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Realistic Mathematics Education Improves Trigonometric Ratios: A Classroom Action Research Study

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ABSTRACT

This study aims to improve mathematics learning outcomes of Grade X Phase E.2 students at SMA Negeri 13 Padang through the implementation of the Realistic Mathematics Education (RME) approach. The research employed a Classroom Action Research (CAR) method using the Kemmis and McTaggart model, which consists of planning, action, observation, and reflection stages. The study was conducted in two learning cycles designed continuously to enhance the quality of the teaching and learning process. Data were collected through essay-type tests in trigonometric ratios to measure students' learning outcomes and observation sheets to assess students' learning activities and engagement during classroom instruction. The results indicate a significant improvement in students' average scores in trigonometric ratios, increasing from 76.67 in Cycle I to 96.86 in Cycle II, representing a gain of 20.19 points. Based on the analysis of test results and observational data, students showed better conceptual understanding, higher participation, and improved ability to connect mathematical concepts with real-life contexts. These findings demonstrate that the RME approach is effective in enhancing students' mathematics achievement and overall learning quality at the secondary school level.

ABSTRAK

Penelitian ini bertujuan untuk meningkatkan hasil belajar matematika peserta didik kelas X fase E.2 SMA Negeri 13 Padang melalui penerapan pendekatan Realistic Mathematics Education (RME). Metode penelitian yang digunakan adalah Penelitian Tindakan Kelas (PTK) dengan model Kemmis dan McTaggart yang mencakup tahap perencanaan, pelaksanaan tindakan, observasi, dan refleksi. Penelitian dilaksanakan dalam dua siklus pembelajaran yang dirancang secara berkelanjutan untuk memperbaiki proses pembelajaran di kelas. Data penelitian dikumpulkan melalui tes rasio trigonometri berbentuk soal esai untuk mengukur hasil belajar peserta didik serta lembar observasi untuk menilai aktivitas, partisipasi, dan keterlibatan peserta didik selama pembelajaran berlangsung. Hasil penelitian menunjukkan adanya peningkatan yang signifikan pada nilai rata-rata rasio trigonometri peserta didik, yaitu dari 76,67 pada Siklus I menjadi 96,86 pada Siklus II, dengan peningkatan sebesar 20,19 poin. Berdasarkan analisis data hasil tes dan observasi, terlihat peningkatan pemahaman konsep matematika, kemampuan berpikir kontekstual, serta keaktifan peserta didik dalam proses pembelajaran. Temuan ini menunjukkan bahwa pendekatan RME efektif dalam meningkatkan hasil belajar dan kualitas pembelajaran matematika di sekolah menengah.

INTRODUCTION

In the current digital era, mathematical literacy has become a central competency emphasized by international assessments such as PISA and TIMSS. These frameworks highlight the importance of students' ability to apply mathematical reasoning in everyday situations. However, Indonesian students' performance in these assessments remains relatively low, suggesting that classroom practices have not yet fully supported the development of higher-order thinking skills. Although the Merdeka Belajar curriculum encourages contextual and student-centered learning, many classrooms continue to rely on teacher-centered instruction, limiting opportunities for students to explore mathematical concepts meaningfully (Agusta, 2020; Fardian et al., 2025; Novianti, 2019; Rangkuti, 2019). This inconsistency between curriculum expectations and classroom implementation contributes to students' difficulties in deeply understanding mathematical ideas. As a result, students often struggle to apply these ideas in unfamiliar contexts.

These instructional challenges are particularly evident in the topic of trigonometric ratios of right-angled triangles, which is a key component of the grade X mathematics curriculum. Trigonometry is not only foundational for further mathematical learning but is also widely applicable in real-life measurement and spatial reasoning tasks (Apriliantyet al., 2024; Putri et al., 2024; Putri et al., 2024; Rahayu, 2022; Rahman, 2018). However, many students struggle with this topic because it is often introduced through abstract formulas without contextual grounding. As a result, students find it difficult to visualize the relationships between sides and angles in triangles and to apply trigonometric ratios in practical situations. This situation reflects a discrepancy between the way the topic is taught and the type of learning experience students need to develop genuine understanding (Maulida, 2022; Pratiwi, 2017).

To further examine these learning challenges, preliminary assessments were conducted in class X E.2 of SMA Negeri 13 Padang before this study. Although the assessment focused on exponents, it provided a clear picture of students' overall mathematical performance. The results are displayed in **Table 1**.

Table 1. Initial Assessment Results Class X Phase E.2 SMA Negeri 13 Padang

Score Range	Description	Percentage (%)
0-25	Emerging	34
26-60	Developing	31
61-80	Meeting Expectations	19
81-100	Highly Developed	16

The data indicate that only 16 percent of students achieved the Highly Developed category, while 65 percent fell into the Emerging or Developing categories. These results highlight the urgent need for a more effective instructional approach that encourages student participation, conceptual understanding, and meaningful engagement with mathematical ideas. The tendency of students to memorize formulas without comprehending their conceptual basis further reinforces the need for instructional strategies that connect mathematical concepts to real-life situations. Such difficulties often lead to challenges when students are required to apply their knowledge in problem-solving contexts.

To address these issues, an instructional model that supports active knowledge construction is required. The Realistic Mathematics Education (RME) approach offers a relevant framework by positioning mathematics as a human activity that originates from meaningful and realistic situations. Through contextual problems, students are encouraged to explore, model, and gradually formalize mathematical concepts through guided reinvention (Rahayu, 2025; Putri et al., 2024; Putri et al., 2024; Rangkuti, 2019; Siagian, 2016). By situating learning in realistic contexts, RME is expected to enhance students' motivation, conceptual understanding, and ability to transfer mathematical knowledge to real-life situations.

Previous studies have provided empirical evidence supporting the effectiveness of RME in improving students' mathematical understanding and engagement. Research by Meika et al, (2023), Haris, (2022), Putri et al. (2024), Zulmaulida et al., (2021). demonstrated that RME-based learning significantly enhances students' comprehension of mathematical concepts. In the context of trigonometry, studies by Apriliantyet al., (2024), Meika et al., (2023), and Putri et al., 2024), revealed that the use of contextual and realistic problem situations helps students interpret trigonometric relationships more meaningfully. These findings indicate that RME has strong potential to address learning difficulties in trigonometric topics at the senior high school level.

However, despite the positive findings, most previous studies have focused on experimental research designs or the development of instructional materials, with limited attention to classroom action research conducted in authentic classroom settings. Furthermore, research that integrates direct measurement activities in trigonometry and examines the implementation of RME for Grade X students within the Merdeka Belajar framework remains scarce. This gap highlights the need for further investigation through classroom-based research. Therefore, this study was conducted as a classroom action research project. This study aims to enhance students' understanding of trigonometric ratios and overall learning outcomes through the implementation of RME, while fostering deeper and more meaningful engagement with mathematical ideas in alignment with the Merdeka Belajar curriculum.

METHOD

This study employed classroom action research (CAR) using the Kemmis and McTaggart model, which was first introduced in 1988 through their foundational work, The Action Research Planner. This model consists of four cyclical stages, namely planning, action, observation, and reflection (Kemmis, 1998). It emphasizes the iterative nature of improving classroom practice, where each cycle is designed to identify instructional problems, implement an intervention, evaluate its impact, and refine strategies for the next cycle. The model is widely used in educational research because it allows teachers and researchers to collaboratively diagnose learning issues and examine the effectiveness of pedagogical innovations in authentic classroom settings. In this study, two full cycles were implemented, each consisting of two meetings, to allow adequate time for intervention using the Realistic Mathematics Education (RME) approach and for evaluating changes in students' mathematical understanding.

The research was conducted at SMA Negeri 13 Padang during the first semester of the 2024/2025 academic year, from August to October 2024. The study took place in the mathematics classroom of grade X E.2, which was selected based on the results of a diagnostic assessment indicating that a large proportion of students had not yet reached the minimum competency level. The chosen timeline enabled the researcher to carry out two cycles of classroom action research without interfering with the school's broader instructional schedule, ensuring smooth integration of the intervention.

The participants consisted of 36 students in grade X E.2, comprising 18 male and 18 female learners. This class was selected purposively due to the significant learning challenges identified during preliminary evaluation. The participants' diverse academic backgrounds and varying levels of prior mathematical understanding made the class an appropriate setting to examine the effectiveness of the RME approach. The focus of the research was on improving student learning outcomes in the topic of trigonometric ratios in right-angled triangles.

The intervention applied the principles of Realistic Mathematics Education (RME), which encourages students to construct mathematical concepts through exploration of meaningful, contextual situations. In Cycle I, students engaged with contextual problems designed to introduce the foundational ideas of trigonometric ratios. They worked collaboratively in groups to discuss, model, and reinterpret the problem situations, while the teacher facilitated learning by posing guiding questions and encouraging the articulation of reasoning.

Based on reflections from Cycle I, adjustments were made for Cycle II to strengthen students' conceptual understanding. In this cycle, students participated in a hands-on project in which they applied trigonometric ratios to measure the height of real objects around the school environment. They used measuring tools such as clinometers, rulers, and measuring tape and followed systematic steps including measurement, data recording, diagram creation, and calculation. This experiential process enabled students to connect abstract trigonometric concepts with real-world applications, thereby reinforcing learning through practical engagement.

Two main instruments were used to collect data. The first was a set of essay-based tests administered at the end of each cycle to assess students' cognitive understanding and problem-solving abilities. Essay questions were selected to allow students to demonstrate their reasoning and application of trigonometric concepts. The second instrument consisted of observation sheets completed by both the teacher and the researcher to document student engagement, participation, collaboration, and responsiveness during instruction. Field notes were also taken to capture classroom dynamics and to provide additional qualitative insights into student learning behaviors.

To ensure the validity and reliability of the data collection instruments, expert validation was conducted by two senior mathematics teachers and one university lecturer specializing in mathematics education. They reviewed the instruments for clarity, relevance to learning objectives, and suitability for measuring conceptual understanding. A small pilot test was administered before the actual intervention to examine reliability and adjust item difficulty. The results confirmed that the instruments were appropriate for assessing the range of student abilities within the class.Quantitative data from the essay tests were analyzed descriptively by calculating mean scores, performance distributions, and changes between cycles. These data were presented in tables and supported by narrative explanations to illustrate patterns in student achievement. Qualitative data from observations and field notes were analyzed through thematic coding, focusing on indicators such as student engagement, interaction, collaboration, and use of mathematical reasoning. Combining quantitative and qualitative analyses enabled a comprehensive evaluation of the impact of the RME approach on students' learning processes and outcomes (Sugiyono, 2019).

The study adhered to ethical principles in educational research. Permission was obtained from the school administration, and the purpose and procedures of the study were explained to the mathematics teacher and students. Participation was voluntary, and students were assured that their performance data would be used solely for academic research and improvement of instructional practice. Confidentiality was maintained throughout the research process.

RESULTS AND DISCUSSION

This classroom action research was conducted in class X E.2 of SMA Negeri 13 Padang with 36 students, consisting of 18 male and 18 female learners. The intervention was carried out in two cycles, with each cycle comprising two meetings followed by an assessment. The research aimed to improve students' understanding of trigonometric ratios through the implementation of the Realistic Mathematics Education (RME) approach.

Before the RME intervention, a preliminary assessment was administered to determine students' initial mathematical readiness. Although the main topic of this study was trigonometric ratios, the preliminary assessment used the topic of exponents because it was the material recently completed in class. The purpose of this assessment was not to test trigonometry but to obtain a baseline indicator of students' conceptual understanding, reasoning, and general problem-solving abilities in mathematics. The instrument consisted of five essay questions that required students to explain steps, justify solutions, and interpret numerical patterns. The questions were developed by the researcher together with the mathematics teacher and reviewed to ensure content relevance and clarity.

The assessment was administered under standard classroom conditions, and students' answers were scored using an analytic rubric emphasizing reasoning, accuracy, and explanation. The results indicated that approximately 84 percent of students had not reached the minimum passing criteria. The distribution of scores showed that many students struggled with conceptual reasoning and written explanations. Although the topic differed from trigonometry, the results reflected broader learning difficulties that needed to be addressed before tackling more abstract content. This reinforced the need for an instructional approach such as RME, which emphasizes understanding mathematical ideas through meaningful contexts.

Cycle I introduced students to trigonometric ratios through contextual problem situations. Before the cycle began, the researcher developed a set of four essay questions specifically designed to assess initial understanding of trigonometric ratios. These items asked students to identify right-angled triangles, apply sine, cosine, and tangent ratios, and interpret them in simple daily contexts. The instrument underwent content validation by two senior mathematics teachers to ensure suitability and difficulty level.

During implementation, the class was divided into six groups of six students. Each group worked collaboratively to analyze contextual problems involving right-angled triangles. The learning activities were structured to encourage discussion, exchange of ideas, and explanation of reasoning. The teacher provided scaffolding by asking guiding questions and prompting students to justify their thought processes. Observations showed that student engagement increased compared to the pre-cycle phase, although some students still relied heavily on peers when completing tasks.

Table 2. Cycle I Assessment Results Class X Phase E.2
SMA Negeri 13 Padang

Score Range	Description	Percentage
0-25	Emerging	0%
26-60	Developing	11%
61-80	Meeting Expectations	45%
81-100	Highly Developed	45%

The post-test results for Cycle I are shown in **Table 2**. The results indicated that student performance had improved compared to the preliminary assessment. However, many students were still developing their conceptual understanding and required more opportunities to connect mathematical formulas with concrete experiences. The reflection phase at the end of Cycle I revealed the need for more visual materials and a more structured activity design to support students in constructing trigonometric concepts. The post-test results in Cycle I are presented in **Table 2**.

Based on insights from Cycle I, further refinements were made for Cycle II. The primary improvement was the inclusion of a practical application project in which students estimated the height of real objects using trigonometric ratios. This project aimed to strengthen conceptual understanding by allowing students to experience mathematics directly in their environment. Before beginning Cycle II, a new assessment instrument was developed consisting of four essay questions focusing on real-life applications. Students were assessed on their ability to interpret measurements, create diagrams, and compute object heights using trigonometric ratios.

The implementation consisted of several structured stages. First, students measured the height of the observer using a meter stick. Next, they measured the horizontal distance between the observer and the object. Then, they used a clinometer to determine the angle of elevation. These measurements were recorded systematically before students created diagrams representing right-angled triangles. Finally, students calculated the height of the object using the appropriate trigonometric ratios. Throughout these stages, students worked collaboratively, and the teacher facilitated discussions and provided clarification when needed. Then, the stages of working on the project on the application of trigonometric ratios in right-angled triangles by students were as follows:

Figure 1. Students measure the height of the subject (observer)

In **Figure 1**, students are shown carefully measuring the height of the observer using a meter stick, which serves as the foundational step in constructing the right-triangle model needed for height estimation. This stage is crucial because the observer's height becomes a component of the final calculation when determining the actual height of the object being measured. The activity also introduces students to the importance of accurate measurement and data collection, reinforcing the idea that mathematical modeling begins with real, tangible quantities. Through this process, students become actively engaged in the mathematical task, taking ownership of the data they collect. In line with the principles of Realistic Mathematics Education (RME), this step encourages students to explore mathematics starting from real experiences, building a bridge between the concrete world and abstract trigonometric reasoning.

Figure 2. Students measure the distance between object and subject (observer) using a meter

Figure 2 illustrates students measuring the horizontal distance between the observer and the object using a long measuring tape. This measurement represents the base of the right-angled triangle that will later be constructed in their diagrams. This step helps students understand how spatial relationships can be converted into mathematical representations. It also allows them to recognize that trigonometric ratios depend on measurable relationships between sides of a triangle. By physically determining the distance rather than being given the value abstractly, students deepen their appreciation of how trigonometry is used in real-life contexts such as surveying, engineering, and architecture. The activity also promotes collaboration as students work in pairs or groups to ensure accurate alignment and measurement, embodying the RME emphasis on social interaction in mathematical learning.

Figure 3. Students calculate the magnitude of the elevation angle

In **Figure 3**, students are depicted using a clinometer to determine the angle of elevation from the observer's eye level to the top of the object. This stage is highly significant because it introduces learners to measurement tools commonly used in real-world applications of trigonometry. The act of reading and interpreting the angle requires precision and reinforces the idea that angles are not merely abstract symbols but are quantities that can be measured directly in the environment. This step also provides meaningful context for understanding the tangent ratio, as students later apply the angle measurement to compute the height of the object. By integrating hands-on instrumentation, the RME approach helps students construct a deeper conceptual understanding of angles as part of a measurable triangle, not just theoretical constructs from a textbook.

Figure 4. Students record all measurement results

Figure 4 displays students documenting the data they have collected, including the observer's height, horizontal distance, and angle of elevation. This stage emphasizes the importance of systematic data management within mathematical problem-solving. Recording information accurately ensures that students can later perform calculations correctly and analyze the results with confidence. The practice of organizing data also trains students' mathematical communication skills, as they learn to present information clearly and logically. In the framework of RME, this process is essential, as it encourages students to reflect on the meaning of the data and prepares them for the abstraction stage, where they transition from real measurements to mathematical modeling. Moreover, the act of writing down results fosters accountability and promotes a habit of thoroughness in mathematical investigations.

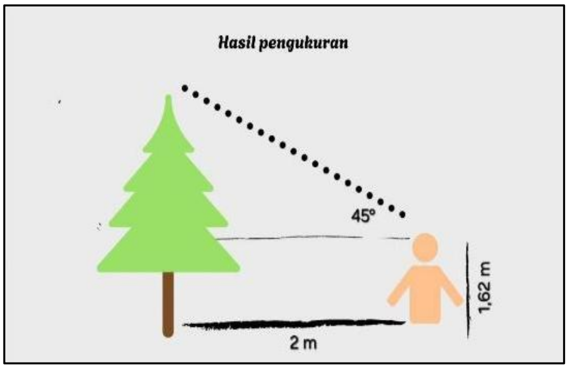

Figure 5. Illustration of the overall data obtained

Figure 5 shows an illustration created by students based on the measurements they gathered. This visual representation is a key step in the mathematization process, where students convert a real-world situation into a structured mathematical model. The diagram typically includes the observer's height, the measured distance to the object, and the angle of elevation, forming a right-angled triangle that becomes the basis for applying trigonometric ratios. Drawing such illustrations helps students internalize the spatial structure of the problem and enhances their ability to visualize geometric relationships. It also demonstrates the RME principle of guided reinvention, in which students rediscover mathematical ideas through problem situations. By constructing their own model, students develop a deeper understanding of how trigonometric formulas emerge from real contexts, rather than seeing them as arbitrary rules.

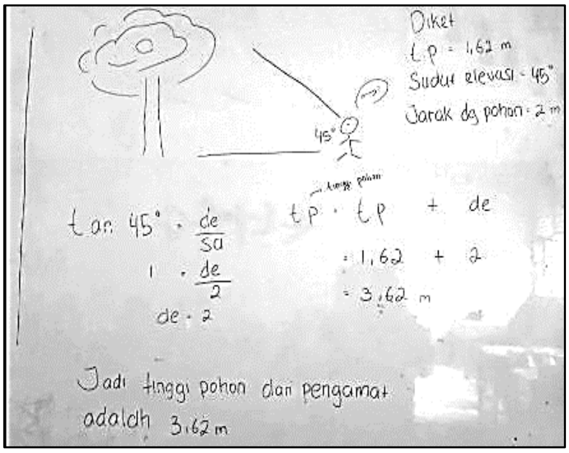

Figure 6. The result of calculating the height of the measured object

In **Figure 6**, the final stage of the activity is presented: students compute the height of the object using the trigonometric ratios derived from their data. Typically, the tangent formula is applied, allowing students to determine the vertical height above eye level and then add the observer's height to obtain the total object height. This step synthesizes all previous measurements and illustrates how abstract trigonometric concepts can be used to solve real problems. Students gain a sense of achievement as they observe how the numbers they measured directly translate into meaningful results. This moment represents the culmination of the RME process, in which learners progress from contextual understanding to formal mathematical reasoning. By completing the cycle, from measurement, modeling, diagramming, and calculation, students actively experience the relevance and power of mathematics in interpreting the physical world.

Beyond the step-by-step activities illustrated in **Figures 1** to **6**, the sequence as a whole demonstrates how students experience a complete cycle of contextual mathematical modeling, starting from data exploration to abstract reasoning. The integration of hands-on measurement, collaborative decision-making, and independent calculation helps reinforce the core principles of Realistic Mathematics Education (RME). Throughout the process, students are not merely passive recipients of information; instead, they actively construct mathematical meaning through interaction with real objects and their environment. This sequence of activities also fosters important 21st-century competencies such as critical thinking, problem-solving, teamwork, and communication.

Furthermore, the series of figures collectively highlight how contextual learning promotes deeper retention of mathematical concepts. By directly engaging with real objects and applying measurement tools such as clinometers and meter tapes, students gain a more tangible understanding of trigonometric relationships and the structure of right-angled triangles. This type of experiential learning enables students to link theoretical formulas with authentic situations, making the learning process more memorable and meaningful. As a result, students develop a more intuitive sense of why trigonometric ratios work and how they can be used to solve realistic problems.

The activities illustrated in **Figures 1** to **6** also demonstrate a gradual transition from concrete to abstract understanding, aligning with the RME notion of progressive mathematization. Initially, students rely heavily on physical measurements and visual observations; however, as they proceed, they shift toward symbolic reasoning, diagram interpretation, and algebraic calculation. This shift indicates that students are successfully moving from informal reasoning toward formal mathematical thinking. The entire workflow captured in the figures therefore not only supports conceptual understanding but also provides evidence of students' cognitive development throughout the intervention.

Finally, the visual sequence emphasizes the importance of structured and reflective mathematical activity. Each step requires students to analyze, record, verify, and justify their results, thereby enhancing their metacognitive awareness. By engaging in tasks that require precision and validation, students learn to monitor their own understanding and identify potential errors in measurement or calculation. This reflective habit is essential for developing mathematical resilience and independence. Overall, the additional insights from the figures reinforce the effectiveness of the RME approach in fostering comprehensive mathematical understanding and meaningful learning experiences.

Table 3. Cycle II Assessment Results Class X Phase E.2 SMA Negeri 13 Padang

Score Range	Description	Percentage
0-25	Emerging (Beginning to Develop)	0%
26-60	Developing (In Progress)	0%
61-80	Meeting Expectations (Developing as Expected)	0%
81-100	Highly Developed (Well Developed)	100%

The post-test results in **Table 3** for Cycle II showed a marked improvement, with 100 percent of students reaching the Highly Developed category. This substantial improvement indicates that students were able to internalize trigonometric concepts more effectively when engaged in hands-on, contextual tasks. Their ability to explain reasoning, construct diagrams, and apply formulas accurately showed significant progress compared to Cycle I.

The improvements observed across cycles align with the fundamental principles of RME. In Cycle I, contextual problems supported guided reinvention as students explored relationships informally. In Cycle II, real-world measurement tasks enabled students to develop models that bridged intuitive understanding and formal mathematics. This process reflects progressive mathematization, where students move from concrete experiences toward abstraction and generalization.

Research by Sandy et al. (2022), Novianti (2019), Agusta (2020), supports these findings, emphasizing that contextual and meaningful tasks promote deeper conceptual understanding and engagement. Throughout both cycles, students demonstrated growth not only in performance but also in confidence, participation, and mathematical communication. The use of realistic problems helped students visualize abstract mathematical ideas and relate them to concrete situations. This aligns with previous studies highlighting the effectiveness of RME in fostering meaningful learning and enhancing student motivation. The increase of 20.19 points from Cycle I to Cycle II underscores the significant impact of RME when implemented systematically and reflectively.

The findings of this study align strongly with the core principles of the Realistic Mathematics Education (RME) approach, which positions mathematics as a human activity grounded in meaningful contexts. Throughout the intervention, students engaged in the essential phases of RME. First, learning began with contextual phenomena, allowing students to explore trigonometric concepts through realistic measurement tasks and everyday situations. Second, students participated in guided reinvention by collaboratively constructing diagrams and models representing right-angled triangles based on field data they collected themselves, enabling them to rediscover the meaning of trigonometric ratios rather than memorizing formulas. Third, the intervention supported progressive mathematization, evidenced by students' transition from informal, intuitive reasoning in Cycle I to more formal symbolic representations and generalized procedures in Cycle II. Fourth, interactivity was an integral component, with students discussing ideas, negotiating meanings, and justifying their reasoning in groups. Finally, students generated both model-of representations derived from real measurements and model-for representations that functioned as formal trigonometric tools applicable to broader problems. These features collectively explain the significant improvement in students' conceptual understanding, engagement, and mathematical communication. The 20.19-point increase from Cycle I to Cycle II further demonstrates the effectiveness and broader potential of RME for senior high school mathematics instruction, in line with previous studies highlighting its positive impact on learning outcomes and student motivation. The RME approach proved effective in promoting student engagement and conceptual understanding. The contextual problems given in each session helped students visualize abstract mathematical ideas, thus facilitating deeper learning. Students were motivated to participate actively through group discussions and presentations. The opportunity to construct knowledge independently encouraged student's mathematical communication skills and teamwork. These findings align with previous research that highlighted the positive impact of RME on learning outcomes and student motivation in mathematics (Agusta, 2020; Novianti, 2019; Reza et al., 2024). The 20.19-point in the average student score from Cycle I to Cycle II reflects the RME approach's potential for broader application in teaching mathematics at the senior high school level. The results of this study suggest that mathematics teachers should incorporate realistic contexts and interactive problem-solving scenarios to foster students's engagement. Such practices can help align mathematics instruction with goals of the Merdeka Belajar curriculum.

The findings of this study also suggest broader implications for mathematics education in Indonesia. The RME approach could be effectively implemented across different topics such as geometry, algebra, and statistics, where students can explore real-life models to build abstract reasoning. Moreover, it encourages the development of 21st-century competencies (critical thinking, collaboration, communication, and creativity) that are essential in preparing students for the challenges of the modern world. Integrating RME principles into the Merdeka Belajar framework could thus promote a more humanistic and meaningful mathematics learning experience.

CONCLUSION

The implementation of the Realistic Mathematics Education (RME) approach was proven effective in improving the mathematics learning outcomes of grade X phase E.2 students at SMA Negeri 13 Padang. This was demonstrated by a 20,19 point increase in the class average score. In addition to the improved test results, students showed greater engagement, motivation, and active participation during the learning process. The use of contextual problems and collaborative group work enabled students to construct their own mathematical understanding. Overall, the RME approach not only enhanced academic performance but also fostered a more meaningful and student-centered learning environment. Further research is recommended to explore the integration of RME with digital learning tools and to examine its long-term effects on students' conceptual retention and mathematical literacy.

In addition to its pedagogical benefits, this study provides valuable insights for policymakers and educators aiming to redesign mathematics instruction in senior high schools. Schools are encouraged to incorporate RME-based learning designs supported by project-based and technology-assisted tools such as GeoGebra or online measurement simulators. Future research may also explore the integration of RME with blended or flipped classroom models to investigate its sustainability and scalability in different learning environments.

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