	31
Highest score	39.44	91.67	47.78	88.89
Lowest score	2.78	43.89	8.33	28.33
Average score	19.4	72.06	21.65	64.44
N-gain score	0.65		0.54	

As shown in Table 4., the average N-gain score of the experimental group surpasses that of the control group. The integration of RME with MathCityMap produced greater numeracy gains than Blended Learning, with experimental scores rising from 19.4 to 72.06, indicating a moderate improvement. These results align with Aulia and Prahmana (2022) and Amarta et al. (2023). Normality and homogeneity tests were conducted using SPSS to confirm group differences. The outcomes of these tests are summarized in Table 5.

Table 5. Prerequisite Test Results

Class	Normality Test		Homogeneity Test	
	Df	Sig.	Levene Statistic	Sig.
Experiment	31	0.053	7.150	0.010
Control	31	0.050		

Table 5 displays the outcomes of the normality tests for both the experimental and control classes, with significance values (Sig.) ≥ 0.05, indicating that the data in both groups are normally distributed. However, the homogeneity test results show significance values < 0.05, suggesting that the data are not homogeneous. Given these conditions—normal distribution but unequal variances—a parametric test, specifically the Independent Samples T-Test, was applied using the Equal Variances Not Assumed approach. The results of this analysis are presented in Table 6.

Table 6. Independent Sample T-Test Result

Class	Average	Sig. (2-tailed)
Experiment	72.06	0.049
Control	64.44	

Table 6. presents the test results, showing a Sig. (2-tailed) value of less than 0.05. Statistical analysis indicates that the experimental class achieved significantly higher average scores than the control class, consistent with Lubis and Siregar (2022), confirming the effectiveness of the developed RME-based learning tools in improving numeracy skills. The integration of technology, including Live Worksheets, enhanced engagement and interactivity, supporting Kuswanti (2023) on the importance of digital tools in numeracy education. Overall, the MathCityMap-assisted RME tools met validity, practicality, and effectiveness criteria. Strong numeracy skills are essential for real-life decision-making (Baharuddin et al., 2021). The findings align with Susanta et al. (2022) and recommend contextual integration for improved mathematics instruction.

Disseminate Stage

The Disseminate stage focuses on broader implementation of validated learning tools to ensure they reach target users, including teachers and students (Sutarni et al., 2024; Asror et al., 2023). Although large scale distribution may exceed a single study, this phase outlines strategies such as teacher workshops to support effective integration of RME based digital tools into mathematics instruction, particularly on sequences and series (Cahyono et al., 2023). Online repositories may also facilitate wider access (Asror et al., 2023

Conclusions and Suggestions

The integration of RME with digital platforms such as MathCityMap has been shown to successfully address students' conceptual difficulties in sequences and series within the Islamic boarding school context. In the Define stage, needs analysis showed that students struggled to distinguish arithmetic and geometric patterns and relied heavily on memorizing formulas without understanding underlying concepts. During the design stage, Prototype 1 was produced, consisting of lesson plans, student worksheets, teacher guides, and assessment instruments integrating Realistic Mathematics Education principles and digital math trails based on the pesantren environment. In the Develop stage, expert validation yielded an average score above 3.75 on a four-point scale, indicating very high validity. Readability testing confirmed clarity of instructions, while limited classroom trials demonstrated 95% implementation fidelity and 84.9% active student participation. After revisions, the validated tools were implemented in research. The experimental class achieved an N-gain of 0.65, higher than the control class's 0.54, and statistical testing (Sig. = 0.049 < 0.05) confirmed a significant difference. These findings indicate that integrating contextual RME strategies with MathCityMap enhances engagement, conceptual understanding, and numeracy achievement more effectively than conventional instruction.

Based on these findings, it is recommended that mathematics teachers in Islamic boarding schools adopt context-based and technology-supported approaches to strengthen conceptual understanding and student motivation. Future research may expand the implementation to larger samples and different mathematical topics to examine broader generalizability. Further refinement of digital math trail features and integration with other Islamic contextual elements is also suggested to enrich learning experiences. Educational stakeholders are encouraged to provide institutional support, including teacher training and infrastructure readiness, to ensure sustainable integration of RME and mobile learning technologies in pesantren mathematics instruction.

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