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The effectiveness of applying realistic mathematics education approach with the support of GeoGebra software (RME-SBG) in teaching calculus for high school students: A case of teaching the concept of derivatives

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ABSTRACT

Research aims: This research investigates the effectiveness of a novel teaching approach called RME-SBG (Realistic Mathematics Education with GeoGebra Software) for instructing high school students on the concept of derivatives. Calculus education often struggles to provide students with a deep understanding and meaningful connections to real-world applications. This study aims to address these shortcomings by employing the strengths of both RME and GeoGebra software.

Methodology: Researchers will recruit participants and form two groups: one using RME-SBG and another receiving traditional instruction. The RME-SBG group will explore derivatives through real-world scenarios and use GeoGebra for visualization and exploration. The control group will receive lectures and practice problems. Data will be collected through pre-tests, post-tests, classroom observations, and student surveys to assess both groups' understanding, problem-solving abilities, and engagement with the material. This analysis will determine the effectiveness of the RME-SBG approach in teaching derivatives.

Results and conclusion: The study found that the RME-SBG group showed statistically significant improvement in their conceptual understanding of derivatives compared to the control group. Students in the RME-SBG group demonstrated a stronger ability to apply derivatives to solve problems compared to the control group. The RME-SBG approach appeared to foster greater student engagement and positive attitudes towards learning derivatives compared to traditional instruction.

Keywords: realistic mathematics education, GeoGebra, calculus, derivatives

INTRODUCTION

One of the core objectives in teaching and learning mathematics is to cultivate a deep understanding in students. This understanding empowers them to not only retain knowledge but also transfer it to new situations. They can then apply concepts to novel problems, analyze issues from diverse perspectives, and explain their solutions in a way that resonates with themselves and others. Beyond acquiring basic mathematical skills, students need a strong foundation in mathematical understanding. This allows them to appreciate the significance of mathematics not just within the subject itself, but also in its broader applications across various disciplines.

Traditional teaching methods often place the teacher at the center, heavily focused on equipping students with formulas and pre-solved examples. Students become passive recipients of pre-existing knowledge, hindering their potential for exploration and discovery. Additionally, these methods train students to solve problems based on formulas found in textbooks or algorithms provided by teachers, which they may not fully grasp. This mechanical and passive approach proves ineffective in fostering a deep understanding of mathematics and honing problem-solving abilities. Consequently, students often encounter confusion and a lack of confidence when faced with real-life mathematical challenges or problems within the subject itself.

In recognition of this need, Vietnam's 2019 Education Law explicitly emphasizes the importance of integrating theory with practice throughout the learning process (National Assembly, 2019). This law mandates education to be delivered through "learning coupled with practice," advocating for a combined approach that incorporates school education with both family and social education. Similarly, the 2018 General Education Program in Mathematics aligns with this philosophy by outlining specific

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requirements for teaching methods that place students at the heart of the learning experience. These methods promote a positive and self-disciplined learning environment, while catering to the individual needs, cognitive abilities, and diverse learning styles of each student (Ministry of Education and Training, 2018).

Practical experience in teaching mathematics, particularly Calculus, has revealed three persistent issues:

(1) Direct knowledge transmission: Teachers often directly present concepts and theorems, depriving students of the opportunity to experience and rediscover the path to forming that knowledge themselves. This results in a portion of students possessing a hazy understanding of the nature of these concepts and theorems, ultimately limiting their overall mathematical comprehension;

(2) Low student engagement: Many students exhibit minimal interest and enthusiasm when learning Calculus concepts. This contradicts the core principles outlined in the 2018 Math Education Program, which advocates for fostering student initiative and positivity, placing learners at the center of the educational experience, and transitioning teachers into roles as guides and facilitators;

(3) Difficulty with practical application: When confronted with practical problems at the high school level, a significant majority of students struggle and appear bewildered. They develop a sense of apprehension and avoidance towards encountering mathematical problems that fall outside the confines of their textbooks.

Calculus, crucial for analyzing change and real-world problems, is often taught in Vietnam with an emphasis on abstract concepts and rote memorization. A survey reveals teacher challenges, including:

(1) Limited time & abstraction: Constrained time and highly abstract concepts hinder deep understanding;

(2) Visualization & engagement: Underutilized visuals and low student interest create additional hurdles;

(3) Topic-specific challenges: Specific difficulties exist for Limits, Derivatives, and Integrals.

Besides the teacher's difficulties in teaching concepts, students also often face difficulties and challenges in learning Calculus. Many students have difficulty accepting new concepts. Some concepts and theorems are not thoroughly understood by students, and are even vague and superficial, especially the concepts of limits, derivatives, and (definite) integrals. Students believe that the presence of many mathematical symbols in the definition makes it difficult for them to access the concept. Meanwhile, Realistic mathematical education (RME) is mentioned as an Educational Theory, applied to mathematics teaching. It is considered a theoretical approach to understanding mathematical concepts through students' daily experiences. The focus of RME is that students can rediscover mathematics but still under the guidance of adults (teachers/lecturers). Instead of the student being the recipient of ready-made mathematics, the student should be an active participant who is oriented to using situations to rediscover mathematics using the different strategies available to them.

Research Across the Globe Supports the Potential of RME to Transform Calculus Learning

Increased interest and appreciation:

(1) Studies in Turkey (Papadakis et al., 2017) show RME can cultivate a positive attitude towards mathematics in students;

(2) Enhanced Mathematical Competence: Greek research (Papadakis et al., 2017) demonstrates RME's effectiveness in developing mathematical skills in young students (ages 4-6);

(3) Greater student engagement: A UK project (Searle & Barmby, 2012) found teachers observed higher student engagement in RME-based lessons compared to traditional methods;

(4) Improved critical thinking: Evidence suggests RME fosters logical, critical, and creative thinking skills (Saefudin, 2012; Sembiring et al., 2008). RME can cultivate student awareness throughout the creative thinking process, which research suggests is heavily reliant on cognitive and intellectual functions, particularly in creative problem-solving (Almeida et al., 2008).

Benefits of RME in calculus learning

Kuiper and Knuver (Suherman & Erman, 2003) highlight the positive impacts of RME on learning:

(1) Increased interest, relevance, and meaning in learning mathematics;

(2) Focus on individual student abilities;

(3) Emphasis on "learning by doing" mathematics;

(4) Encouragement of non-algorithmic problem-solving strategies;

(5) Utilization of real-world contexts as the foundation for learning.

These findings suggest that RME can be a valuable tool in promoting student engagement and developing a deeper understanding of Calculus concepts.

Beyond its effectiveness in Calculus, recent studies suggest RME can further enhance student learning by:

(1) Improving reading & writing (Sumirattana et al., 2017);

(2) Boosting mathematical communication (Gyamerah et al., 2021; Habsah, 2017);

(3) Developing higher-order thinking (Fadlila & Sagala, 2021);

(4) Enhancing problem-solving skills & math confidence (Yuanita et al., 2018).

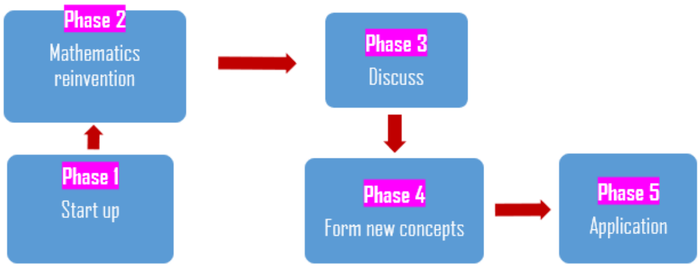


Figure 1. Teaching phases are based on the RME-SBG model (Source: Authors' own elaboration)

Research by Muchlis (Efrida et al., 2012) demonstrates a significant improvement in problem-solving abilities of students using RME compared to traditional methods. The positive impact of RME on Calculus learning is further supported by global research (Arnellis et al., 2020; Gravemeijer, 1999; Khairudin et al., 2022; Suparatulatorn et al., 2023). These studies highlight RME's effectiveness in fostering a deeper understanding of abstract Calculus concepts like limits, derivatives, and integrals.

Although Realistic Mathematics Education (RME) provides a solid pedagogical foundation for the formation of mathematical concepts through real-world contexts, recent educational research emphasizes that the effectiveness of such active teaching approaches can be further enhanced through the integration of technology-supported instructional frameworks. In the era of digital education, contemporary pedagogical frameworks have increasingly shifted toward learner-centered approaches, in which active learning theory plays a pivotal role in optimizing learner engagement, interaction, and autonomy using technological platforms (Goswami, 2024). Salmon's five-stage model is widely recognized as the backbone of online instructional design and organization, offering a structured progression that guides learners from initial access and socialization to knowledge construction and the development of deeper conceptual understanding (Graham & Valsamidis, 2006). In addition, the TPACK framework (Technological Pedagogical Content Knowledge) serves as a guiding model for instructors to achieve a coherent integration of subject-matter expertise, pedagogical strategies, and digital tools (Graham et al., 2006). Furthermore, the framework of technology-supported self-regulated learning (SRL) highlights the integration of knowledge, skills, and attitudes, enabling learners to effectively manage the phases of preparation, performance, and self-reflection within modern educational environments (Zimmerman, 2011).

This study investigates a new approach, RME-SBG (Realistic Mathematics Education with GeoGebra Software), to enhance high school students' understanding of derivatives. RME-SBG bridges theory and practice with real-world contexts and GeoGebra's dynamic visualizations. Compared to traditional methods, RME-SBG aims to improve students' grasp of derivatives, problem-solving skills, and overall learning experience. This research contributes to finding effective pedagogical tools in calculus education, potentially boosting student engagement and achievement.

To comprehensively evaluate the impact of the RME-SBG model, the research team focuses on addressing the following key research questions:

RQ1 How does the implementation of the RME-SBG model affect students' learning outcomes compared to traditional teaching methods?

RQ2 How does students' ability to solve real-world problems related to derivatives change when they are taught through real-life contexts and mathematical modeling?

RQ3 How does the RME-SBG model influence students' learning attitudes, interest, and level of engagement in learning activities related to derivative concepts?

METHOD

Study Design

Quasi-experimental: Utilize pre-test and post-test design with two groups:

1) Experimental group: Teaching mathematics concepts based on RME-SBG model (see **Figure 1**)
2) Control group: Taught derivatives using traditional methods.

Teaching derivatives using the traditional teacher-centered approach. This approach emphasizes deductive reasoning, in which the teacher first presents the definitions, formulas, and rules of derivatives, followed by illustrative examples and the organization of intensive textbook-based practice to reinforce procedural fluency.

Participants

Sample size

Aim for at least 76 high school students (37 students in the experimental class and 39 control students-**Table 1**) to ensure sufficient statistical power. The sample size was determined through a power analysis based on an independent-samples t-test applied to post-test outcomes, with a significance level of $\alpha = 0.05$, a desired statistical power of $1 - \beta = 0.80$, and an assumed medium effect size ($g = 0.50$). These parameters are consistent with prior studies examining the effects of RME and technology-supported mathematics instruction. The results of the analysis indicated that the minimum required sample size was 72 students.

Table 1. Experimental group and control group

Group	Number of students
Experimental group (learning according to RME approach)	37
Control group (traditional learning)	39

Selection

Randomly assign students to either group to minimize selection bias.

Matching

Consider matching based on relevant factors like prior math achievement to control for individual differences. Both groups were assessed using a pre-test, and the results indicated no statistically significant differences in baseline knowledge between the two groups. In addition, both groups were taught the same content over the same instructional period, with an equivalent number of class sessions, and by the same instructor. The same pre-test and post-test assessment instruments were administered to both groups to ensure consistency in data collection and analysis.

Materials

Teaching materials

Experimental group: Develop RME-based learning activities incorporating GeoGebra. Activities should emphasize real-world contexts and mathematical modeling of rate-of-change phenomena relevant to students' lives.

Control group: Utilize traditional textbook materials and classroom instruction methods for teaching derivatives.

GeoGebra Software: Both groups can have access to GeoGebra, but the experimental group will use it actively during RME activities for visualization and exploration.

Assessment tools

Pre-test and post-test: Standardized mathematics achievement tests focusing on derivative concepts.

Interviews: Conduct semi-structured interviews with a subset of students (5-10) from each group to gain qualitative insights into their learning experiences and understanding of derivatives.

Experimental Process

In this study, both qualitative and quantitative research methods are used. The research was conducted by choosing one of the two equal branches as the experimental group and the other as the control group. During the research process, applications were conducted before and after the research in both groups. The research design is shown in **Table 2**.

Procedure

1. Data collection tools: The academic achievement test and a semi-structured interview form were prepared as the primary data collection tools for the research.
2. Subject selection: A total of 73 senior high school students from the new general education program were chosen to participate in the study, divided into experimental and control groups.
3. Teaching materials: Prior to the intervention, teaching materials aligned with the calculus course objectives and targeted behaviors were developed for both groups.
4. Course hours: Before the study began, the monthly course hours for both groups were established, adhering to the total course hours recommended by the Ministry of Education.
5. Pretest: A standardized mathematics achievement test was administered to both groups as a pretest.
6. Teaching techniques: The experimental groups received instruction using teaching techniques aligned with the RME approach. Control groups were taught using traditional methods, primarily lectures and question-answer sessions. The experimental groups were instructed using teaching techniques aligned with the Realistic Mathematics Education (RME) approach, emphasizing problem solving grounded in real-world contexts and students' processes of self-reinvention of knowledge. In contrast, the control groups were taught using traditional methods, primarily through teacher-led lecturing, structured demonstrations on the board, and systematically repeated practice activities designed to ensure proficiency in derivative calculations.
7. Instructor: The researcher, acting as the instructor, taught both the experimental and control groups throughout the study.
8. Pre-test: Administer the pre-test to both groups to assess baseline knowledge of derivatives.
9. Intervention: Implement the teaching approach for each group for a predetermined period (e.g., 4-6 weeks).
    a) Experimental group: Conduct RME-based activities with GeoGebra support. Encourage active participation, problem-solving, and reflection on real-world applications. The instructional process was organized into the following stages: Start-up (introducing learning situations grounded in real-life contexts), Mathematics Reinvention (guiding students to explore and generalize concepts through visualization), Discussion (facilitating peer discussion and exchange of

Table 2. The table describes the activities of teachers and students in each teaching phase

Phase	Activities
Start up	The teacher selects and proposes real contexts (real in the students' minds).
Mathematics reinvention	Teachers create opportunities for students to participate in mathematical activities, discover and reinvent the path of forming mathematical knowledge.
Discuss	Students exchange and discuss issues surrounding the mathematical knowledge they have just acquired and discovered (under the guidance of teachers and learning materials).
Form new concepts	Students use informal language to construct mathematical knowledge. The teacher formalizes the student's answers to lead to formal mathematics.
Application	Students apply the mathematical knowledge they have just acquired to solve similar problems

ideas), Forming New Concepts (abstracting and formally constructing the concept of derivatives), and Application (applying the acquired knowledge to solve related problems and analogous real-world situations).

b) Control group: Deliver traditional derivative instruction through lectures, textbook exercises, and question-and-answer sessions. The teacher presented the concepts, definitions, and rules for computing derivatives, illustrated them using examples from the textbook, and conducted practice activities involving problem-solving, along with question–answer interactions to reinforce and assess students' understanding.

10. Post-test: Administer the post-test to both groups to evaluate learning gains in derivative understanding.
11. Interviews: Conduct individual interviews with selected students from each group to explore their perspectives on the learning experience and perceptions of derivative concepts.
12. Data Analysis
    a) Quantitative: Analyze pre-test and post-test scores using statistical tests to compare learning outcomes between groups.
    b) Qualitative: Analyze interview data through thematic analysis to identify key themes and patterns regarding student learning and experiences with RME-SBG model.

Experimental tasks

The derivative is one of the core and central concepts of calculus. In mathematics education research, Zandieh (2000) developed a theoretical framework to analyze how students understand the concept of the derivative, emphasizing that understanding a derivative is not merely memorizing its definition but also making connections among rates of change, limits, geometry, and real-world contexts.

The study by Weber et al. (2012) illustrates that understanding the derivative through the Calculus Triangle helps students connect different representations of the derivative, thereby deepening their understanding of the role of the derivative in function analysis and its applications in various contexts.

In addition, Feudel and Biehler (2021) point out that although the derivative can be clearly defined in mathematics textbooks, students still face difficulties when applying this concept in real-world contexts such as economics or physics. This indicates that teaching should integrate algebraic, geometric, and applied-context representations in order to enhance learners' ability to interpret and apply the concept.

Furthermore, research in mathematical cognition shows that the concept image—the system of images, descriptions, and rules that learners associate with a concept—also plays an important role in learning derivatives. This is evidenced by the classic work of Tall and Vinner (1981) on concept image and concept definition in the context of limits and derivatives, which has become a theoretical foundation for many subsequent studies.

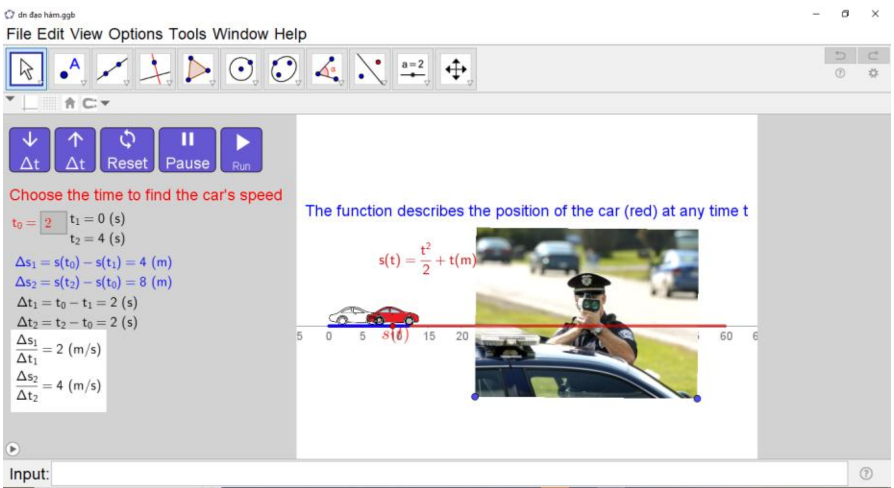


Figure 2. Simulate images of traffic police measuring vehicle speed based on RME-SBG model (Source: Authors' own elaboration)

Table 3. Task 1: Write your answer in the corresponding column on the right

No	Question
1	What is the function you chose?
2	The moment at which the velocity needs to be calculated (i.e. time t_0) is ?
3	According to your knowledge, is there any way to directly determine the vehicle's speed at any given time (if only based on existing knowledge)
4	How is the average velocity of an object moving in a straight line with a position function: $s = s(t)$from time $t = a$ to time $t = b$, determined?

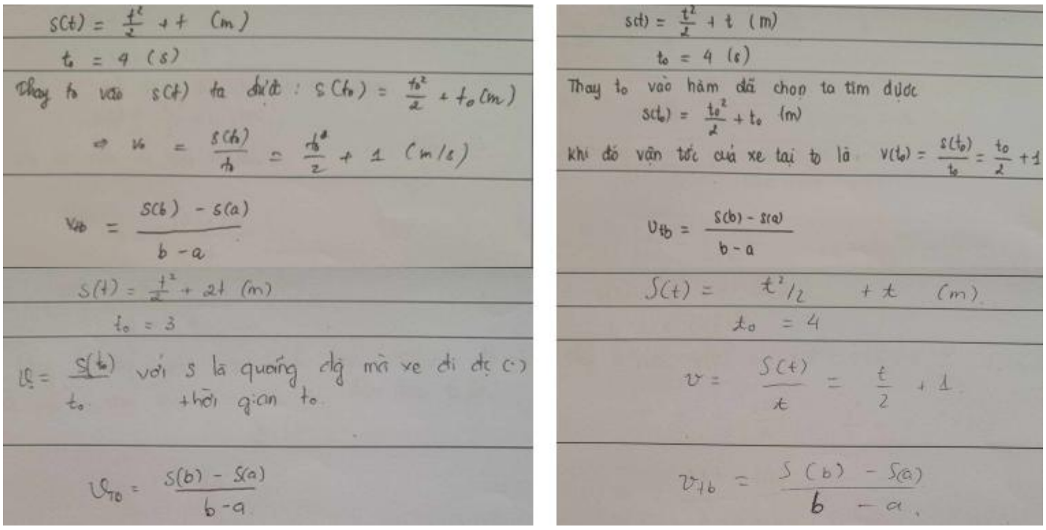


Figure 3. Some students' products on worksheet (**Table 3**) number 1-Task 1 (Source: Authors' own elaboration)

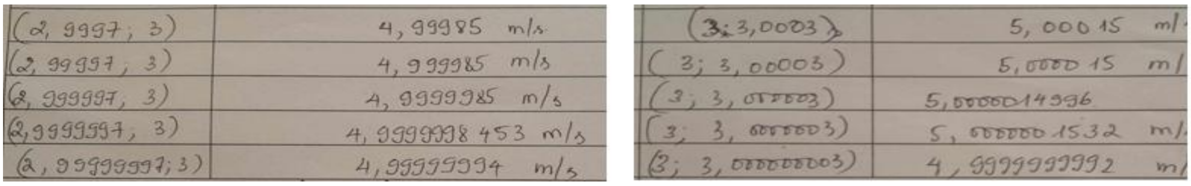


Figure 4. Average velocity over intervals (t; 3) and (t; 3) (Source: Authors' own elaboration)

Focusing on the learning content "Calculate the instantaneous speed of the car," Students actively engage with the RME-SBG model. This exercise aims to guide them through finding the average velocity over various intervals (as illustrated in **Figure 4**). Subsequently, they will summarize the key knowledge points within a 3-minute timeframe. Meanwhile, participants in the observation group passively learn by watching a 3-minute lecture video without directly engaging with the paper tasks. In educational psychology, a problem refers to a situation where an obstacle separates the current state (known) from the desired state (unknown), requiring overcoming steps to reach the goal. These problems can be categorized into well-structured and ill-structured (Reed, 2016). Well-structured problems operate within a clearly defined space with readily identified initial and final states, connected by specific, allowable actions. Conversely, ill-structured problems lack fully defined initial, intermediate, and final states, requiring the solver to actively interpret and define them as part of the solution process.

Application process: An example of using the RME-SBG model to teach the concept of derivatives

The model in **Figure 2** depicts a police officer measuring the speed of vehicles moving on a highway. For each different type of speed camera, the determination of this speed is different. As students, after learning calculus, do we have any way to determine the speed of a moving car at any given time?

Some students chose functions (see **Figures 3, 4, 5** and **6**):

$$f(t) = \frac{t^2}{2} + 2t \tag{1}$$

In **Figure 4**, it can be observed that students construct tables of average velocity over time intervals that progressively approach a fixed instant. Because the chosen intervals are increasingly narrow, the resulting average velocity values gradually stabilize and converge toward a specific value. Directly observing these numerical values converging to a single value helps students more readily recognize the meaning of approaching the velocity at a specific moment in time, rather than merely considering velocity over an extended time interval.

From those results, they drew conclusions (**Figure 5**).

Table 4. Task **2**: Based on the answers H1 and H2 in task 1, please complete the missing parts in the following boxes

The intervals $(t; t_0)$	**Average velocity over intervals $(t; t_0)$**	**Intervals $(t_0; t)$**	**Average velocity over intervals $(t_0; t)$**
….	….	….	….
H5: Do you have any comments on the average speed of the car above in intervals? (t; t₀), where $t < t_0$ as $t_0 - t \to 0$?			
H6: Do you have any comments on the average speed of the car above in intervals? $(t_0; t)$, where $t > t_0$ as $t - t_0 \to 0$?			
H7: Do you have any comments on the vehicle's speed at very close times, as close as you can (it means $\|t_0 - t\| \to 0$).			

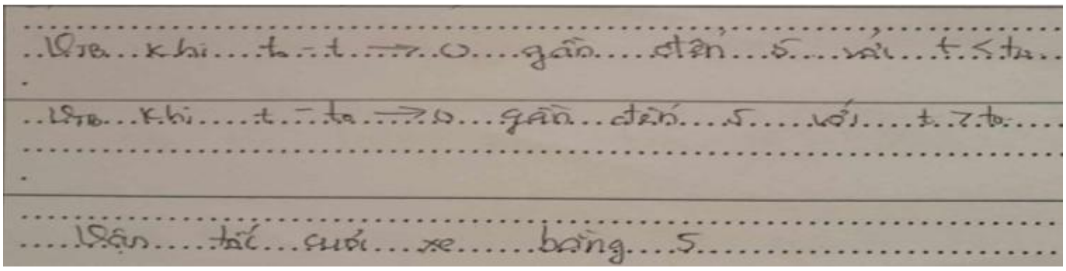


Figure 5. Student's results for **Table 4** (Source: Authors' own elaboration)

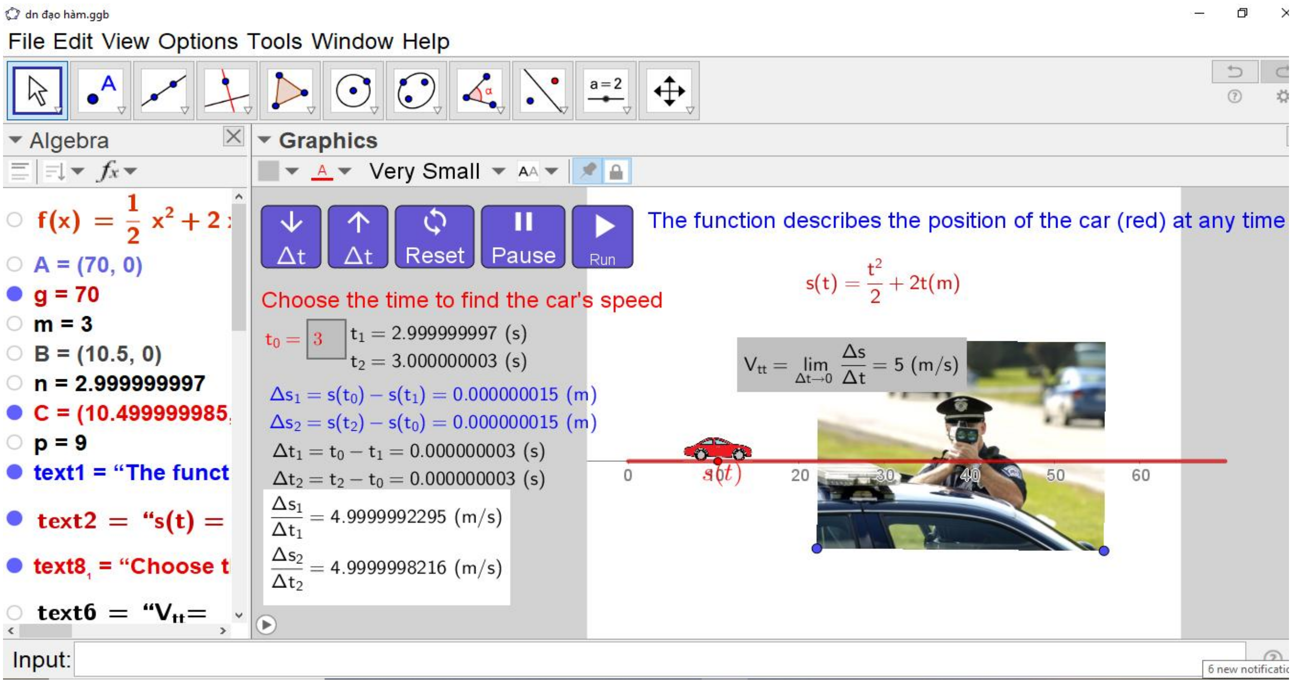


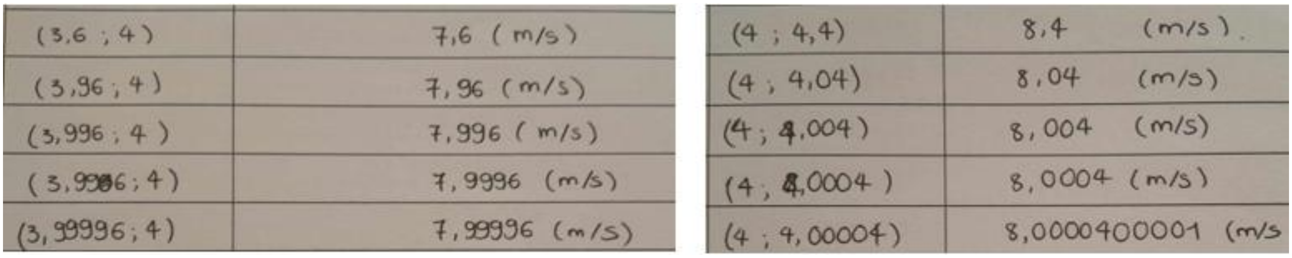
Figure 6. The speed of the car when the interval function is $s(t) = \frac{1}{2}t^2 + 2t$ at $t_0 = 3$ by RME-SBG model (Source: Authors' own elaboration)

In **Figure 5**, students do not stop performing calculations but also articulate their own observations and conclusions based on the numerical tables. They point out that as the time interval becomes smaller, the average velocity approaches the velocity at the specific instant under consideration. This indicates that students are able to reason from data rather than merely applying given formulas. Drawing conclusions from concrete data helps them develop a more robust understanding of the underlying nature of the concept.

In another situation, when working with the rate function:

$$f(t) = \frac{t^2}{2} + 4t \tag{2}$$

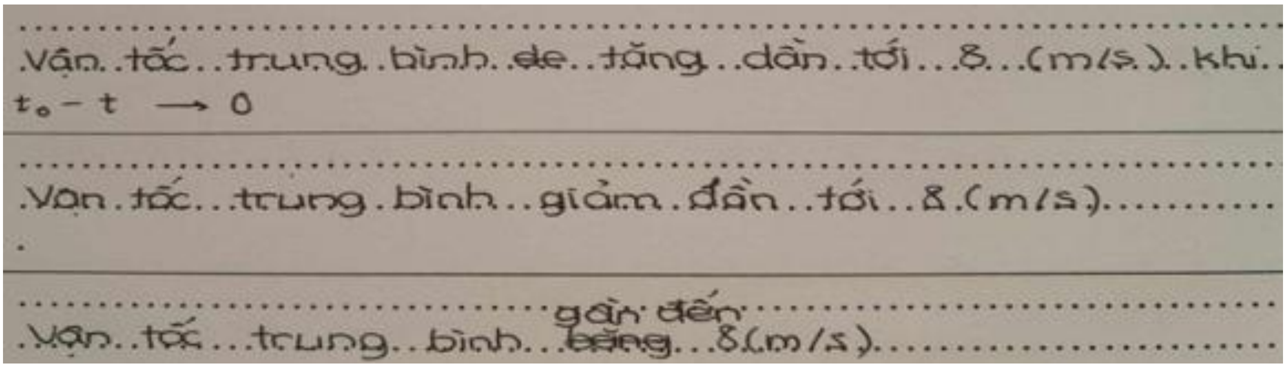
Another group of students obtained the results shown in **Figure 7** and **Figure 8**.



(3,6 ; 4)	7,6 (m/s)
(3,96 ; 4)	7,96 (m/s)
(3,996 ; 4)	7,996 (m/s)
(3,9996 ; 4)	7,9996 (m/s)
(3,99996 ; 4)	7,99996 (m/s)

(4 ; 4,4)	8,4 (m/s)
(4 ; 4,04)	8,04 (m/s)
(4 ; 4,004)	8,004 (m/s)
(4 ; 4,0004)	8,0004 (m/s)
(4 ; 4,00004)	8,0000400001 (m/s

Figure 7. Average velocity over intervals (t; 4) and (t; 4) (Source: Authors' own elaboration)



Vận tốc trung bình đe tăng dần tới 8 (m/s) khi $t_0 - t \to 0$

Vận tốc trung bình giảm dần tới 8 (m/s).

Vận tốc trung bình ~~bằng~~ gần đến 8 (m/s).

Figure 8. Student's results for **Table 4** (Source: Authors' own elaboration)

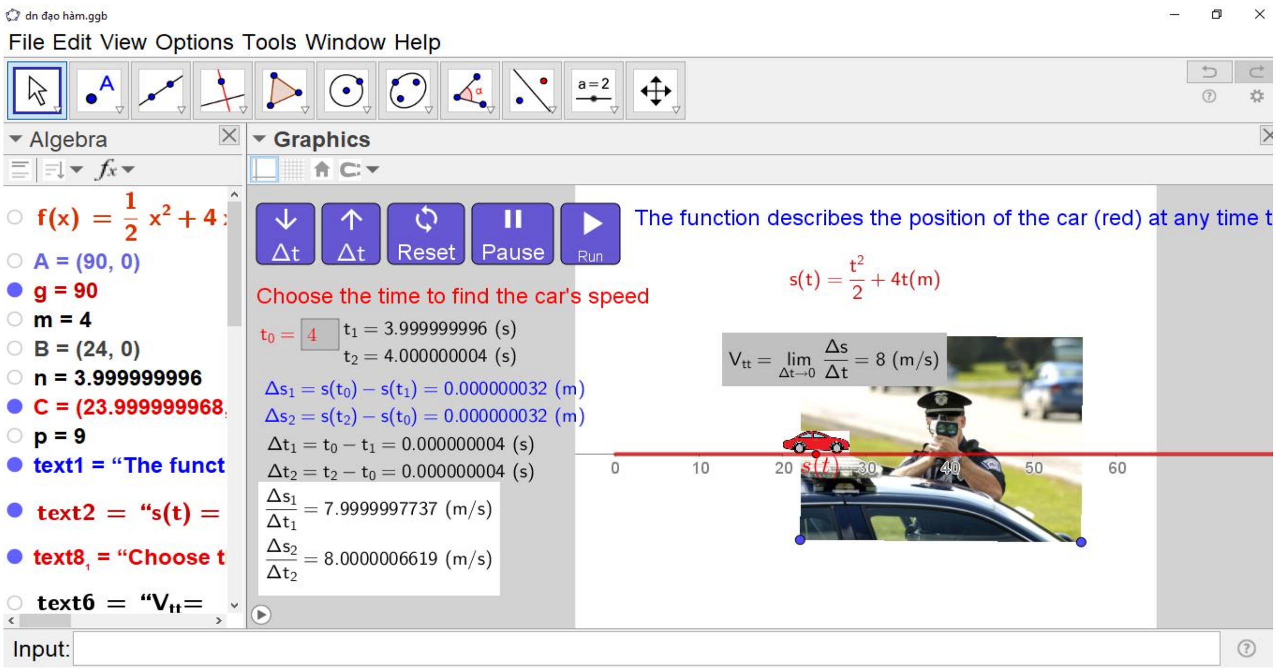


Figure 9. The speed of the car when the interval function is $s(t) = \frac{1}{2}t^2 + 4t$ at $t_0 = 4$ by RME-SBG model (Source: Authors' own elaboration)

Specifically, **Figure 7** presents tables of average velocity over intervals of the form (t, 4), in which the time variable t approaches 4 from the left. The data show that as ttt gets closer to 4, the average velocity values become closer to each other and converge to about 8 m/s.

Figure 8 shows tables of average velocity over intervals of the form (4, t), meaning that time approaches 4 from the right. Similar to **Figure 7**, the average velocity values in **Figure 8** also gradually converge to about 8 m/s as t gets closer to 4.

From the results in both **Figure 7** and **Figure 8**, students concluded that when the time is very close to 4, the velocity of the car is very close to 8 m/s. This was observed by the students through the RME-SBG model as shown in **Figure 9**.

From those results, they drew conclusions shown in **Figure 8**.

Worksheet number 2 includes questions from Q.1 to Q.3 in **Table 5**.

Table 5. Questionnaire of worksheet number 2

Questions/requests	Answer
Q.1. Through the above situation, finding the velocity of a car moving in a straight line (with a position function $s = s(t)$) at a time t_0 any lead to calculating the limit of any expression?	
Q.2. Limit $\lim_{t \to t_0} \frac{s(t)-s(t_0)}{t-t_0}$ if it exists and is finite, it is called the derivative of the function $s(t)$ at a time $t = t_0$. Let me state this definition for the general case: Derivative of a function $f(x)$ at the point x_0.	
Q.3. From the definition you described in Q.2, please propose steps to calculate the derivative of a function $f(x)$ at a given point x_0, giving an illustrative example.	

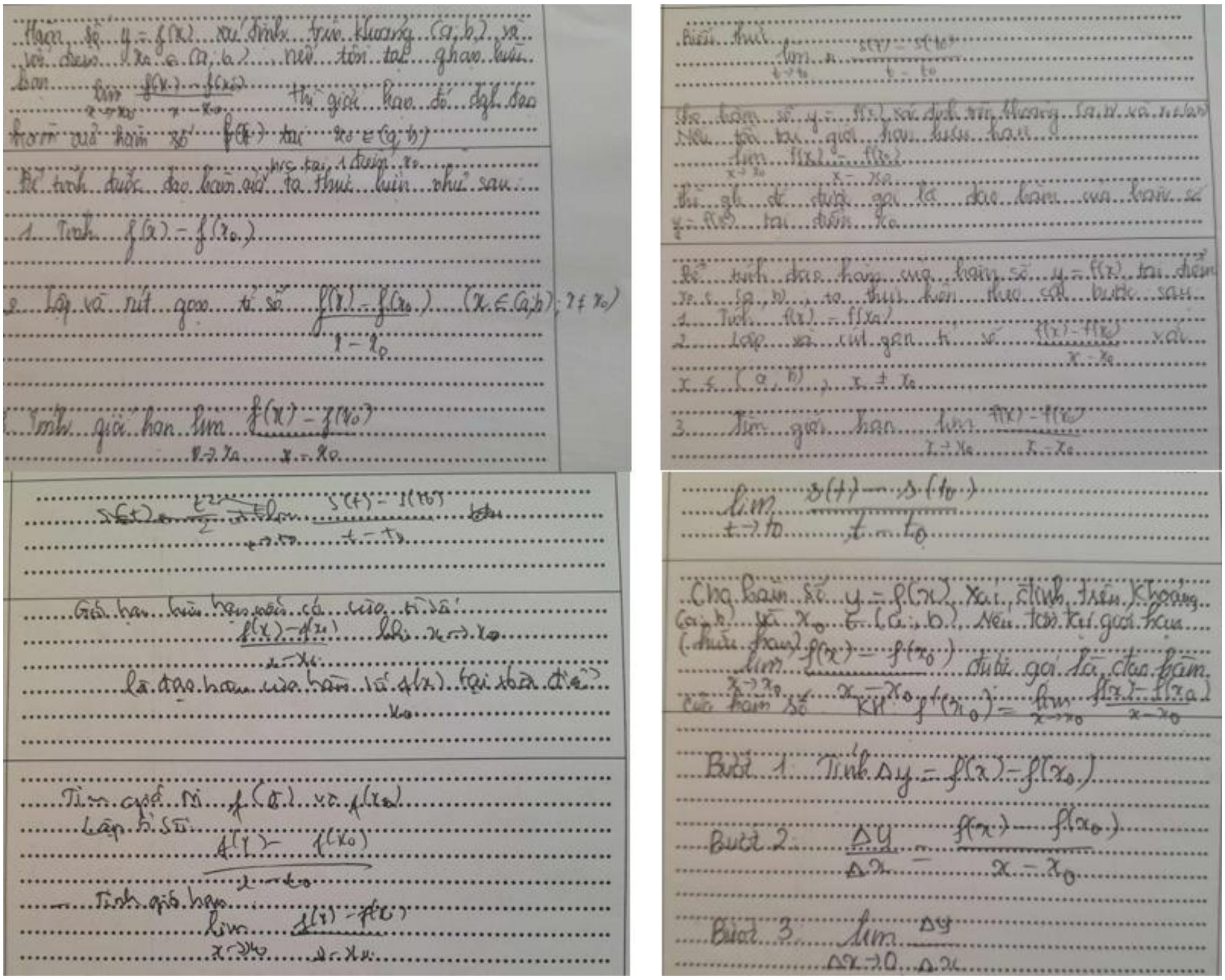


Figure 10. Some students' products on worksheet number 2 (Source: Authors' own elaboration)

In the students' work on Worksheet Number 2, they carried out all the steps needed to approach the concept of the derivative from the velocity problem. First, they identified the change in the function by calculating $\Delta y = f(x) - f(x_0)$. Next, the students formed the ratio $\frac{\Delta y}{\Delta x}$ to represent the average velocity over a very small interval. Then, they considered the limit of this ratio as $\Delta x \to 0$, thereby arriving at the concept of instantaneous velocity and the derivative.

The work shown in **Figure 10** indicates that students did not only perform calculations but also explained in words the meaning of each step, such as why it is necessary to take a difference, why it must be divided by the change in the variable, and why a limit has to be considered. This reflects the transition from thinking in terms of average velocity to thinking in terms of derivatives. Through step-by-step presentation and reasoning, students gradually formed an understanding of the derivative as the limit of a difference quotient, rather than merely as a ready-made formula.

From Figure 8, the role of Worksheet Number 2 in consolidating knowledge can be clearly seen: it helps students systematize computational procedures, connect them with the real meaning of velocity, and thus gain a deeper understanding of the nature of the derivative. Therefore, this figure does not only illustrate the final result, but also reflects the students' process of thinking and reasoning when approaching a new concept.

Based on the results presented by the experimental class (**Figure 3**, **Figure 4**, **Figure 5**, **Figure 6** and **Figure 10**), the majority of students answered correctly with the support of the RME-SBG model. Many students said they felt quite excited when using the model to learn how to explore new concepts. Besides, with the movement or change in size of geometric objects in the model such as points, lengths, areas, algebraic operations are performed easily and quickly. In particular, the fixed, immutable element of

Table 6. Questionnaire of worksheet number 3

Task 1: Each student takes 2 examples, calculates the derivative using the definition, then checks the results using the RME-SBG model		
Functions	Value t_0	Derivative of the function at x_0
Task 2: Using the RME model, show an example of a function that has no derivative at value (individual work or group discussion)		
Functions	The value t_0 at which the function has no derivative is:	Explain

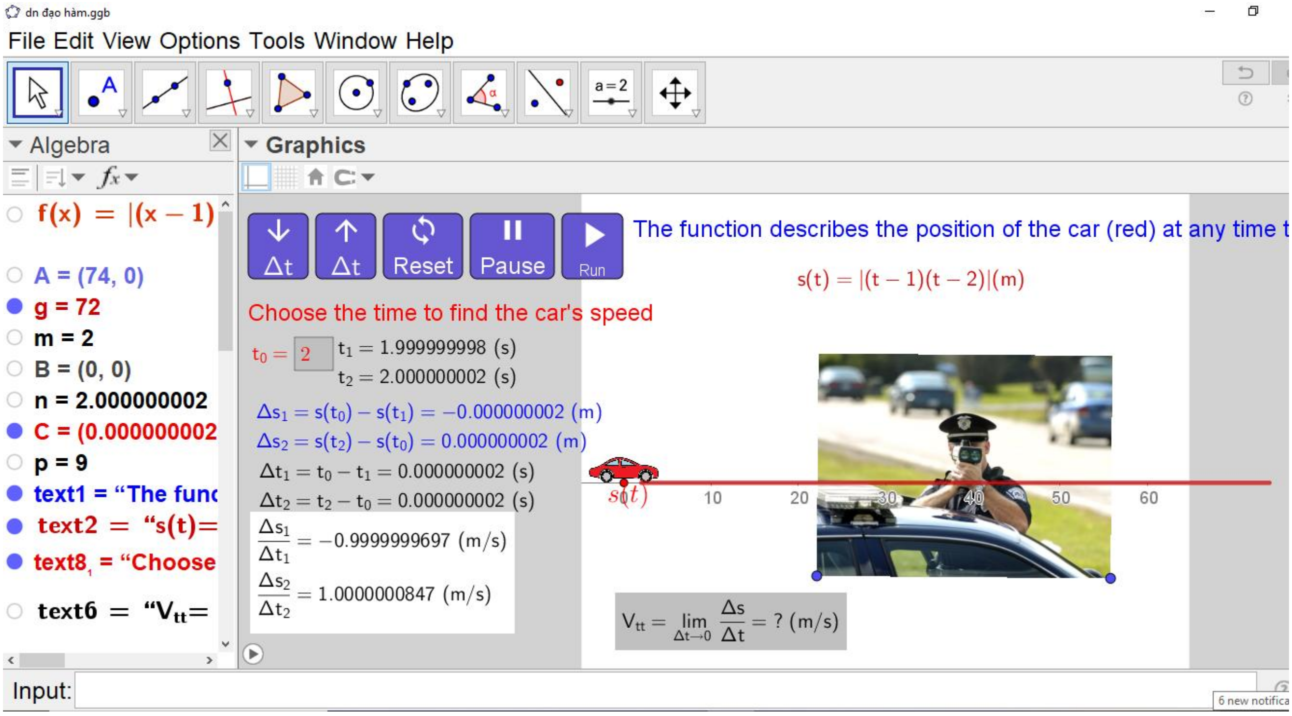


Figure 11. Use the RME-SBG model to illustrate an example of a function (see **Table 6**) with no derivative at $t_0 = 2$ (Source: Authors' own elaboration)

algebraic thinking is changed and replaced by the change and variation of extremely small quantities according to calculus thinking, leading to the calculation of the instantaneous speed of the object, which is essentially the problem of finding the limit of a function. From there, students can approach the concept of derivatives in a more intuitive and natural way. Obviously, this is a quite different approach of RME compared to traditional teaching.

In **Figure 11**, by observing the results on the RME-SBG model, students will see that:

$$\lim_{t\to 2^-} \frac{|(t-1)(t-2)|}{t-2} = -1 \tag{3}$$

while

$$\lim_{t\to 2^+} \frac{|(t-1)(t-2)|}{t-2} = 1 \tag{4}$$

This implies that

$$\lim_{t\to 2^-} \frac{|(t-1)(t-2)|}{t-2} \neq \lim_{t\to 2^+} \frac{|(t-1)(t-2)|}{t-2} \tag{5}$$

therefore $\lim_{t\to 2} \frac{s(t)-s(2)}{t-2}$ does not exist. In short, the function:

$$s(t) = |(t-1)(t-2)| \tag{6}$$

has no derivative at $t_0 = 2$. By doing the same, students can get more examples.

Above is an example illustrating the use of the RME-SBG model to support teachers and students in teaching and learning the concept of derivatives of functions. Starting from the idea of the problem of calculating the instantaneous velocity of a straight motion at a moment in time, the concept of the derivative of a function is formed more naturally.

RESEARCH RESULTS

Outcomes and Measures

Primary outcome: Measure the difference in learning gains between the experimental and control groups on the post-test in terms of derivative understanding.

Secondary outcomes: Explore student attitudes towards derivative learning, confidence in applying derivatives, and perceptions of RME-SBG model's effectiveness through interview data.

Ethical considerations:

Obtain informed consent from participants and ensure anonymity in data collection and analysis.

Provide equal access to learning resources and support to both groups.

Report research findings objectively and transparently.

Qualitative Analysis

Students' feedback

Student 1 I think the RME-GeoGebra approach made derivatives a lot more relatable and understandable. The real-world examples really helped me to see how derivatives are used in the real world, and the GeoGebra tools were really helpful for visualizing and understanding the concepts. I felt like I had a much better understanding of derivatives after using the RME-SBG approach. I was able to solve problems that I would have struggled with before, and I felt more confident in my ability to apply derivatives to new situations.

Student 2 I really enjoyed the RME-SBG approach. It was a lot more engaging than traditional methods, and I felt like I was learning more. I liked that the activities were based on real-world problems. It made the material more relevant and interesting, and it helped me to see how derivatives could be applied to my own life. The GeoGebra tools were also really helpful. They made it easy to visualize the concepts and to see how they worked.

Student 3 I think the RME-SBG approach was really effective for teaching derivatives. It helped me to develop a deeper understanding of the concepts, and it made me more confident in my ability to apply them. I liked that the approach focused on understanding the concepts rather than just memorizing formulas. The real-world examples and the GeoGebra tools helped me to see how the concepts worked in practice. Overall, I thought the RME-SBG approach was a great way to learn about derivatives. I would recommend it to anyone who is struggling to understand these concepts.

Student 4 I think the RME-SBG approach was a lot more effective than traditional methods. I was able to learn the concepts faster and more easily, and I felt like I had a much better understanding of them. I liked that the activities were engaging and interactive. They kept me interested and motivated to learn. The GeoGebra tools were also really helpful. They made it easy to visualize the concepts and to see how they worked.

Interview results

Thematic analysis of interviews:

(1) Identify key themes emerging from student interviews related to their learning experiences and perceptions of derivatives;

(2) Compare and contrast themes between the experimental and control groups to understand how RME and GeoGebra influenced student perspectives;

(3) Look for evidence of deeper understanding, real-world connections, and problem-solving confidence in the RME-SBG group.

The qualitative data from these interviews were analyzed using a systematic thematic analysis process. Initially, the transcripts were reviewed to generate codes related to students' experiences. These codes were then grouped into three primary themes:

(1) Enhanced Visual Intuition, where students used GeoGebra to transform abstract derivative rules into dynamic visual movements;

(2) Real-world Contextualization, involving the ability to link mathematical symbols to practical scenarios like car speed or production costs; and

(3) Increased Learner Agency, characterized by students' improved confidence in exploring new problems.

To ensure the reliability of this analysis, two researchers independently performed the coding process, and any differences in interpretation were resolved through consensus, achieving an inter-rater reliability rate of 85%.

Interview 1

Interviewer What did you think of the RME-GeoGebra approach to teaching derivatives?

Student 1 I thought it was really helpful. I liked that we started with real-world problems and then used GeoGebra to model them. It helped me to understand the concepts better and see how they applied to the real world.

Interviewer Can you give me an example of a real-world problem that you worked on?

Student 1 We looked at the problem of calculating the distance traveled by a car over a certain period of time. We used GeoGebra to create a graph of the car's speed over time. Then, we used the derivative of the graph to find the car's distance traveled.

Interviewer How did using GeoGebra help you to understand this problem?

Student 1 It helped me to visualize the problem and see how the derivative was related to the car's speed. I could see how the derivative was changing over time, and how that reflected the car's changing speed.

Interviewer Overall, would you recommend the RME-SBG approach to teaching derivatives to other students?

Student 1 Yes, I would. I think it's a very effective way to learn derivatives. It helps students to understand the concepts better and see how they apply to the real world.

Interview 2

Interviewer What did you think of the RME-SBG approach to teaching derivatives?

Student 2 I thought it was a lot more engaging than traditional methods. I liked that we were able to work on real-world problems and use GeoGebra to explore them.

Interviewer Can you give me an example of a real-world problem that you worked on?

Student 2 We looked at the problem of designing a roller coaster. We used GeoGebra to create a model of the roller coaster and then used the derivative of the model to find the roller coaster's maximum speed.

Interviewer How did using GeoGebra help you to understand this problem?

Student 2 It helped me to see how the derivative was related to the roller coaster's motion. I could see how the derivative was changing over time, and how that reflected the roller coaster's changing speed.

Interviewer Overall, would you recommend the RME-SBG approach to teaching derivatives to other students?

Student 2 Yes, I would. I think it's a great way to get students interested in mathematics and to help them to develop their problem-solving skills.

Interview 3

Interviewer What did you think of the RME-SBG approach to teaching derivatives?

Student 3 I thought it was very helpful for understanding the concepts. I liked that we started with real-world problems and then used GeoGebra to model them. It helped me to see how the concepts applied to the real world and to develop my problem-solving skills.

Interviewer Can you give me an example of a real-world problem that you worked on?

Student 3 We looked at the problem of calculating the cost of producing a product. We used GeoGebra to create a model of the production process and then used the derivative of the model to find the cost of production at different levels of output.

Interviewer How did using GeoGebra help you to understand this problem?

Student 3 It helped me to visualize the problem and see how the derivative was related to the cost of production. I could see how the derivative was changing over time, and how that reflected the changing cost of production.

Interviewer Overall, would you recommend the RME-SBG approach to teaching derivatives to other students?

Student 3 Yes, I would. I think it's a very effective way to learn derivatives and to develop problem-solving skills.

Table 7. Descriptive statistics of pre-test scores for experimental and control groups

								Shapiro-Wilk	
	Group	N	Mean	Median	SD	Minimum	Maximum	W	p
Pretest	Experiment	37	6.22	6.50	1.07	4.00	7.50	0.889	0.001
	Control	39	6.21	6.50	1.15	4.00	7.50	0.874	< .001

Note. N: Sample size, SD: Standard Deviation, W: Shapiro-Wilk test statistic, p: Probability Value

Table 8. Independent samples T-Test and Mann-Whitney U results for pre-test score comparison

		Statistics	df	p
B	Student's t	0.0435	74.0	0.965
	Mann-Whitney	717		0.966

Note. H_0: µTN ≠ µĐC

Table 9. Post-test performance summary for RME-SBG and traditional groups

								Shapiro-Wilk	
	Group	N	Mean	Median	SD	Minimum	Maximum	W	p
Posttest	Experiment	37	7.41	7.50	1.17	5.00	9.00	0.919	0.010
	Control	39	6.45	6.50	1.14	4.00	8.00	0.914	0.006

Note. p < 0.05 indicates a significant difference

Table 10. Independent samples T-Test

		Statistics	df	p
Posttest	Student's t	3.62	74.0	< .001
	Mann-Whitney	399		< .001

Note. p < 0.05 indicates a significant difference

Table 11. Shapiro-Wilk normality test results for post-test scores

	W	p
Posttest	0.924	< .001

Note. A low p-value suggests a violation of the assumption of normality

Quantitative Analysis

The analysis of the results obtained in the research was made as follows.

Pre-test scores

Jamovi 3.2.21 statistical software was used to analyze data. All the data obtained were entered into the program, and necessary measurements were made. To test the difference in post-experiment learning achievement of experimental group students (learning with RME) and control group students (learning with traditional teaching methods), t-Test for independent groups were used.

Based on the results described in **Table 7**, it can be seen that the average score of students in the experimental class is 6.22 and that of students in the control class is 6.21. On the other hand, the median of the experimental group and the control group are both 6.5. Using the normality test of the Shapiro–Wilk distribution, both have $p < 0.05$, so the distribution of scores of both experimental and control classes is not normally distributed. Using the Mann–Whitney U test, the result shows $p = 0.966 > 0.05$ (**Table 8**), so the hypothesis H_0 is accepted: The learning results of the two experimental and control classes are equivalent (the median of both classes is 6.5) with a level meaning $\alpha = 0.05$. In other words, before the experiment (with the influence of the researcher), the learning performance of both experimental and control classes was almost the same.

Post-test scores

From the results of descriptive statistical analysis of post-test performance after the experiment, we see that the mean test scores of the control class and the experimental class are 6.45 and 7.41, respectively, the median of the control class was 6.50 while the median of the experimental class was 7.50. Using the test for normality of the Shapiro-Wilk distribution, in both the experimental and control classes, shows that $p < 0.05$ (see **Table 9**), so the score distribution of this class is not a normal distribution. Using the Mann-Whitney U test, the result shows $p < 0.05$ (**Table 10**, **Table 11** and **Table 12**), so the hypothesis H0: The learning results of the experimental and control classes are the same, rejected at the significance level. In other words, the learning achievement of the experimental class was better than the control class after the experiment. To further clarify the impact of the RME-SBG model, the descriptive data shows a clear shift in score distribution. While the control group's mean score remained relatively stable (6.45), the experimental group achieved a significantly higher mean (7.41) with a narrower standard deviation. This indicates that the RME-SBG approach not only improved the overall performance but also helped low-achieving students bridge the gap in their understanding more effectively than the traditional method. These quantitative gains align closely with the positive feedback and deeper conceptual insights reported by the students during the qualitative interviews.

Table 12. Levene's Test for equality of variances for post-test results

	F	df	Df2	p
Posttest	0.183	1	74	0.670

Note. A low p-value suggests a violation of the assumption of normality

To evaluate the practical significance of the findings, the effect size for the Mann-Whitney U test was calculated. Based on the test statistic U = 399 and a total sample size of N = 76, the standardized Z-score was derived to compute the effect size correlation r\approx 0.41. According to Cohen's (1988) guidelines, this value represents a medium-to-large effect size. This indicates that the implementation of the RME-SBG model produced not only a statistically significant difference (p < .001) but also a substantial practical impact on students' performance regarding the concept of derivatives, distinguishing it clearly from conventional instructional methods.

Triangulation of Findings

The effectiveness of the RME-SBG model is evidenced by the convergence between quantitative and qualitative data. Quantitatively, post-test results indicate that the experimental group achieved a higher level of improvement (mean = 7.41), which was statistically significant compared to the control group (mean = 6.45), with p = 0.01. This statistically significant gain is directly explained by qualitative feedback, in which students emphasized that the RME-SBG approach enabled them to "develop a deeper understanding" and "visualize concepts" using GeoGebra. Triangulation analysis confirms that the observed increase in academic achievement is not merely procedural in nature but also stems from deeper conceptual understanding and higher levels of student engagement with real-world applications.

DISCUSSION AND LIMITATIONS OF THE RESEARCH

Discussion

Realistic Mathematics Education (RME) tackles the challenge of student understanding in calculus by incorporating real-world contexts and problem-solving experiences. Students grapple with authentic mathematical tasks that mirror real-life situations, allowing them to apply their knowledge meaningfully. This approach fosters a deeper grasp of core calculus concepts beyond rote memorization. Students actively engage in the learning process, working collaboratively and independently to explore and discover mathematical ideas. This fosters a sense of ownership and a more profound understanding of calculus.

High school calculus education can be significantly enriched by implementing Realistic Mathematics Education (RME). This approach fosters a dynamic classroom environment through collaborative problem-solving, real-world modeling, and mathematical discourse. Students work together to tackle complex problems, learning from each other's perspectives and strengthening their problem-solving skills. RME also emphasizes modeling, where real-world scenarios and applications demonstrate the relevance of calculus in everyday life. Connecting abstract concepts to real phenomena, like analyzing motion or predicting population growth, deepens student understanding. Finally, mathematical discourse encourages discussions about concepts and strategies, further solidifying students' grasp of calculus and honing their communication skills. By incorporating these elements, RME creates a more engaging and effective learning experience for high school calculus students.

The research findings reveal a clear advantage for students taught under the RME-SBG model. This conclusion is strengthened through data triangulation, in which the statistically significant differences in post-test scores are consistent with student interview responses regarding their improved ability to solve complex problems that they had previously found challenging. While quantitative data reflect higher levels of academic achievement, qualitative data elucidate the underlying reasons for this improvement: Students used GeoGebra to model real-world situations, such as calculating the distance traveled by car or describing the motion of a roller coaster. This modeling process—central to the RME approach—narrowed the gap between abstract derivative formulas and practical applications, thereby leading to the positive statistical outcomes observed.

The transformative power of the RME (Realistic Mathematics Education) approach in high school calculus education is undeniable. By emphasizing real-world contexts, educators can create a dynamic and engaging environment that not only deepens student understanding but also fosters appreciation for calculus' practical applications. RME bridges the gap between abstract concepts and their real-world relevance, offering students a tangible connection to the material. Presenting calculus problems within contexts like analyzing a basketball shot or modeling population growth allows students to see firsthand how calculus solves real problems. This not only makes the subject more relatable but also sparks curiosity and enthusiasm as students discover the power of calculus in addressing real-world challenges. Additionally, integrating real-world contexts fosters a deeper understanding of the underlying concepts and principles of calculus. The significant disparity in post-test results, where the experimental group (Mean = 7.41) substantially outperformed the control group (Mean = 6.45), is visually evident when comparing their score distributions. This growth, or 'learning gain', suggests that the RME-SBG model does not merely improve rote memorization but fosters a deeper conceptual shift. By moving from realistic contexts to formal mathematical symbols through GeoGebra, students in the experimental group demonstrated a more robust ability to apply derivatives to novel problems compared to the marginal improvements observed in the control group. However, to fully capitalize on these pedagogical advantages, certain practical constraints and limitations in implementation must be carefully examined.

Limitations of the Research

While Realistic Mathematics Education (RME) boasts numerous advantages, it’s crucial to acknowledge its limitations. Implementing RME effectively requires well-trained teachers and a shift from content delivery to open-ended inquiry, which can be challenging in traditional systems. However, the primary technical challenge of the model lies in the preparation phase; designing dynamic GeoGebra applets that align with the principle of guided reinvention in RME is time-consuming and requires a high level of digital competence on the part of teachers. Assessing student learning goes beyond rote memorization, making evaluation subjective and time-consuming. Students who are not yet familiar with using GeoGebra may encounter difficulties, as technical operations can at times distract their attention from the core mathematical concept of derivatives. Open-endedness might frustrate students who prefer clear steps, and RME might not cover traditional content as comprehensively, potentially raising concerns for standardized testing. Additionally, the term “realistic” can be subjective, and the transition from RME’s inquiry-based approach to a more formal style in higher education can be difficult for students. Furthermore, the scalability of the RME-SBG model faces practical hurdles related to technological infrastructure. In many high schools, especially in disadvantaged areas, the lack of stable internet and computer laboratory access can hinder the implementation of simulation-based learning. Additionally, the time required to design RME-compliant lessons is substantially higher than traditional methods. For the RME-SBG approach to be feasible on a larger scale, it requires a centralized repository of pre-designed GeoGebra applets and official curriculum guidelines that balance inquiry-based activities with the time constraints of the national education system. It is also important to distinguish the RME-SBG model from conventional technology integration, such as static PowerPoint presentations or online drill-and-practice’ exercises. Unlike these passive approaches, the RME-SBG model utilizes GeoGebra as a dynamic ‘guided reinvention’ tool. Instead of merely consuming digital content, students interact with simulations to construct their own mathematical understanding. This active engagement allows for a more profound conceptual development, as technology serves as a bridge between realistic contexts and formal calculus principles rather than just a medium for information delivery.

Although the RME-SBG approach shows positive effects, this study has several limitations. The first is inequality in access to technology: In many schools, especially in disadvantaged areas, limited internet connectivity and lack of devices make it difficult to implement GeoGebra-based learning effectively. The second limitation concerns teacher training. RME-SBG requires teachers to have strong technological pedagogical content knowledge, and the design of dynamic GeoGebra applets based on guided reinvention is time-consuming and demands high digital competence. Teachers who are not sufficiently trained may struggle to apply the model consistently. In addition, some students are not familiar with GeoGebra, and technical operations may distract them from focusing on the core mathematical concept of derivatives. Finally, this study mainly examines short-term learning outcomes and does not address long-term retention of derivative concepts, which should be considered in future research.

However, despite these limitations, RME’s focus on real-world applications, student-centered learning, and problem-solving skills remains valuable. Carefully consider these pros and cons within your specific educational context and student needs to determine if and how to integrate RME to enrich your math program.

CONCLUSIONS

This study explores the potential of a novel approach, RME-SBG (Realistic Mathematics Education with GeoGebra Software), to revolutionize how high school students learn Calculus. RME-SBG bridges the theory-practice gap by incorporating real-world contexts and GeoGebra’s dynamic visualizations. GeoGebra plays a crucial role in modern education, transforming how students grasp complex concepts. Its interactive tools and visually appealing representations not only facilitate a deeper understanding of mathematical principles but also provide a dynamic platform for exploration. Integrating GeoGebra with RME fosters an enriching learning environment. This seamless blend promotes critical thinking, collaboration, and problem-solving skills. Students gain exposure to a wide range of resources and tools, allowing them to explore different perspectives, engage in virtual discussions, and participate in interactive simulations that bring abstract concepts to life. This immersive experience fosters active engagement and empowers students to take ownership of their learning journey.

The study investigates the effectiveness of RME in enhancing student achievement in Calculus. The results demonstrate that the RME group significantly outperformed the traditional teaching group, highlighting the potential of RME-SBG to unlock a deeper conceptual understanding of Calculus. Here are some key benefits:

(1) Contextualization: RME frames concepts within real-world scenarios, making them relevant and relatable;

(2) Active Exploration: RME emphasizes student-centered learning through activities and problem-solving, fostering a deeper understanding;

(3) Multiple Representations: RME encourages representing concepts in various ways (graphs, diagrams, symbols), promoting a richer understanding.

Based on these findings, several recommendations are proposed for educational stakeholders to enhance the quality of mathematics instruction. For curriculum designers, it is essential to integrate a higher density of realistic context-based problems into textbooks to support the RME philosophy and make abstract concepts more accessible. For policymakers, the focus should be on investing in comprehensive professional development programs. These initiatives should move beyond basic software training to emphasize Technological Pedagogical Content Knowledge, empowering teachers to integrate technology meaningfully into their pedagogy. Such efforts are crucial for the successful implementation of the 2018 General Education Curriculum in Vietnam, which prioritizes the development of students’ competencies through practical and interdisciplinary learning.

However, to fully realize the benefits of this innovation, the study concludes that addressing technical challenges is a prerequisite. Educational institutions need to strengthen professional development for teachers, particularly in software proficiency, while also ensuring stable and coherent information and communication technology (ICT) infrastructure. By combining RME's pedagogical strengths with GeoGebra's visual and interactive capabilities, RME-SBG offers a powerful approach to transforming Calculus education and fostering a deeper love of mathematics in students.

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