

Design Research on an RME-Based Mathematics Module for Teaching Data Collection and Handling in Primary Schools

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Received: 24 July 2025

Accepted: 24 April 2026

Published: 08 May 2026

Abstract: Elementary school mathematics education is critical to fostering students' intellectual skills and problem-solving capacities; however, early learners tend to view mathematics, including early conceptions about statistics, data collection, and analysis, as an abstract subject with negligible practical applications to their real lives. Realistic Mathematics Education (RME) would be one remedy, involving students' immersion in rich real-world contexts; however, empirical support for its application to early statistical learning remains limited. This study developed, implemented, and validated an RME-based instructional module on data collection for third-grade students using a design-research methodology (preliminary research, prototyping, assessment) conducted collaboratively with teachers. The module was trialed in two urban primary schools, with evidence gathered from standardized tests, classroom observations, teacher surveys, and student interviews. Quantitative analysis also demonstrated a substantial increase in data-handling ability with mean scores rising from 58% pre-test to 78% post-test, $t(51) = 6.72$, $p < .001$, mean difference = 20.0 percentage points (SE = 2.98; 95% CI [14.02, 25.98]), Cohen's $d_z = 0.93$, an effect size reflecting a large effect. In addition, the McNemar test showed a significant increase in the proportion of students meeting the minimum mastery-learning criteria following the intervention. Qualitative observations indicated increased engagement, more balanced collaborative problem-solving, and improved mathematical exposition. The teacher's response showed relevance and practicality but also raised concerns about time management and a preference for more differentiated tasks for advanced learners. These findings confirm the value of RME in enhancing early pupils' statistical ability, but also reveal a continuing need for iterative design supported by active contributions from teachers. Future work should examine long-term retention and scalability across diverse school contexts.

Keywords: RME, mathematics module, data collection, primary students.

Article's DOI: <https://doi.org/10.23960/jpmipa.v27i2.pp847-866>

■ INTRODUCTION

In recent years, awareness of statistical literacy among primary school students has grown, especially with the increasing reliance on data for knowledge construction in today's changing societies. It is critical to prepare students with basic data-handling skills early on to enable problem-solving and equip them to interact with

complex information in school and real-life situations. Various education reforms worldwide have highlighted the critical importance of building statistical knowledge, with educators called upon to employ pedagogical practices that engage students in real-world contexts. In Indonesia, where data collection and analysis are integrated into learning early on, educators face many

difficulties finding relevant resources and planning lessons that align with learning objectives. In Vietnam, various stakeholders have highlighted the need for school practitioners to present statistical knowledge relevant to students' everyday lives (Do et al., 2021; Nguyen et al., 2020).

Realistic Mathematics Education (RME) has been an effective framework for increasing understanding by situating learning in contexts that are observable and explorable by pupils. Founded on the notion that mathematics is a human activity, RME stresses "guided reinvention" as a principle whereby learning is mediated by circumstances in which students reinvent fundamental notions by thinking about daily occurrences (Solomon et al., 2021). In a learning approach such as this, students engage with mathematical concepts while linking informal thinking to the use of more elaborate forms (Tong et al., 2022). Case studies indicate that RME contributes to the development of mathematical literacy, problem-solving ability, and a positive learning disposition (Palinussa et al., 2021). Students are asked to consider scenarios they might encounter outside class. RME-based lessons contribute to an increase in their ability to gather data methodically, sort it out, and represent it (Palinussa et al., 2021).

Studies on applying RME to statistical learning contexts invariably report successful results. In a previous investigation, Fauzan et al. (2018) developed a learning trajectory tailored to statistical learning among junior high school students, demonstrating how a well-structured RME-focused methodology can enhance students' fundamental understanding. More recent studies have reported that RME improves understanding of data-related concepts, strengthens competencies in data collection, classification, and representation (Uyen et al., 2021), and leads to greater overall growth at Level 4 of statistical thinking processes (Altaylar & Kazak, 2021). Nguyen Huu et al. (2022)

emphasized that RME fosters greater student engagement, problem-solving abilities, and positive attitudes toward learning mathematics through authentic contexts, and suggest extending its application, such as to statistics, to further enhance understanding and achievement. These findings underscore the adaptability of RME across educational levels and instructional modes. However, while much of the existing work has examined junior high school learners or teacher perspectives, there is limited research on the systematic application of this approach for younger students in the early grades, particularly to develop robust data-handling skills aligned with local curricula.

Aside from established successes with RME, initiatives to promote data education among primary school pupils have been influenced by policy mandates that place greater emphasis on data literacy. For example, mathematics learning standards across countries increasingly encourage teachers to weave data exploration, interpretation, and presentation into beginning mathematics instruction (Van Zanten & Van den Heuvel-Panhuizen, 2021). Indonesia's Minimum Competency Assessment (AKM) is one such example, testing students' ability to apply mathematical knowledge to practical, real-life contexts through data analysis. These policy trends reflect growing agreement among policymakers and teachers about the merit of data literacy in preparing students to make efficient decisions (Nguyen et al., 2020). Simultaneously, international education reform has been consistent with these trends, focusing on statistical skills throughout K–12 schooling.

Notwithstanding progress made, substantial disparities persist in access to informative resources that adequately represent RME principles in forms amenable to immediate application in lessons, particularly in statistics. Many available text-comparative data concepts express themselves in an abstract,

decontextualized manner, with a corresponding loss of opportunity to blend realistic scenarios relevant to children's everyday lives. In addition, practitioners might feel professionally unequipped to prepare such problem-solving-in-context or to frame class activities to accommodate varying backgrounds. These issues underscore an immediate need to prepare empirically verified modules to guide students stepwise through stages of statistical inquiry, from initial explorations of real problems to the construction of mathematically sound representations (Basuki & Wijaya, 2019; Lestari et al., 2023).

To address such issues, researchers have focused on design-based conceptions of materials, including Realistic Mathematics Education (RME), to develop integrated learning strategies. For instance, Jessen et al. (2023) combined RME with the Theory of Didactic Situation (TDS) to facilitate Lesson Study (LS) in upper secondary mathematics, whereas Khanh et al. (2021) found that teachers perceive RME positively.

Even though such studies comprehensively highlight different aspects of RME, few focus specifically on early education in statistics, underscoring a persistent lack of resources for primary-level data. The development of statistical competence should begin in primary school to lay the foundation for future statisticians (Frischemeier, 2020; Friedrich et al., 2024). Additionally, preparing such learning resources requires extensive validation through expert consultations, user contributions, and cyclical refinements to ensure that learning modules meet criteria for clarity, interest, and relevance to the course syllabus (Rudyanto et al., 2019).

Effective RME-based modules also include images or stories from students' community engagements or classroom contexts, thereby facilitating students' understanding of the significance of data collection, documentation, and analysis. Such a strategy promotes ownership

of the learning process, enhancing intrinsic motivation. Moreover, the scholarly literature emphasizes the value of structuring collaborative tasks systematically so that students can compare results, discuss methodology, and provide helpful feedback on each other's interpretations (Meryansumayeka et al., 2022). In cultivating learner-centered learning environments, instructors prepare their students to acquire complex skills, including evaluation and synthesis, that are indispensable for gaining high-level statistical literacy.

Materials from RME also assist educators by offering distinctive structures for teaching and transparently outlined learning paths that track prospective students' responses and common errors (Fauzan & Diana, 2020; Ralmugiz et al., 2021). These paths indicate how students can move from explorations in contexts to textbook-based presentations of statistical concepts, guided by the principle of guided reinvention. Educators who grasp such a developmental progression are better prepared to design tasks that foster deep thinking and enable pupils to interact socially. Teacher education and professional development programs, such as incorporating RME-based lesson design, have been associated with improvements in pedagogical content knowledge and higher levels of self-efficacy (Mariana et al., 2021).

Nonetheless, a lack of professional support or a shortage of planning time can undermine the translation of theoretical benefits into practical applications in class. In fact, the effective application of resources grounded in RME relies on continuous collaboration among policymakers, educators, and curriculum designers (Vossen et al., 2020). In their absence, even well-framed modules will be unable to directly respond to diverse student needs across different learning contexts. Moreover, a study indicates that educators may need specialized training to operationalize inquiry-based strategies,

particularly if they have been conditioned to rely on more standard strategies (Putri & Aisyah, 2020). Addressing these practical concerns is necessary to ensure RME's long-term sustainability as a learning methodology.

This work aims to create a module with a realistic mathematics education (RME) foundation, with a specific emphasis on data collection for primary school pupils. Such a transition is observed in Indonesia, owing to the Minimum Competency Assessment (AKM), which evaluates students' ability to apply mathematical principles to practical data analysis. The statistics module, grounded in RME and formulated in this study, addresses these requirements by engaging students in authentic, context-rich experiences that closely mirror AKM tasks, such as gathering, categorizing, and interpreting information from everyday situations. This module establishes a basis for students to grasp AKM-related tasks. By tapping into the value of contextually related activities and the core principles of scaffolding, the module aims to provide educators with concise guidance to involve students in active inquiry. In devising the learning resources, the research draws upon lessons learned from prior RME investigations, including specific systematic models such as those proposed by Van den Heuvel-Panhuizen (2020) and Fauzan et al. (2022).

The objective is to develop a validated resource that helps teachers introduce statistical concepts early on, thereby equipping students with essential skills for data interpretation both inside and outside the classroom. This work ultimately addresses the urgent need, highlighted in various studies, for accessible, evidence-based strategies to enhance statistics education at the primary level. Through data-collection integration into realistic contexts, the inclusion of discussion-based activities, and the systemic integration of reinvention with guidance, the module proposed here seeks to foster extensive engagement with

statistical principles. The confluence of national policy considerations with ongoing explorations into RME identifies a critical priority for such an initiation. As a contribution to ongoing discussion related to aligning teaching practices with a data-driven society's needs through illustrating how data-related abilities can be effectively created by elementary pupils from a realistic standpoint with a view to creating reflective and aware learners, this work centers on a single question: What is the process for developing a valid and reliable RME-based module on data collection for primary school students?. To evaluate near-term learning improvement using a design-research framework, a paired pre-post design was employed.

The research employed a design-based methodology to create, apply, and assess a module on data collection for elementary students grounded in RME principles (Alim et al., 2020; Fauzan et al., 2022; Ulfah et al., 2020). The iterative stages included a preliminary study, prototyping, and evaluation, corresponding to the guided reinvention principles of RME (Solomon et al., 2021). The development process adhered to the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation), as shown in Figure 1. ADDIE Development Cycle.

The development model used in this study was based on the ADDIE framework, consisting of five main stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). In this study, each stage was carried out systematically and in an interrelated manner to support the development process of learning modules based on RME. The analysis stage was conducted through curriculum analysis, a review of the literature on statistics instruction in elementary schools, and the identification of teachers' needs in teaching data-collection materials. The design stage included designing the module structure, developing context-based learning scenarios, creating student

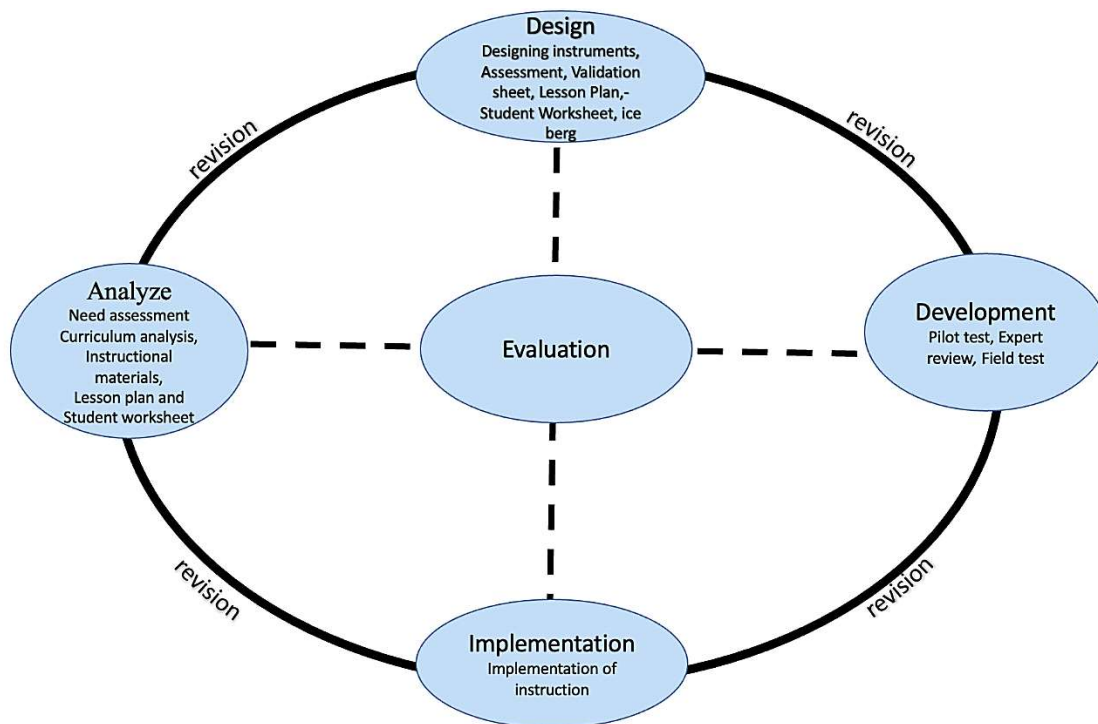


Figure 1. ADDIE development cycle

worksheets, and designing research instruments to evaluate the learning process and outcomes. Next, during the development phase, the module prototype was refined through expert validation, pilot testing, and design refinements based on feedback from validators and teachers involved in the study.

The implementation phase involved applying the module in mathematics lessons in third-grade elementary school classes, where teachers facilitated context-based learning activities that involved student data collection, grouping, and representation. During implementation, observations were conducted of student activities, group interactions, and the teacher's role in facilitating class discussions. In this study, the evaluation stage of the ADDIE model was conducted not only at the final stage but also continuously throughout the development process. Evaluation was carried out through expert validation, teacher feedback, results from limited trials, and analysis of student learning

outcomes following the module's implementation. These evaluation results were used as the basis for revising and refining the module at each stage of development.

In this study, teachers were primarily involved in the needs analysis and module prototype development stages through initial interviews and focus group discussions (FGD). These activities aim to identify practical challenges teachers face when teaching data collection and representation concepts to elementary school students, while also exploring potential learning activities aligned with RME principles. During these discussions, teachers and researchers addressed the scope of basic statistics material for third-grade students, particularly skills in collecting, classifying, and representing categorical data. Additionally, the discussion highlighted examples of contextual learning activities that can be conducted in the classroom, such as simple classroom surveys, grouping objects related to students' daily experiences, and using real-life

situations as discussion materials to understand data concepts.

Feedback from teachers in the FGD was used to refine the design of the developed module. Some of the improvements made included clarifying the step-by-step guidelines so that students could gradually transition from concrete representations to more formal data representations, for example, from drawings to tally marks, frequency tables, and simple graphs. Additionally, the instructions for learning activities were simplified to make them easier for students to understand, and the structure of group work in the teacher's guide was clarified to support student interaction and discussion during learning. It should be emphasized that this study was not designed as a formal training program or workshop to improve teachers' competencies in RME. Therefore, this study did not measure teachers' level of understanding of RME before and after the discussion activities. The primary focus of the study remained on the development and validation of RME-based learning modules, as well as on their evaluation in elementary school students' learning.

■ **METHOD**

Participants

The study involved two Grade 3 classes from two urban public primary schools in Banda Aceh, Indonesia (purposive sampling; Nguyen et al., 2020; Yilmaz, 2020), comprising 52 students and three teachers (two classroom teachers and one pedagogical mentor). Both classes completed the pre-test and post-test and participated in full module implementation. School selection considered (a) explicit curricular inclusion of data collection at the primary level; (b) urban contexts offering diverse, authentic situations for RME tasks; and (c) Grade 3 alignment with recommended cognitive readiness for foundational statistical literacy.

Research Design and Procedures

In the current research, validity and reliability concerns were carefully addressed through a critical analysis of various parameters. To establish content validity, expert evaluations were conducted, including responses from RME experts and experienced primary school teachers. These professionals reviewed the education module to ensure alignment with curriculum benchmarks and contextual relevance to students' everyday lives, thereby ensuring that teaching resources were both academically sound and practically meaningful (Fauzan & Arnawa, 2020).

The reliability of the instruments was also confirmed through pilot testing. Results from pilot testing enabled researchers to make refinements, especially regarding clarity and consistency, leading to improved instruments' ability to measure students' understanding of ideas and to more accurately capture their beliefs, with higher reliability (Duyen & Loc, 2022). Additionally, inter-rater reliability was maintained to ensure a standardized interpretation of qualitative information. Several raters were involved in the validation of observation protocols and the coding of interview transcripts. The use of such a methodology mitigated the risk of personal bias and strengthened data credibility by securing agreement among observers on their interpretation of the data (Jessen et al., 2023).

Instruments

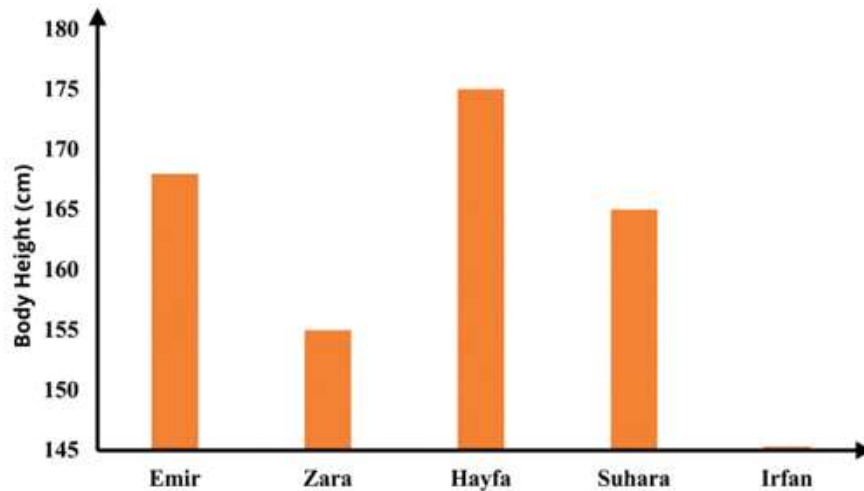
The achievement measure comprised 20 items targeting data-collection competencies (collecting, classifying, interpreting categorical data): 15 multiple-choice (MCQ) and five long-answer items, adapted from prior RME evaluations (Fauzana et al., 2020; Uyen et al., 2021). Parallel forms with identical blueprints were used at pre-test and post-test. Observation protocols documented student engagement, group interactions, and teacher facilitation (Fauzan

& Diana, 2020; Jessen et al., 2023). Three trained observers cross-checked records to support inter-observer agreement. Student questionnaires captured attitudes and perceived task difficulty; teacher questionnaires elicited judgments of clarity, feasibility, and curricular alignment (Do et al., 2021; Mariana et al., 2021). Semi-structured interviews with teachers and small student groups provided explanatory depth (Basuki & Wijaya, 2019). Student worksheets,

completed tasks, and test responses were reviewed to identify conceptual understanding, recurrent errors, and RME-induced strategies (Palinussa et al., 2021). The following are four long-answer problems that assess statistical skills, particularly in data collection and presentation.

Problem 1.

Indicator: Interpreting data, The diagram below shows the heights of five children in centimeters.



Write the information shown in the diagram above in your own words.

Problem 2

Indicators: Organizing/Classifying data, Data Collection

The number of cows on the farm over the course of a year, from January to December, is as follows: 13, 15, 16, 14, 15, 19, 12, 17, 10, 11, 18, 15. (a) Determine the total number of cows on the farm over the course of a year. (b) Present the data in a bar chart

Problem 3

Indicator: Organizing/Classifying data.

The data from the third-grade students' math test are as follows. Present the data above in the form of a bar chart!

No.	Score	Frequency
1.	5	3
2.	6	5
3.	7	7
4.	8	9
5.	9	8

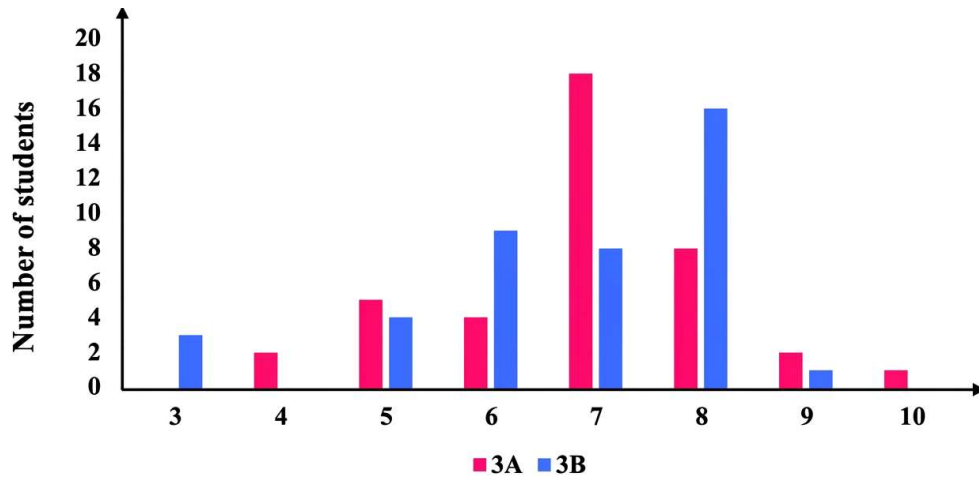
Problem 4

Indicator: Interpreting data

The bar charts below show the results of the midterm math exams for classes 3A and 3B.

- a) How many students are in Class 3A?
- b) How many students are in Class 3B?
- c) How many students obtained the highest score in Class 3B?

This multifaceted approach is consistent with recommendations to triangulate data for



robust conclusions in design research (Ardiansyah et al., 2021; Duyen & Loc, 2022).

Data Analysis

Quantitative data analysis was conducted using McNemar’s test with a 95% confidence

interval (CI) to examine whether the minimum criteria for mastery learning meet the school criterion. Field notes, interview transcripts, and student artifacts were analyzed via inductive thematic coding (Basuki & Wijaya, 2019). Two independent coders developed and reconciled

Table 1. Overview of data collection instruments

Instrument	Purpose	Data Type	Reference Basis
Achievement Tests	Assess mastery of data collection competencies	Quantitative scores	Fauzana et al. (2020), Uyen et al. (2021)
Observation Protocols	Document engagement, group work, and teacher facilitation	Qualitative field notes	Fauzan and Diana (2020), Jessen et al. (2023)
Questionnaires (Students)	Examine attitudes, perceived difficulty	Quantitative & Qualitative	Tong et al. (2022)
Questionnaires (Teachers)	Assess module clarity, feasibility, and alignment	Qualitative responses	Mariana et al. (2021)
Focused Interviews	Explore in-depth experiences, perceptions	Qualitative interviews	Basuki and Wijaya (2019)
Document Analysis	Investigate conceptual errors, solution strategies	Qualitative coding	Palinussa et al. (2021)

codebooks. Triangulation across observations, interviews, questionnaires, and documents strengthened credibility (Fauzan et al., 2022).

The coding reconciliation process was conducted in several stages. First, the two researchers independently coded the qualitative data from observation notes, interview transcripts,

and student work. At this stage, each researcher identified preliminary themes and assigned codes based on patterns emerging from the data. After the initial coding process was completed, both researchers then compared the coding results they had produced independently. The next stage involved a discussion to examine the coding

discrepancies that arose. Any codes that were inconsistent or differed were discussed collaboratively, with reference to the original data and the context of the observed learning activities. During this discussion, the researchers revisited the definition of each category, clarified the boundaries between codes, and merged codes with similar meanings. If there were differences in interpretation regarding a particular data segment, the final decision was reached through mutual agreement after considering the alignment between the code and the meaning embedded in the data. The results of this process were used to compile an agreed-upon codebook as the basis for further analysis.

Content validity was established through expert review by RME specialists and experienced primary educators (Fauzan & Arnawa, 2020). Instrument reliability was supported by pilot testing and subsequent revisions for clarity and consistency (Duyen & Loc, 2022), inter-rater reliability procedures for essay scoring (ICC) and observation notes, and acceptable internal consistency ($\alpha = .82$). These procedures, embedded in a design-research cycle with collaborative lesson study, ensured rigorous development, implementation, and evaluation of the module.

Quantitative data analysis was conducted using two complementary statistical procedures. A paired-samples t-test was used to compare students' pre-test and post-test scores to determine whether there was an improvement in learning outcomes following the implementation of the RME-based learning module. This analysis was chosen because test scores are continuous, allowing comparison of means before and after the intervention.

Additionally, the McNemar test with an interval was used to analyze changes in the proportion of students meeting the minimum mastery-learning criteria before and after the intervention. In this analysis, student scores were

categorized into two groups: students who met the mastery criteria and those who did not. The use of these two analyses is intended to provide a more comprehensive picture of changes in student learning outcomes, including increases in average scores and shifts in learning.

■ RESULT AND DISCUSSION

This section presents empirical findings from the design research cycle in four strands: (a) module validation, (b) student achievement, (c) classroom observation during implementation, and (d) teacher perceptions and practicality.

Module Validation

Expert reviews and preliminary revisions

During prototyping, RME experts and experienced primary teachers evaluated the draft based on four criteria: content accuracy, contextual relevance, linguistic clarity, and instructional consistency with RME (guided reinvention, multiple representations, structured discussion) (Van Zanten & Van den Heuvel-Panhuizen, 2021; Solomon et al., 2021). Two practical refinements emerged across reviews. First, reasoning prompts were made more explicit so that students would justify category and graph choices rather than merely produce them (Palinussa et al., 2021). Second, scaffolding for the concrete-to-formal transition was strengthened to support movement from pictures or narratives to tallies, frequency tables, and simple bar/picture graphs (Fauzan & Diana, 2020; Meryansumayeka et al., 2022). Revisions subsequently applied stepwise tasks (picture 'tally' 'table' 'bar chart) and added sentence stems, such as "Explain why this graph is suitable for these data."

To situate these actions transparently, Table 2 presents validator comments (e.g., simplification of wording, clearer instructions, consistent option numbering, enlarged figures, and more culturally familiar contexts), echoing concerns raised in



Figure 2. Mathematics module cover: data collection and presentation (grade 3)

RME-based material design about accessibility and contextual fit (Ralmugiz et al., 2021; Rudyanto et al., 2019; Nguyen et al., 2020). The revisions were made based on the feedback and summarized in Table 3.

Pilot findings and revisions

A small-scale pilot involving Grade 3 students confirmed high engagement with real-life contexts (canteen items, mini-surveys). However, students showed hesitations when translating pictures into tables or graphs, a persistent hurdle noted in early statistics learning (Fauzan & Diana, 2020; Uyen et al., 2021). Revisions implemented before full-class implementation included (i) step-by-step guiding

Table 2. Validators' comments on the assessment instrument and learning materials (n = 5).

Validator 1	Validator 2	Validator 3	Validator 4	Validator 5
1. The instrument is aligned with the indicators.	1. Several items are too lengthy.	1. Some items do not fully assess higher-order thinking skills (HOTS)	1. The context of the questions should be adjusted to students' daily experiences.	1. The language structure needs refinement.
2. The wording of some items should be simplified.	2. Sentences should be simplified.	2. More variation in the context of the questions is needed.	2. Some illustrations are unfamiliar to students.	2. Consistency in mathematical terminology must be ensured.
3. Some answer choices are unclear.	3. Numbering of answer choices must be consistent.	3. Avoid excessive repetition of terms.	3. Instructions should be made more specific.	3. Ensure alignment with the curriculum.
4. The figures in the items should be enlarged for better readability.	4. Add more detailed instructions for students.	4. Data tables should be presented more neatly.	4. Use examples closer to students' cultural backgrounds.	4. Punctuation should follow proper rules.

questions that modeled concrete-to-abstract moves, (ii) worked examples for table/graph construction, (iii) group-work structures (role distribution and time boxes) to balance

participation (Jessen et al., 2023; Mariana et al., 2021), and (iv) larger, cleaner visuals for tables and graph frames to improve readability.

Table 3. Summary of pilot study findings and revisions

Aspect Observed	Pilot Findings	Revisions
Student Engagement	Positive response to contextual tasks, but difficulty shifting to abstract forms	Added step-by-step guiding questions; integrated concrete-to-abstract examples
Instruction Clarity	Instructions are lengthy/ambiguous	Simplified wording; clearer step-by-step directions
Group Work Dynamics	Unequal participation; dominance of a few students	Teacher Guide updated with role distribution and time allocation strategies
Visual Presentation	Small/unclear figures and data tables	Enlarged and reformatted visuals for better readability

Validation outcomes

A second expert review round indicated robust validity and readiness for classroom use (Alim et al., 2020; Syafriafdi et al., 2019). Aggregated scores (content, pedagogy/RME

focus, language, design, grade-level suitability) are reported in Table 4. Minor suggestions (e.g., reordering instructions to improve flow, harmonizing terminology) were implemented prior to implementation.

Table 4. Expert validation scores for the revised module (5-point scale; n = 5)

Dimension	Mean Score (Max 5)	Interpretation
Content	4.6	Excellent alignment
Pedagogy (RME focus)	4.7	Very strong RME integration
Language	4.3	Clear, minor refinements needed
Design	4.5	Engaging and coherent
Grade-Level Suitability	4.6	Highly appropriate

Mean ratings: Content = 4.6 (excellent alignment); Pedagogy/RME = 4.7 (strong RME integration); Language = 4.3 (clear, minor refinements); Design = 4.5 (engaging/coherent); Grade-level suitability = 4.6 (highly appropriate). These indicators align with reported features of effective RME-based material (Fauzan & Arnawa, 2020; Van den Heuvel-Panhuizen, 2020).

Student Achievement and Mastery of Data Collection and Presentation Concepts

Primary pre-post outcome

Two Grade-3 classes (n = 52) completed a 20-item assessment (15 multiple-choice and 5 constructed-response items) aligned to indicators of early data literacy (collecting, classifying, interpreting basic categorical data) (Fauzana et

al., 2020; Uyen et al., 2021). Mean performance increased from 58.0% (SD = 18.0) at pre-test to 78.0% (SD = 18.0) at post-test, yielding a mean difference of 20.0 percentage points (SE = 2.98; 95% CI [14.02, 25.98]), $t(51) = 6.72$, $p < .001$, Cohen’s $d_z = 0.93$ (large). Effect size was calculated using Cohen’s d_z , which is commonly used for within-subject pre-post comparisons. The magnitude and precision of the gain are consistent with improvements reported in RME-based statistics teaching where contextualized tasks and guided reinvention support mathematization (Uyen et al., 2021; Fauzan et al., 2018; Fauzan & Diana, 2020).

Bars display class means for total score (percentage), error bars indicate SD. The upward shift reflects a large paired effect (Cohen’s $d_z = 0.93$) after a RME-oriented instructional window.

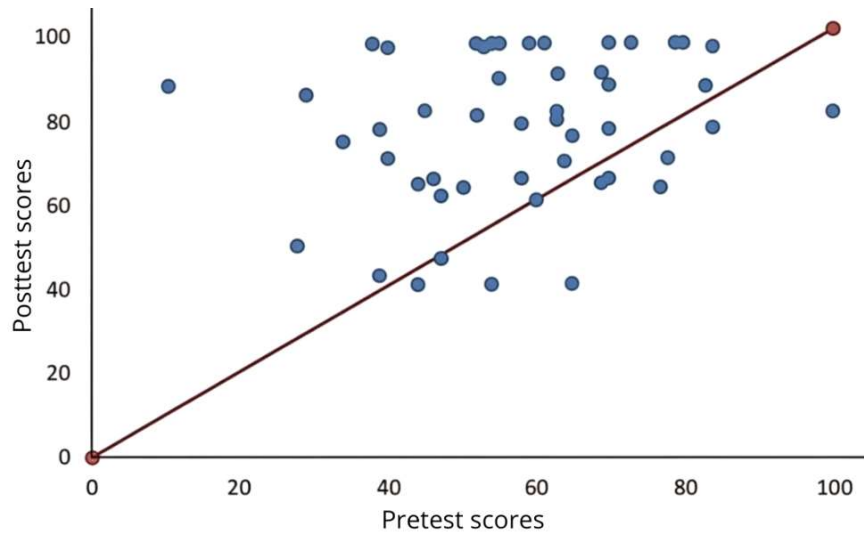


Figure 3. The scatter plot of pre-test and post-test scores

Standards-based attainment

To complement continuous outcomes, attainment against the school’s minimum mastery-learning criteria was examined. The proportion meeting the minimum mastery-learning criteria rose from 30.8% (16/52) at pre-test to 69.2%

(36/52) at post-test. A McNemar test with continuity correction indicated a significant shift, $\chi^2(1) = 15.04, p < .001$, suggesting that the module helped move a large share of students across a consequential criterion often used in school decision-making.

Table 5. Pre–post outcomes for the RME-based module (Grade 3, n = 52)

Panel A. Continuous outcome

Outcome	n	Pre (M ± SD)	Post (M ± SD)	Mean diff (pp)	SE	95% CI	t (df)	p	Cohen's dz
Total test score (%)	52	58.0 ± 18.0	78.0 ± 18.0	20.0	2.98	[14.02, 25.98]	6.72 (51)	< .001	0.93

Panel B. Dichotomous outcome (paired)

Outcome	n	P	Cohen's dz	Pre n (%)	Post n (%)	Improved (b)	Declined ©	McNemar χ^2 (df)
Minimum criteria of mastery learning (meets)	52	< .001		16 (30.8%)	36 (69.2%)	22	2	15.04 (1)

Task-level and representational gains

Item and task traces indicated three learning shifts aligned with trajectories reported in RME studies (Muhtarom et al., 2019; Fauzan & Diana, 2020; Uyen et al., 2021).

Categorization strategies. Learners transitioned from intuitive grouping to systematic tallying and frequency tabulation, enabling clearer justification of categories. Graph interpretation. Misreadings of picture-graph keys (e.g., one icon

representing two items) diminished; students increasingly verified scales before making comparisons.

Context's representation linkage. Given short narrative prompts or mini-surveys, more than 65% of students independently produced appropriately labeled tables and bar charts, evidencing a stronger grasp of mathematization steps expected in early statistics (Duyen & Loc, 2022; Palinussa et al., 2021).

Robustness and score quality checks

Parallel test forms and acceptable internal consistency for the total scale (reported in the Methods section) mitigate concerns about measurement artifact (Fauzana et al., 2020). Constructed-response scoring followed double-rating with prior calibration; inter-rater agreement was monitored to improve reliability, in line with procedures recommended for classroom-based RME evaluation (Jessen et al., 2023). Distributional checks on the difference scores indicated no serious violations of the paired t inference, given the sample size and the test's robustness.

Classroom Processes Observed During Implementation

Engagement and group dynamics

Observation protocols documented high engagement when tasks leveraged familiar contexts (snacks at recess, extracurricular preferences), aligning with evidence that authenticity supports motivation and sense-making in RME activities (Ardiansyah et al., 2021; Meryansumayeka et al., 2022). Initially, several groups relied on a single "solver." After teachers enacted the role-and-time structure embedded in the Teacher Guide (recorder, presenter, checker; timed segments), participation became more balanced, and artifacts (classification schemes, graphs) improved in completeness and accuracy, an effect consistent with collaborative

norms reported in RME lesson designs (Mariana et al., 2021; Solomon et al., 2021).

Classroom observations indicate that student engagement increases when learning activities use contexts that are closely related to students' daily experiences. Activities such as collecting data from classmates encourage more active participation during group work. This was also confirmed by one of the teachers involved in the study. The teacher stated that:

"When they are asked to collect data from their own classmates, the students become more enthusiastic. They are also more confident in explaining the graphs they created during class discussions." (Teacher Interview)

Additionally, the teacher observed that group discussion activities made students more engaged in completing tasks together.

"Usually, there are a few students who stay quiet, but during group work, they start participating in discussions and sharing their opinions." (Teacher Interview)

Observations during group discussion activities also showed that students began to participate more equally in completing group tasks. The role-sharing structure outlined in the teacher's guide helped encourage participation from students who had previously been passive.

Communication and reasoning

Classroom discourse evolved from brief prompted answers to spontaneous justifications, for example, "We selected a bar chart because our data are categorical and bar height supports comparison," echoing the guided-reinvention pathway where learners articulate rationale as they bridge informal to formal representations (Fauzan et al., 2018; Van Zanten & Van den Heuvel-Panhuizen, 2021). Small-group talk was associated with increased metacognitive

monitoring (correcting missing labels or misread keys), a pattern linked to improved mathematical communication in RME contexts (Palinussa et al., 2021; Chasanah & Usodo, 2020).

In addition to increased student engagement, the group discussion process revealed improvements in students' ability to explain their choices in data representation. In some groups, students not only created tables or graphs but also began to provide reasons for using those representations. For example, classroom observation notes recorded the following interaction during a group discussion:

During the group discussion, one student explained to a groupmate, *"Let's just use a bar chart because the data types are different."* The student then pointed to the data table they had previously created. (Class observation notes)

This finding indicates that context-based learning activities encourage students to connect the data they collect with appropriate forms of representation. This is also reflected in students' responses when interviewed about their experiences during the learning activities. One student stated: *"When we calculate and group the data ourselves, it becomes easier to understand."* (Student interview)

Another student also shared a similar experience when asked to explain the activity they had done. *"First, we asked our friends, then we took notes, and after that, we made tables and graphs."* (Student interview)

Contextual materials and optional technology

Visual prompts and tangible artifacts functioned as representational bridges, supporting gestures and talk that moved from pictures to tallies, then to tables and charts (Meryansumayeka et al., 2022; Rudyanto et al., 2019). In several lessons, teachers invited learners to enter counts into simple spreadsheets to aggregate class data and project real-time charts. Although optional,

this activity heightened enthusiasm and reinforced transfer to everyday digital tools, consistent with reports that basic technology can amplify motivation and visibility of patterns in mathematics learning (Umbara & Nuraeni, 2019; Cirneanu & Moldoveanu, 2024).

Teacher Perceptions and Practicality Alignment and feasibility

Survey and interview responses converged on three themes. First, teachers noted close alignment with Grade 3 expectations to organize, represent, and interpret simple categorical data and with AKM (minimum competency assessment)-style contexts, echoing the literature's emphasis on coherence between tasks, curricula, and assessment demands (Do et al., 2021; Van Zanten & Van den Heuvel-Panhuizen, 2021). Second, the module was viewed as feasible and adaptable: the same lesson frames transferred across different class sizes when roles and time boxes were specified, resonating with reports of adaptable RME artifacts when teacher guidance is explicit (Nguyen et al., 2020; Fauzan & Arnawa, 2020).

Time and differentiation

Two practical constraints emerged. Teachers emphasized time management to support rich discussion within fixed periods and requested optional extension tasks for high-achieving students (Afriansyah et al., 2021). Such challenges mirror common implementation considerations for inquiry-oriented pedagogies (Fischer et al., 2023). The Teacher Guide's pacing options (split-lesson scheduling, brief gallery walks, rolling discussions) and suggested enrichment (larger or more complex datasets, student-initiated surveys, applying representation choices to unfamiliar contexts) were identified as actionable routes to sustain inclusivity while maintaining challenge.

Integrative perspective

Teacher narratives triangulated with achievement gains and observation notes: the module was perceived as instructionally sound and engaging, with clear remedies to address recurrent bottlenecks (picture'!table/graph transitions; equitable participation; pacing). Their willingness to iterate adjusting roles, timing, and enrichment suggests sustainability beyond the study, consistent with findings that teacher buy-in and professional learning underpin diffusion of RME designs (Mariana et al., 2021; Vossen et al., 2020; Khairunnisak et al., 2024).

Consolidated Interpretation

Across strands, evidence supports three claims. First, expert and pilot validation demonstrated high content and design validity with specific, actionable refinements (Tables 2–4), aligning with scholarship that emphasizes explicit learning trajectories, contextual authenticity, and multi-representation scaffolds in RME materials (Van den Heuvel-Panhuizen, 2020; Fauzan & Arnawa, 2020; Meryansumayeka et al., 2022). Second, the module produced substantial short-term achievement gains—a 20-point increase with a large paired effect ($d_z = 0.93$) and improved KKM attainment confirmed by McNemar's test (Table 5; Figure 4), consonant with reports that RME improves statistical thinking and literacy in school settings (Uyen et al., 2021; Altaylar & Kazak, 2021; Fauzan et al., 2018). Third, observed process improvements, more balanced groupwork, explicit justifications, and successful context'representation transitions, mirror mechanisms of guided reinvention and classroom communication emphasized in the RME tradition (Solomon et al., 2021; Palinussa et al., 2021; Chasanah & Usodo, 2020).

While the present cycle focused on immediate learning gains, the pattern of results, paired with teachers' pragmatic suggestions for

pacing and differentiation, indicates a viable path for scale-up and iterative refinement (Do et al., 2021; Nguyen et al., 2020). Subsequent cycles could extend to long-term retention checks and comparative designs, as recommended in prior work on RME-based statistics instruction (Fauzan & Diana, 2020; Uyen et al., 2021).

The results reported: (a) strong expert validation and pilot feedback; (b) a statistically and practically significant pre–post improvement on a parallel assessment; and (c) observational evidence of more balanced participation, clearer justification of representational choices, and smoother transitions from everyday contexts to formal displays, together with positive teacher appraisals of alignment and feasibility. Quantitatively, students' mean total scores increased from 58.0% to 78.0%, a 20.0 percentage-point gain accompanied by a large paired effect (Cohen's $d_z = 0.93$) and a precise confidence interval (95% CI [14.02, 25.98]) (Table 5, Panel A; Figure 4). From a standards-based perspective, the proportion meeting the school's minimum criteria of mastery learning rose from 30.8% to 69.2%; paired transitions favored improvement (22 improved vs. 2 declined), with McNemar's test confirming that this pattern is unlikely due to chance ($\chi^2(1) = 15.04, p < .001$; Table 5, Panel B). These outcomes indicate not only higher mean performance but also a substantial shift in the level of criterion attainment.

Two design decisions appear central to the observed gains. First, we strengthened an explicit concrete-to-formal trajectory—pictures'representation transitions, paired with sentence stems that cued justification (e.g., “This graph fits because our data are categories”). This sequencing operationalizes RME's guided reinvention, in which learners reorganize informal reasoning into conventional representations through structured tasks and whole-class discussion (Van den Heuvel-Panhuizen, 2020; Van Zanten & Van den Heuvel-Panhuizen, 2021;

Solomon et al., 2021). The item-level patterns reported in the Results, systematic categorization, correct key/scale interpretation, and reliable mapping from context to display, are direct targets of such scaffolds and mirror earlier RME trajectories in number and statistics (Fauzan & Diana, 2020; Fauzan et al., 2018; Muhtarom et al., 2019; Duyen & Loc, 2022).

Second, group-work structures (role distribution and time boxes) were engineered to broaden participation and reduce procedural errors in table/graph construction. This responds to evidence that explicit participation norms enhance mathematical communication and shared problem-solving in RME-oriented lessons (Mariana et al., 2021; Palinussa et al., 2021; Chasanah & Usodo, 2020). Together with context fidelity, tasks keyed to learners' everyday experiences, these features likely sustained motivation and sense-making (Basuki & Wijaya, 2019; Ardiansyah et al., 2021; Meryansumayeka et al., 2022). Optional spreadsheet aggregation, used in several lessons, provided a low-threshold digital extension that made distributional patterns visible in real time without supplanting paper-based reasoning (Umbara & Nuraeni, 2019; Cirneanu & Moldoveanu, 2024).

The magnitude and profile of improvement align with reports that RME strengthens statistical literacy and data handling by placing abstract concepts in authentic contexts and sequencing representational supports (Uyen et al., 2021; Altaylar & Kazak, 2021). Our findings extend this literature in two ways. First, most prior RME statistics studies involve older learners or focus on teacher perceptions (Fauzan et al., 2018; Nguyen et al., 2020); we provide Grade-3 evidence with a statistically complete report (mean difference with CI, t , and Cohen's d), thus offering a benchmark for early primary. Second, we specify where young learners stall, particularly the picture/table transition, and show how explicit step sequences and reasoning prompts can be

embedded in lesson artifacts and teacher guides. This responds to calls to make RME trajectories teacher-actionable through validated materials and reflective logs (Ralmugiz et al., 2021; Rudyanto et al., 2019; Jessen et al., 2023).

Teacher perspectives in our study, emphasizing curricular alignment (including AKM-style contexts), feasibility with pacing adjustments, and the need for enrichment pathways, resonate with work showing that perceived alignment to national expectations is a key lever for adoption (Do et al., 2021; Van Zanten & Van den Heuvel-Panhuizen, 2021). The time-on-task tension we observed is typical in inquiry-oriented pedagogy and calls for pragmatic scheduling strategies (e.g., split lessons, gallery walks) (Fischer et al., 2023). Requests for enrichment mirror recommendations to accommodate a range of readiness levels via larger or less familiar datasets and student-initiated mini-surveys (Afriansyah et al., 2021; Nguyen et al., 2020).

Cross-context comparisons suggest that the RME principles underlying our design, contextualized tasks, guided reinvention, and discussion-rich classrooms are portable, though sensitive to local conditions (Revina & Leung, 2019; Palinussa et al., 2021). Our urban setting complements rural evidence of improved reasoning and communication when RME tasks are attuned to students' lived worlds (Palinussa et al., 2021). The combined picture supports the view that RME can be enacted across diverse contexts when materials are adapted to cultural and institutional realities and when teachers are supported to interpret learning trajectories (Vossen et al., 2020; Khairunnisak et al., 2024).

■ CONCLUSION

This study designed, validated, and trialed a Realistic Mathematics Education (RME) module to strengthen Grade-3 students' understanding of data collection and representation. Across an

iterative design-research cycle, experts confirmed the module's content accuracy, contextual relevance, and RME alignment; pilot feedback led to clearer reasoning prompts and an explicit, concrete-to-formal representational trajectory. Classroom observations and teacher accounts converged with these outcomes, showing more balanced participation, better attention to graph keys and scales, and stronger justifications for representational choices. The study contributes early primary evidence that contextualized, discussion-rich trajectories, supported by teacher-actionable artifacts (reasoning stems, role structures, and stepwise transitions from pictures to tables and graphs), can yield practically important gains within routine instructional windows. It also models statistically complete reporting for pre-post designs (means, confidence intervals, and effect sizes). It offers pragmatic guidance for pacing, differentiation, and low-threshold digital extensions that preserve paper-and-pencil mathematization.

Limitations include the absence of a comparison group, a short duration, and an urban sample, which may limit generalizability. Future research should employ quasi-experimental or randomized designs, examine retention and transfer with delayed post-tests, test scalability across diverse settings (including rural schools), and study differentiation pathways and professional-development dosage. Fine-grained analyses (e.g., item-level models and discourse studies) could further illuminate how students' appropriate representational tools. Taken together, the findings provide a validated, adaptable pathway for embedding early statistics within everyday classroom realities while remaining faithful to RME principles and national assessment demands.

■ ACKNOWLEDGMENTS

We would like to thank Universitas Syiah Kuala (USK) for funding this study through the

Scheme "Penelitian Lektor" (contract number 273/UN11.2.1/PT.01.03/PNBP/2022). We also extend our gratitude to all teachers and students participating in the study.

■ DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used ChatGPT solely to assist with language refinement and proofreading. All content generated by the tool was carefully reviewed, revised, and verified by the authors. The authors take full responsibility for the accuracy, integrity, and final content of the published article.

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