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Cracking the Code of Differentiation in Additional Mathematics: Unraveling Student Struggles and Teacher Strategies in Problem-Solving Mastery in Malaysian Secondary Education

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Abstract

Problem-solving skills are fundamental to learning mathematics and are a key part of the mathematics curriculum. The Malaysian Education Blueprint (2013-2025) emphasizes developing students' problem-solving abilities, yet challenges persist, especially in differentiation-related problems at the secondary level. A mixed-method approach was used in this study to assess students' performance in problem-solving related to differentiation and explore teachers' perceptions of students' mathematical problem-solving abilities. The quantitative component involves administering a problem-solving test to 30 students, while the qualitative aspect includes interviews with three Maths teachers. The findings indicate that students' performance in problem-solving related to differentiation remains low, and the teachers attribute this to challenges in foundational understanding and engagement in differentiation, such as weak basics, a lack of question comprehension, low conceptual understanding, difficulties in interpreting visual information, and a general lack of interest among students. Teachers emphasized the need to enhance students' thinking skills for deeper conceptual understanding and recommended effective learning strategies to boost engagement. This study highlights the importance of improving both cognitive skills and motivation in mathematics education, providing valuable insights for ongoing efforts to enhance mathematical problem-solving proficiency among secondary school students in Malaysia.

Keywords: Additional Mathematics; cognitive skills; mathematical differentiation; problem-solving proficiency.

1 Introduction

Problem-solving is crucial in mathematical education as it helps students develop skills to solve real-world problems [40] by influencing knowledge and idea construction [9]. Hence, evaluating students' problem-solving skills can extend beyond academic performance to encompass comprehension and engagement in the various stages of the problem-solving process [19]. According to Charles et al. [3], the problem-solving is the amalgamation of prior knowledge, experience, information, and intuition to unravel a situation with an unknown solution . Therefore, it is a complex process involving visualization, imagination, abstraction, and information association [34]. Nevertheless, mastering problem-solving is fundamental in mathematics education because problems are inherent in life [38]. The recommendation is to incorporate problem-solving into all levels of the mathematics curriculum, emphasizing its real-world applications to help students develop a genuine appreciation for mathematics [53]. Problem-solving is a crucial part of the mathematics curriculum in Malaysia [22], where the Malaysian Education Blueprint $(2013-2025)$ emphasizes the importance of problem-solving for 21st-century education, aiming to develop students' skills to solve real-life problems.

However, Malaysia, like many other countries, faces the challenge of addressing students' lack of problem-solving skills, which has emerged as a significant issue. A recent study by Abidin et al. [52] revealed that secondary school students perceive problem-solving questions as difficult and time-consuming, with many of them requiring teacher guidance to solve such problems. This indicates limited independence and low confidence in applying problem-solving strategies. Similarly, Zaharin et al. [51] highlighted that despite efforts to implement Higher Order Thinking Skills (HOTS), Malaysian students still struggle with problem-solving due to their heavy reliance on rote memorization and lack of initiative to solve problems independently. Additionally, the issue of problem-solving persists among students and often stems from difficulties in comprehending and interpreting mathematics word problems [29], making it challenging for them to translate these problems into mathematical notation [21]. Many students also lack a solid grasp of the fundamental skills required for effective mathematics learning, even though possessing these skills could significantly enhance the quality of mathematics education [18]. One such mathematical concept that requires problem-solving skills is calculus, focusing on differentiation. Differentiation, also known as derivatives, measures how a function changes with respect to its input and has various everyday applications. However, many students struggle to master the concepts and methods required to solve differentiation problems [12], Common challenges include failing to underline keywords, create differentiation formulas, simplify problems, or monitor their steps for mistakes [54]. These difficulties are compounded by outdated learning approaches that emphasize memorization without comprehension [23, 26], negatively impacting students' thinking processes.

According to Zulu and Nalube [54], solving differentiation problems requires students not only to provide correct answers but also to deliver convincing explanations. This highlights the need for a deep understanding of the concept and the ability to apply it in real-world situations. However, many students lack these skills. Hamid and Ramli [11] found that students failed to master the fundamental concepts and procedures of differentiation, attributing this weakness to ineffective teaching methods, limited student effort, and a discontinuity between secondary and tertiary mathematics curricula. Similarly, Othman et al. [26] observed that students often follow procedural steps mechanically without comprehending the underlying reasoning, leading to poor mastery of differentiation. For instance, they frequently struggle to correlate tangents and function differentials [32] and to transform information between written language or visual representations into mathematical symbols [8]. Moreover, by memorizing problem-solving algorithms, they often struggle to respond to questions related to differentiation problem-solving

[25]. This reliance on memorization often leads to the misuse or misapplication of mathematical expressions [49], resulting in procedural skills that lack conceptual understanding. The weak mastery of mathematical literacy among students at the school level also could leads to difficulties in learning mathematics at higher levels. As a result, many pre-university students struggle with calculus due to the weak fundamental of differentiation and integration during secondary school [35]. Consequently, they are unable to fully grasp the concept of differentiation, which is essential for success in advanced calculus [33]. Differentiation, commonly taught in high school advanced mathematics, often reflects the same learning difficulties [8]. Addressing these issues is crucial, as differentiation serves as the foundation for more advanced calculus topics studied at the tertiary level.

Equally, the significance of teachers is especially apparent when focusing on the aspect related to students' mathematical problem-solving skills and teaching them how to solve problems and why solving them is crucial. How teachers perceive the content, implement instructional strategies, and apply those strategies in teaching intricate content like differentiation affect students' achievement [13]. It has been reported that teachers attribute children's problems in solving mathematics word problems to fundamental factors such as the absence of understanding of the concepts being tackled, failure to attempt various mathematical problems, and weak links between theory and practice [46]. This perspective agrees with the growing acknowledgment that the focus of the teaching strategies has to move from rote learning to more active forms of teaching and learning using a logical approach. [41].

This viewpoint is taken a step further with the perspective of teachers who see the reality in their classroom setting. Many students face challenges when they are translating a mathematical problem into symbols. This problem is more clearly expressed when learning differentiation requires synthesizing and applying previous knowledge to novel situations [7]. These problems often arise from the students' narrow understanding of performing differentiation because of the concept's lack of real-life applications [54]. Likewise, students still struggle with basic concepts, facts, and applying procedures, even though problem-solving is often considered crucial [36]. Many students are also inclined to understand the mathematics procedures without knowing and understanding the facts behind it [15].Through a thorough analysis of teachers' perspectives and students' performance and challenges, this study seeks to provide essential insights for improving students' ability to solve problems in secondary mathematics education in Malaysia.

Accordingly, to guide this study, the following research questions (RQ) were posed:

1. How do secondary school students in Malaysia perform in mathematical problem-solving, particularly in the context of differentiation?
2. What are the key challenges faced by students when solving differentiation problems?
3. How do teachers perceive their students' problem-solving abilities in differentiation, and what teaching strategies do they employ to improve these abilities?
4. What instructional changes teachers proposed to improve students' conceptual understanding and problem-solving skills in differentiation?

2 Methodology

2.1 Participants

This study focused on secondary schools located in the Southern District of Johor, Malaysia. A sample of 30 Form 5 students aged 17, who were currently enrolled in Additional Mathematics classes, was selected. These students were chosen from among the 30 secondary schools in the district, ensuring that the sample reflected a range of performance levels in mathematics. This class size aligns with typical Malaysian secondary school classroom sizes, providing a realistic representation of a learning environment. Furthermore, the students were actively studying Additional Mathematics, specifically the topic of differentiation, which directly relates to the study's focus on problem-solving skills in this area. Purposive sampling was employed to select students who had prior exposure to the topic of differentiation, as it was important to assess their problem-solving abilities in a context in which they were familiar. The purposive sampling approach was used throughout the study to ensure that participants (both students and teachers) had relevant experience with the topic of differentiation, thereby providing meaningful insights into the research questions

2.2 Research design

This study utilized a mixed-methods research design. By combining quantitative and qualitative data collection methods, the design comprehensively helps to understand students' problem-solving abilities in differentiation. The design also enables data triangulation to enhance the findings' validity and reliability. It was conducted in three phases:

Phase 1: A differentiation-related problem-solving test was given to the 30 selected students to investigate their ability to apply the concepts they had learned. The test consisted of three open-ended problems. The test was designed to assess students' conceptual understanding and procedural knowledge of differentiation.

Phase 2: The students' responses from Phase 1 problem-solving test were subjected to document analysis. This phase allowed for an in-depth examination of the specific errors and misconceptions demonstrated by the students. It unveiled patterns in student performance, such as common mistakes made by students in applying differentiation rules and difficulties in interpreting word problems.

Phase 3: To complement the data collected from Phase 1 and Phase 2, semi-structured interviews were conducted with three experienced mathematics teachers. These teachers were selected through purposive sampling and had at least ten years of experience teaching Additional Mathematics. The interviews focused on the teachers' perceptions of their students' problem-solving abilities, the challenges they observed, and the instructional strategies they used to address these difficulties.

2.3 Instruments

2.3.1 Problem solving test

The problem-solving test was designed to assess the differentiation-related problem-solving skills of secondary school students, specifically addressing this study's first two research questions. The test comprised three items, each targeting different differentiation aspects to evaluate procedural knowledge and conceptual understanding. It was developed based on the subtopics outlined in the differentiation curriculum stipulated by the Ministry of Education Malaysia (2018). The subtopics covered in this study included tangents to the curves and differentiation; differentiation of ax^n (n is an integer); differentiation of the sum of algebraic functions; tangents and normals to the curves; differentiation of products and quotients of algebraic functions; differentiation of composite functions; applications of differentiation to determine minimum and maximum values, connected rates of change, small increments, and approximations; second-order differentiation. These subtopics were selected because they represent key concepts within the differentiation curriculum and are critical for solving higher-order mathematical problems. Understanding these concepts is essential for developing students' problem-solving skills in mathematics. Each test item was carefully designed to challenge students at different cognitive levels, ensuring that the test could accurately assess their ability to engage with both routine and non-routine problems in differentiation. This approach ensured that the test could accurately assess students' ability to apply differentiation techniques in both practical and theoretical contexts. The items also reflect common challenges students encounter when solving differentiation-related problems. The test was reviewed by an experienced Additional Mathematics teacher to ensure alignment with the Malaysian Additional Mathematics curriculum and the appropriateness of difficulty for secondary school students. The test was designed to align with the Malaysian Additional Mathematics curriculum and targeted three key aspects:

- Application of differentiation in geometric contexts.
- Application of differentiation in real-world problems.
- Analysis of turning points and the nature of functions.

The items in this problem-solving test were designed based on the format and scoring scheme of the Sijil Pelajaran Malaysia (SPM), the national standard for assessing student performance in Additional Mathematics. To ensure the questions' appropriateness in terms of difficulty and alignment with the objectives of the study, the items were reviewed by a mathematics teacher with over 15 years of experience teaching Additional Mathematics. The teacher evaluated the items for content suitability, level of difficulty, and alignment with the Malaysian Additional Mathematics curriculum. Feedback from this review was used to refine the items, ensuring their adequacy in assessing students' problem-solving abilities. Although this review was not part of a formal validation process, it provided valuable insights to ensure the test items were consistent with the objectives of the curriculum. The total marks for the test were 27, distributed across three items, with varying levels of complexity to assess students' conceptual understanding and problem-solving skills.

Examples of Test Items:

Item 1: Required students to calculate the surface area of a composite shape using the second derivative rule and find the dimension that maximize the surface area. This item assessed students' ability to apply basic differentiation techniques in a geometric context as Figure 1.

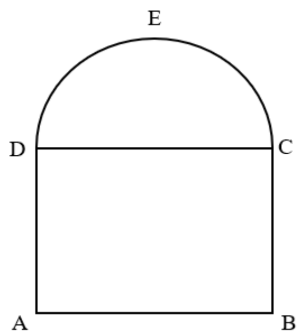

Figure 1: A composite shape.

In the left diagram, CDE is a semicircle. $AD = y$ cm and $AB = 4x$ cm, while the perimeter of the whole diagram is 4 meters (use $\pi = 3.142$);

a) Express the surface area of the whole diagram in terms of x and π.
b) Find the width of the rectangle when the surface area of the whole diagram is at its maximum.

Item 2: Involved a real-world application problem where students had to interpret a word problem and differentiate an algebraic function to determine the rate of change. This item tested students' ability to translate verbal information into mathematical equations.

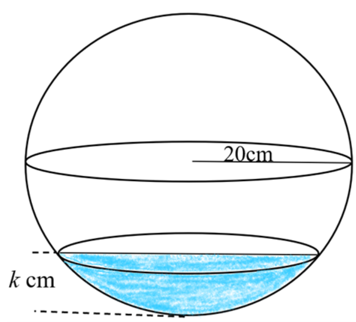

Figure 2: A sphere container.

The diagram in Figure 2 shows a sphere container with a radius of 20 cm that is filled with water to a height of k cm. Given that the height of the water increases at a rate of 0.4 cm/s.

a) Show that the horizontal surface area of the water inside the container is $A = \pi(40k - k^2)$.
b) Find the rate of change of A in terms of π when $k = 9$.

Item 3: Asked students to determine the turning points of a function and identify whether the points were maxima or minima using the second derivative test. This item aimed to measure students' deeper understanding of the relationships between functions and their derivatives.

The curve $y = x^3 - 9x^2 + 24x - 17$ that passes through $K(1, -1)$ has two turning points at $L(4, -1)$ and M. Find:

a) The gradient of the normal to the curve at point K.
b) The equation of the tangent to the curve at point K.
c) Coordinate M and determine whether M is the minimum or maximum point.

Scoring Method:

The problem-solving test was scored using the Sijil Pelajaran Malaysia (SPM) grading schema, which allocates marks based on two main criteria:

1. **K1 (Method):**
   Marks were awarded for correctly applying the steps or methods required to solve each part of the problem.
2. **N1 (Value):**
   Marks were given for obtaining accurate intermediate and final answers.

The test items were allocated marks as follows:

- Item 1: 10 marks.
- Item 2: 7 marks.
- Item 3: 10 marks.

For instance, Item 3 required students to differentiate the given function to find the gradient at a specific point, use the results to determine the equations of the tangent to the curve and solve for turning points and classify them as maximum or minimum using the second derivative.

Each part of the solution was assigned marks, with a total of 10 marks for the entire item. The distribution ensured that both the problem-solving process and the accuracy of results were assessed. Students who applied the correct method but made minor calculation errors could still earn partial marks under the "K1" category. Conversely, correct answers without proper working steps would not receive full credit, emphasizing the importance of demonstrating procedural understanding alongside the correct result.

The student's overall performance was categorized into three levels based on their total score as Table 1:

Table 1: Scoring criteria used to categorize students' problem-solving performance in differentiation.

Level	Score
High	$19-27$
Medium	$10-18$
Low	$0-9$

This grading system allowed the researchers to classify students' problem-solving abilities into high, medium, or low categories, providing a clear overview of their proficiency in applying differentiation concepts.

2.3.2 Mathematics teacher interview

In addition to the problem-solving test, semi-structured interviews were conducted with three experienced mathematics teachers who had been teaching Additional Mathematics for over 15 years. The purposive sampling technique was used to select these teachers, ensuring that they possessed the requisite expertise to provide deep insights into students' mathematical problem-solving abilities in differentiation. This approach is commonly employed in qualitative research to gather rich, targeted data from individuals with significant experience or knowledge in the subject area [27]. Moreover, these teachers were selected because they were directly involved in teaching the differentiation topic within the Malaysian curriculum. Their extensive teaching experience and familiarity with students' learning challenges provided valuable insights into the observed difficulties and effective teaching strategies for improving students' mathematical problem-solving abilities in differentiation.

The semi-structured interview format allowed for flexibility, enabling the researcher to explore the teachers' views on a wide range of topics. The interview questions are as below:

- What is the students' overall performance in differentiation?
- What are the common instructional challenges faced by teachers?
- What are the difficulties students faced in understanding differentiation concepts?
- What are the strategies that teachers use to address these challenges?
- What suggestions for improving students' conceptual understanding and problem-solving skills?

The interview questions were designed to elicit detailed responses and focused on exploring teachers' perceptions of students' weaknesses in foundational mathematics knowledge, conceptual misunderstandings, and the application of differentiation in non-routine problem-solving contexts. The first interview question aims to obtain teachers' views on the general level of student achievement in the topic of differentiation, addressing Research Question 1 (RQ1), which assesses students' performance in solving mathematical problems related to differentiation. The second interview question is designed to identify the challenges faced by teachers when teaching differentiation. Responses to this question contribute to answering Research Question 3 (RQ3), which examines teachers' perceptions of students' abilities and the challenges encountered in the context of problem-solving. The third interview question focuses on students' weaknesses in understanding fundamental concepts, such as the relationship between functions and their derivatives. This question helps to address Research Question 2 (RQ2), which seeks to identify the main challenges faced by students. The fourth interview question is intended to explore the teaching strategies employed by teachers to assist students in overcoming their difficulties. Answers to this question directly contribute to Research Question 3 (RQ3) by providing insights into effective teaching strategies. The final interview question aims to elicit practical suggestions from teachers for improving the teaching and learning of differentiation. Responses to this question support Research Question 4 (RQ4), which examines proposed instructional changes to enhance students' problem-solving skills.

All the interview questions were framed based on Cohen et al. [5], who suggest that semi-structured interviews are an appropriate method for collecting in-depth data on teachers' perceptions and experiences. These questions were carefully designed to ensure that the data collected aligns closely with the study objectives, providing a comprehensive understanding of the challenges and opportunities in teaching differentiation.

2.4 Research procedure

The data collection process started by administering the problem-solving test and then interviewing semi-structured interviews with the Mathematics teachers. The problem-solving test was given to the selected students in a classroom with an advised response time of 60 minutes. All students answered the three test items at the same administration round in order to obtain a minimalization of variation between answers due to different sessions. Once the test was finished and analyzed in the process interviews with the teachers were also conducted. Individual semi-structured interviews were undertaken; each interview lasted 20–30 minutes. The interviews were audio recorded (with permission) to assist accurate transcription and analysis. The insights presented through this process helped epp a better understanding of the teachers' teaching and learning strategies regarding mathematical problem-solving including their challenges with teaching differentiation.

The approval from the Ministry of Education to perform this research was obtained by having an official letter through the Educational Research Application System (eRAS 2.0). Before conducting this research, informed consent form was given to all participating teachers and the parents or legal guardians of the student participant. They were provided with detailed information about the study's purpose, procedures, and rights, including confidentiality assurance and the option to withdraw at any time without penalty. All data collected were treated with strict confidentiality, and personal identities were protected throughout the analysis and reporting processes.

2.5 Data collection and data analysis

Data collection for this study involved two key methods:

1. Problem-Solving Test: The test data were quantitatively analyzed using the SPM scoring schema. The results were categorized into high, medium, and low performance levels to assess students' overall problem-solving abilities.
2. Semi-Structured Interviews: Qualitative data were collected through interviews with the teachers. The thematic analysis method was employed to identify key themes and patterns in the teachers' responses. These themes included:
    i) Challenges faced by students in solving differentiation problems.
    ii) Teacher's perceptions of students' conceptual understanding.
    iii) Current instructional practices and their effectiveness.
    iv) Suggestions for instructional improvements.

The combination of quantitative and qualitative data provided a holistic view of students' problem-solving abilities and the instructional challenges faced by teachers. By triangulating data from both sources, the study ensured the validity and reliability of its findings.

3 Results

The analysis of the students' problem-solving in differentiation showed a notable trend in their understanding and application of the concepts. The results are presented in four parts: mathematical performance, challenges towards students, teachers' perceptions, and teachers' instructional suggestions.

3.1 Mathematical performance

The data from the problem-solving test revealed that the overall performance of the students was low, as shown in Figure 3. Of 30 students, 22 (73%) were categorized as low-performing, while 8 (27%) demonstrated medium performance. No students fell into the high-performing category. Furthermore, descriptive statistics were calculated to further understand students' overall performance. The mean score was 7.07, indicating a generally low level of achievement in solving differentiation problems. The median score was 6.00, suggesting that half of the students scored below this value. The standard deviation of 4.68 indicates moderate variability in the test scores.

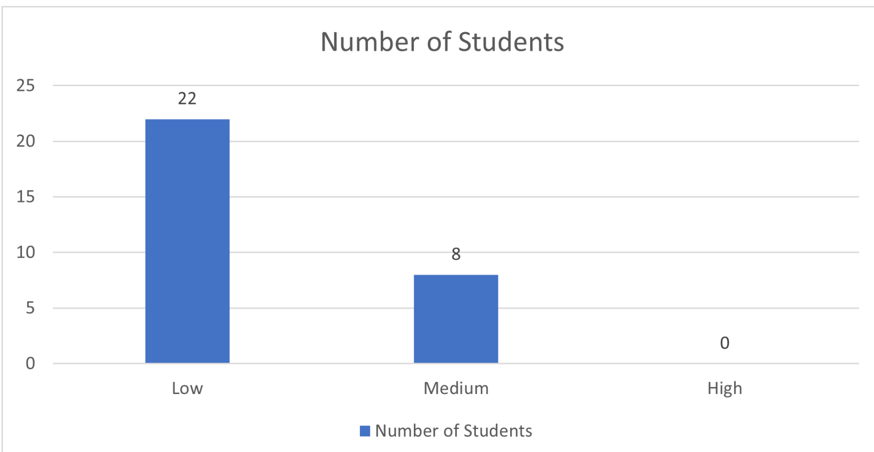

Figure 3: Problem-solving performance.

Samples of the performance data from the three problem-solving items provided further insights:

Item 1: Figure 4 shows Student A's response. Student A has provided all correct answers and demonstrates a clear understanding of utilizing the concept of differentiation to calculate the area, substitute values, and employ the second derivatives rule to determine whether the value represents a maximum or minimum.

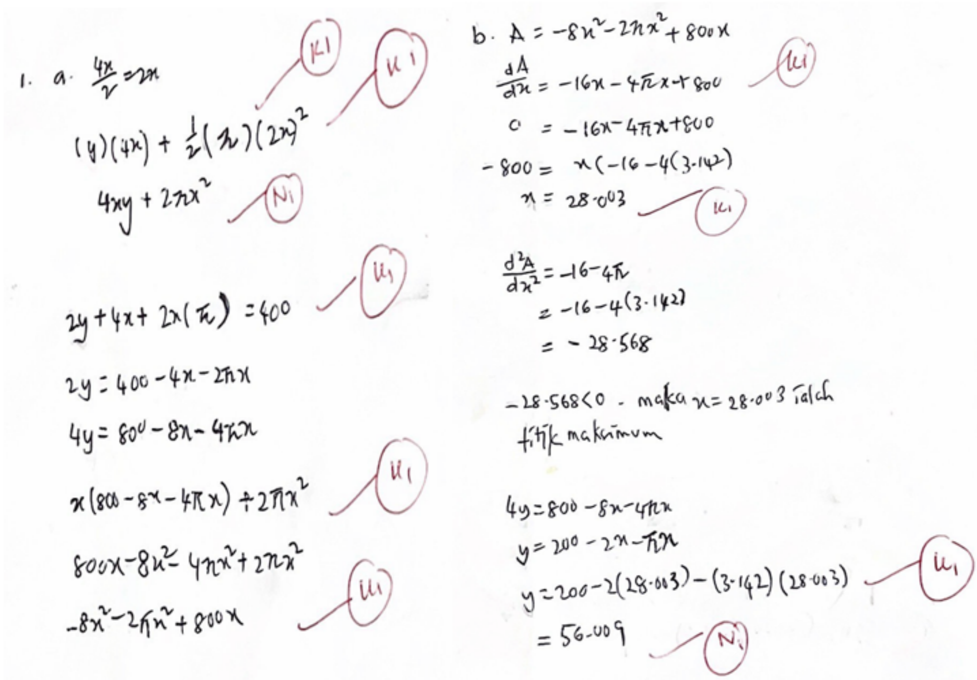

Figure 4: Student A's response to Item 1, annotated by scoring criteria (K1 = marks for correct method, N1 = marks for correct value).

Student B, illustrated in Figure 5, demonstrated difficulty following through with multiple steps despite getting the initial part right. The student shows proficiency in identifying the area but struggles with the subsequent steps outlined in the questions. The students struggled with applying the second derivatives rule correctly. The challenges students face in solving problem-type questions stem from their inability to employ appropriate problem-solving strategies [41] and a lack of comprehension of the provided information [30]. As a result, they encounter difficulties in providing accurate answers to the posed questions.

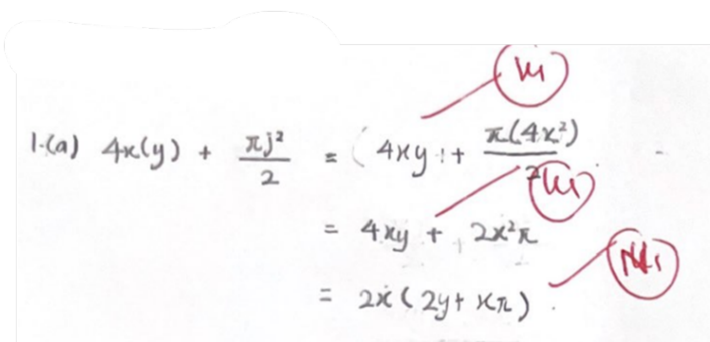

Figure 5: Student B's response to Item 1.

Item 2: Translating the word problem into mathematical form proved to be a significant challenge. Most students, including Student C, misinterpreted the problem, resulting in incorrect application of formulas, as shown in Figure 6. Despite attempting to use the given formula and substituting the provided values, Student C's calculated answer was incorrect, reflecting a lack of understanding of the problem. The difficulty in translating real-life problems into mathematical expressions was evident across most responses, as highlighted by Fatmanissa et al. [8], who emphasized the difficulty in grasping the topic and extracting meaningful mathematical representations from the textual content of the problem.

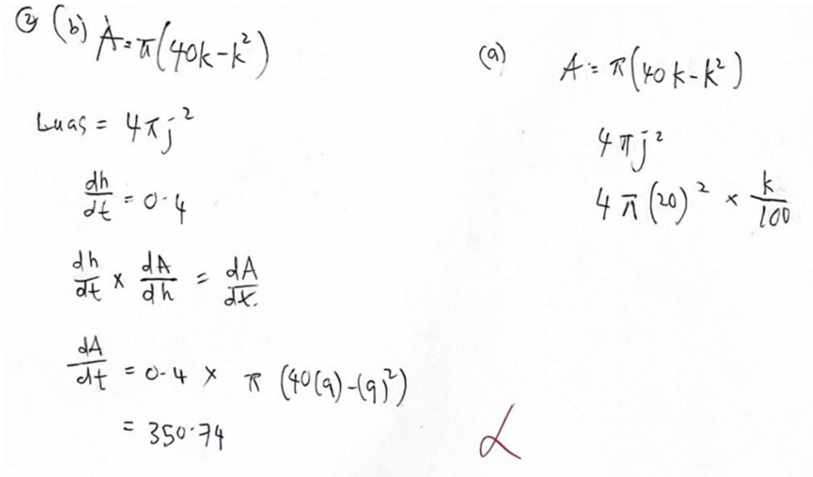

Figure 6: Student C's response for Item 2.

Item 3: In Figure 7, Student D's response to Item 3 is displayed, where the student answered all components correctly. Student D exhibited a comprehensive understanding of differentiation, showing proficiency in determining the slope of the tangent and the normal, identifying turning points, and applying the second derivative rule to determine minimum or maximum points.

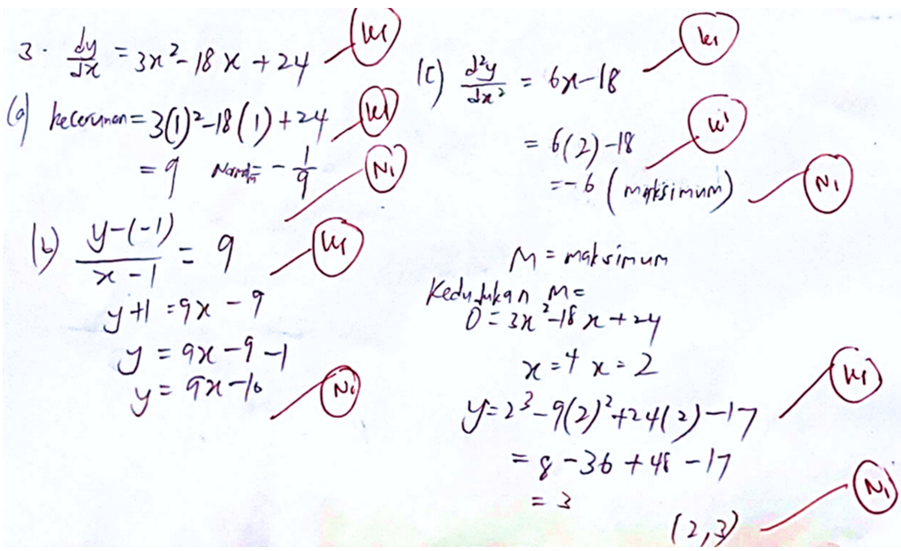

Figure 7: Student D's response for Item 3.

In Figure 8, Student E's response to Item 3 indicates an incorrect answer. The inaccuracies stem from apparent confusion with the topic of integration, resulting in entirely incorrect solutions. Therefore, Student E lacks understanding in identifying minimum or maximum points, aligning with the challenges highlighted by Fatimah and Yerizon [7], who emphasized students' difficulties in determining such points in derivative-related problems.

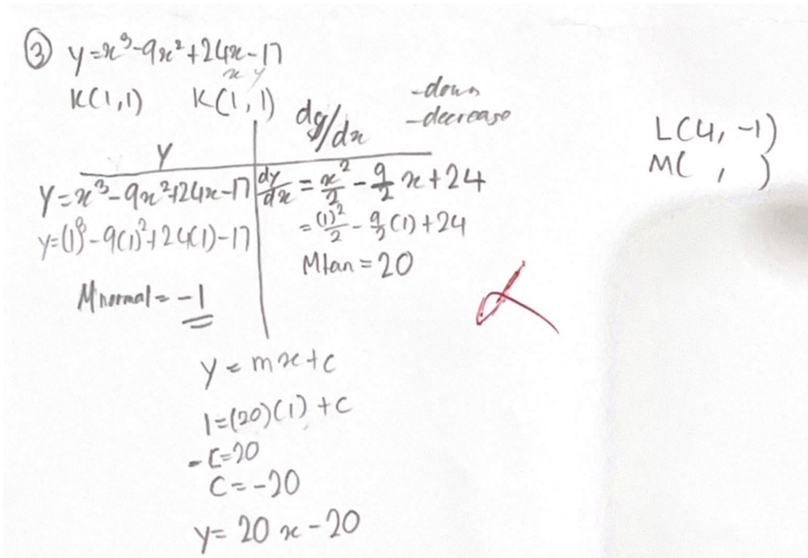

Figure 8: Student E's response for Item 3.

Overall, the problem-solving test results based on Figure 3 revealed that the majority of the students struggled with understanding and applying the concept of differentiation effectively. Based on the analysis of individual responses to the problem-solving items, 90% of students had difficulties with the multi-step problem-solving, particularly in translating word problems into mathematical expressions and incorrectly applying differentiation rules such as the second derivative test. It is common when students misinterpret the problem and incorrectly apply formulas, but the need for targeted interventions is crucial, focussing on strengthening students' conceptual comprehension and problem-solving strategies in differentiation.

3.2 Challenges – students

The key challenges identified from the test data results are as follows:

i) **Weak foundational knowledge**:
73% of students lacked a solid grasp of basic mathematical concepts that underpin differentiation, such as understanding derivatives as rates of change or their relationship with slopes.

ii) **Difficulty translating word problems into mathematical equations**:
80% of students failed to extract the correct mathematical information from word problems and struggled with applying the correct differentiation techniques to solve them.

iii) **Low conceptual understanding of differentiation**:
Students often applied memorized procedures without understanding the underlying concepts, leading to incorrect solutions in more complex problems, such as determining maxima and minima.

iv) **Limited problem-solving strategies**:
80% of students relied on memorized steps and failed to adapt when faced with unfamiliar problems. They struggled with multi-step problems that required strategic thinking and persistence.

3.3 Teachers' perception

The interviews with teachers revealed several consistent themes regarding their perceptions of students' problem-solving abilities in differentiation. All three teachers noted that many students exhibit a superficial understanding of differentiation, often relying on memorization of formulas without grasping the underlying concepts. This lack of deep understanding became particularly evident when students faced non-routine problems requiring them to apply their knowledge in unfamiliar contexts.

Teachers also identified a disconnect between students' procedural knowledge and their ability to solve real-world problems. One teacher mentioned, "*Many students can perform basic differentiation when asked to follow steps, but they struggle to understand why they're doing it or how it applies to real-life scenarios.*" This observation aligns with the performance data, where 73% of students scored in the Low category $(0 - 9)$, indicating that their problem-solving abilities are limited to procedural knowledge without deeper conceptual understanding.

In terms of teaching strategies, teachers reported that they primarily use direct instruction and work examples as the primary methods for teaching differentiation. While they recognized the limitations of these approaches, they felt constrained by the curriculum and time pressures, which made it difficult to experiment with more student-centred or inquiry-based methods. For example, one teacher noted, "*I'd like to incorporate more real-world problems, but there's not enough time in the syllabus to go beyond the basics.*" This was evident in Item 2, where students struggled with translating a contextual problem into a solvable mathematical model, scoring an average of 1.8 out of 7 marks.

Despite these challenges, the teachers expressed interest in adopting new strategies to help students improve their problem-solving abilities. One teacher suggested that technology could enhance students' understanding of differentiation, saying, "*If students could see the functions and derivatives visually, it might help them understand what's happening beyond just memorizing rules*". However, the use of technology in teaching differentiation was limited, mainly due to a lack of resources or training. The lack of visual aids in current teaching practices could explain students' difficulty in visualizing abstract concepts, particularly in problems requiring graphical interpretations in Item 3, such as tangents and normal.

The interviews also highlighted teachers' concerns about student motivation and engagement. They noted that many students view differentiation as difficult and irrelevant to their daily lives, which reduces their willingness to engage deeply with the material. Teachers suggested that connecting differentiation to real-world applications could help improve motivation, but this approach was not commonly used due to the focus on preparing students for exams.

Overall, while teachers are aware of the limitations of their current instructional methods, they feel constrained by external factors such as time and curriculum requirements. They recognize the need for more dynamic, engaging teaching strategies to address students' conceptual gaps and improve their problem-solving abilities in differentiation.

3.4 Teachers' instructional suggestion

Several instructional challenges that affect students' conceptual understanding and problem-solving abilities in differentiation were identified. Teachers indicated that while primarily using direct instruction and worked examples, these methods often fall short of helping students grasp the deeper conceptual meanings of differentiation. They acknowledged that students rely on memorized procedures without fully understanding how to apply them in real-world contexts or non-routine problems.

They also highlighted the following points regarding potential improvements:

i) Need for real-world applications: Teachers expressed that students might benefit from seeing how differentiation applies to real-life problems, such as calculating rates of change in physics or economics. However, this approach was not widely implemented due to curriculum constraints and time limitations. *Students often ask me when we are ever going to use this topic in real life as they don't see the practical value of differentiation. So, I think it is good if we can show them how it is used to calculate the rates of change in real-world contexts, like modelling population growth or decay rates and the spread of disease in biology which use this topic. They will engage more as they see when to use it. Unfortunately, with the pressure to cover the syllabus quickly, we don't get to explore these kinds of applications as much as I want.*

ii) Limited use of technology: While one teacher suggested that visual tools, such as graphing software, could help students better understand the behaviour of functions and their derivatives, the use of technology in differentiation lessons was minimal. Teachers cited a lack of resources and training as barriers to integrating technology into their instruction. *Incorporating technology like a graphing calculator or software that shows the dynamic movement of functions would really help the students grasp how the differentiation works, as they could see how the slope of a tangent line changes at different points on a curve. However, our school doesn't provide enough resources for that, and to be honest, most of us haven't been trained to use these tools effectively in the classroom.*

iii) Engagement and Motivation: Teachers noted that students often view differentiation as abstract and irrelevant, diminishing their motivation to engage with the material. They proposed incorporating more interactive and engaging activities could improve student interest, but these suggestions were not fully integrated into their teaching practices. *The differentiation topic is the first time they learn in Form 5 for Add Maths, so the students struggle to see its relevance as it is seen as too abstract by them. I've thought about using more interactive activities, but it's hard to find the time to incorporate them as we as teachers also struggled to finish the syllabus within the given time.*

In summary, teachers recognized the need for instructional changes to better support students' understanding of differentiation but were limited in their ability to implement more dynamic approaches due to time, resource, and curricular constraints. The discussion section will propose potential research-based instructional strategies to address these limitations and improve student outcomes in differentiation.

4 Discussion

The low performance of students in solving differentiation problems reflects broader trends observed in calculus-related topics, where students tend to struggle with understanding abstract concepts and applying them to real-world situations. These findings have significant implications for students' readiness for tertiary education. Differentiation serves as a foundation for advanced calculus topics, including integration, multivariable calculus, and differential equations, which are integral to courses in engineering, physical sciences, and economics. Weaknesses in this area can hinder students' ability to succeed in these fields, underscoring the need for stronger preparatory strategies in secondary education. The fact that none of the students demonstrated high-level performance suggests that traditional teaching methods may not adequately prepare students for problem-solving in this area. This aligns with previous research highlighting the challenge of transitioning from procedural to conceptual understanding in differentiation [46].

The specific errors observed in student responses indicate that many approach differentiation problems as isolated mathematical tasks rather than as part of a broader conceptual framework. For example, some students misapplied integration techniques in differentiation questions (e.g., Student E), reflecting confusion that arises when procedural knowledge is emphasized without sufficient conceptual understanding. Mendezabal and Tindowen [20] similarly found that students often relied on memorized procedures without comprehending the underlying ideas, resulting in weak conceptual and procedural mastery in calculus. Likewise, Qetrani and Achtaich [31] reported that students performed well on procedural tasks but struggled with conceptual ones. Their findings showed that exam scores were more strongly correlated with procedural knowledge, indicating that current assessment systems tend to prioritize form and technique over deeper understanding. These findings underscore the need to help students build stronger connections between mathematical concepts and apply them meaningfully in problem-solving contexts.

Next, the challenges identified in the data provide critical insights into why students struggle with differentiation. Firstly, students are weak in foundational knowledge. As the teachers pointed out, many students lack a strong foundation in algebra and functions, which are essential for understanding differentiation. Without this base, students are unable to grasp the higher-level concepts required for solving differentiation problems. Research indicates that lack of foundational knowledge can significantly hinder students' ability to grasp advanced mathematical concepts. For instance, foundational knowledge is recognized as a key factor in educational outcomes, where students with a solid grounding in basic concepts are more likely to succeed in mathematics subject [45]. This is relevant in mathematics where the progression from basic algebra to calculus requires a deep understanding of functions and their properties. Additionally, students have difficulties with word problems. The difficulty students face in translating word problems into mathematical equations is a common challenge in mathematics education. This issue, which has been documented in other studies [8], suggests that students need more practice with problems that require them to move between verbal and mathematical representations of a problem. Next is the limited conceptual and procedural knowledge. The reliance on memorized procedures, without understanding their conceptual underpinnings, is a recurring theme in the data. This suggests that students need more opportunities to explore the reasoning behind the procedures they use, as well as how these procedures can be applied in novel contexts [37]. Lastly, the students' problem-solving strategies are a concern. The lack of strategic thinking in problem-solving is concerning, as differentiation problems often require students to plan multi-step solutions. Teachers should consider incorporating more problem-solving exercises that require students to think critically and persist through challenges as suggested by Yusuf et al. [50], who highlighted the need for comprehensive problem-solving strategies that encompass various problem types.

The teachers' perceptions of students' problem-solving abilities in differentiation reflect a common challenge in mathematics education: the tendency for students to rely heavily on procedural knowledge rather than developing a deep conceptual understanding [2]. Teachers consistently noted that students could follow steps in simple problems but struggled when faced with more complex, non-routine problems. This reliance on memorization is problematic because it limits students' ability to transfer their knowledge to new contexts or apply it in real-world situations, a finding that is consistent with research on transfer of learning [44]. This limitation is particularly concerning for students transitioning to tertiary education, where the emphasis shifts from procedural fluency to analytical reasoning and problem-solving. University-level mathematics often requires students to connect differentiation concepts to broader mathematical frameworks, making conceptual understanding critical for success.

One of the central issues identified by teachers is that students often fail to see the purpose behind differentiation, reducing their engagement and motivation to engage with the material fully. This aligns with the broader literature on student engagement, which shows that students are more likely to disengage when they do not perceive a subject as relevant or applicable [4]. Teachers' reliance on traditional methods such as direct instruction and worked examples, while helpful in teaching basic procedures, may not be sufficient to foster the deep understanding necessary for solving complex problems [48].

Moreover, the teachers interviewed expressed a desire to adopt more dynamic and student-centred teaching methods but felt constrained by the curriculum, time limitations, and a lack of resources. This is a common challenge in mathematics education, where teachers often feel pressured to cover a large amount of content in a limited amount of time, leaving little room for more inquiry-based or project-based learning strategies. Teachers also indicated that they would like to integrate more real-world applications into their lessons, which research shows can increase student engagement and improve conceptual understanding [10]. However, these innovative methods are difficult to implement without the necessary support or training [1].

The use of technology was another area where teachers felt improvements could be made. They acknowledged that tools like graphing calculators or software such as GeoGebra could help students better visualize the abstract concepts involved in differentiation. Research supports this idea, suggesting that visual representations and dynamic tools can enhance students' understanding of complex mathematical concepts by allowing them to interactively explore and manipulate these ideas [39]. However, due to resource constraints and a lack of teacher training, the limited use of technology in the classroom means that students are not receiving the full benefits of these tools.

In conclusion, while teachers are aware of the challenges their students face and clearly understand the areas where improvements are needed, their ability to implement effective teaching strategies is hindered by structural and resource-related barriers. To bridge the gap between procedural fluency and conceptual understanding, it is essential to provide teachers with the resources and training necessary to incorporate more engaging, student-centred approaches, such as inquiry-based learning, real-world applications, and technology-enhanced instruction. For instance, teachers can use GeoGebra to visualize graphs of functions and their derivatives during a 5-10 minute teaching session, rather than as an additional activity. This approach allows technology to serve as a simple and effective learning tool without adding to the teacher's workload. Similarly, Desmos can be utilized to demonstrate gradient changes in real time, providing students with a deeper understanding without requiring extensive preparation. These approaches enable technology to function as a simple yet effective learning tool, alleviating additional workload on teachers while enhancing students' understanding.

The data collected through interviews with mathematics teachers provided valuable insights into the challenges students face when solving differentiation problems. Teachers consistently identified issues related to students' weak foundational knowledge, lack of conceptual understanding, and limited engagement with the subject. Although the teachers did not specify concrete instructional strategies during the interviews, their concerns suggest that addressing these gaps will require changes to current teaching practices. Based on these insights and supported by existing research, several instructional strategies are proposed to improve students' conceptual understanding and problem-solving skills in differentiation.

The first one is the scaffolding to build conceptual understanding. One instructional change that could address the challenges highlighted by teachers is the use of scaffolding. Scaffolding involves providing structured support to students during the early stages of learning and gradually reducing this support as students gain mastery of the concept [47]. This approach allows students to develop a deeper understanding of differentiation by guiding them through increasingly complex problems while providing the necessary assistance at each stage. Research has shown that scaffolding can significantly improve students' problem-solving skills by helping them break down complex problems into manageable steps. Doo et al. [6] found that metacognitive scaffolding in online learning environments had a strong positive impact on students' learning outcomes, particularly when learners were supported in monitoring and regulating their thinking. Similarly, Martin et al. [17] emphasized that combining structured materials with responsive teacher support leads to better student performance, especially when scaffolds are gradually faded as learners gain understanding. In the context of differentiation, scaffolding could begin with basic derivative problems where students are shown how to interpret functions and their derivatives. Teachers could then gradually reduce the scaffolds as students demonstrate proficiency, eventually enabling them to tackle more advanced problems independently. This step-by-step approach can enhance students' confidence and problem-solving abilities in differentiation, making it easier for them to apply these skills in unfamiliar contexts.

Another strategy to improve students' understanding and motivation is incorporating real-world applications of differentiation to enhance engagement. Teachers noted that students often struggle to connect abstract mathematical concepts to practical situations, which decreases their interest in the subject. Research suggests that presenting mathematics in real-world contexts can increase student engagement and help them see the relevance of the subject to everyday life [2]. By integrating applications of differentiation into fields such as physics, economics, and biology, teachers can help students better understand the importance of the topic [14]. For example, teachers could introduce problems that involve calculating rates of change in real-world scenarios, such as the acceleration of an object in physics or the rate at which a population grows in biology. These applications not only make the subject more engaging but also allow students to see how differentiation is used to solve real problems outside the classroom [42]. In addition to real-world contexts, proficiency in differentiation is a prerequisite for many tertiary education programs. Students entering fields such as mathematics, computer science, or environmental studies often face calculus-intensive coursework, where differentiation serves as a building block for more complex analytical models and theories.

Besides, teachers frequently mentioned that students struggled with the abstract nature of differentiation, particularly when interpreting graphical representations of functions and derivatives. One effective way to address this issue is by integrating technology into the teaching of differentiation. Tools such as graphing calculators and mathematical software (e.g., GeoGebra, Desmos) can help students visualize the behavior of functions and their derivatives, providing a more concrete understanding of abstract mathematical concepts [24]. Research has demonstrated that technology-enhanced learning environments can improve students' conceptual understanding by allowing them to manipulate mathematical objects dynamically and observe the immediate impact of changes [28]. In the context of differentiation, students could use graphing software to explore how the slope of a function changes at different points, giving them a visual and interactive experience that reinforces their understanding of derivatives.

Lastly, implementing differentiated instruction can help address the diverse learning needs of students in the classroom. Teachers noted that students vary in their levels of understanding and ability, which makes it difficult to use a one-size-fits-all approach to teaching differentiation. Differentiated instruction involves tailoring lessons to meet the needs of individual students or groups, providing more focused attention to those who struggle while challenging those who are ready for more advanced material [43]. In practice, differentiated instruction could involve offering simpler problems or additional support to students who have difficulty grasping the basics of differentiation, while simultaneously providing more complex, real-world problems to students who excel [16].

In summary, while the teacher interviews revealed several challenges that students face in understanding differentiation, the proposed instructional changes are drawn from existing literature on effective teaching practices. By incorporating strategies such as scaffolding, real-world applications, technology integration, and differentiated instruction, teachers can enhance students' conceptual understanding and problem-solving skills in differentiation. Strengthening students' differentiation skills at the secondary level is critical for their success in tertiary education. Advanced mathematical topics in university courses rely heavily on the ability to understand and apply differentiation concepts. Addressing these foundational challenges early can ensure students are better prepared for the academic rigor of higher education and its associated career pathways. These strategies, informed by both teacher insights and research, provide a roadmap for improving student outcomes in mathematics.

5 Conclusion

The findings of this study highlight the significant challenges students face in mastering differentiation-related problem-solving skills. A predominant majority of students fell into the low-performance category, highlighting a critical gap between expected and actual proficiency levels. Students exhibited particular difficulties in translating word problems into mathematical equations and selecting the appropriate problem-solving strategies for non-routine problems. These challenges are compounded by their limited exposure to diverse problem types and a superficial understanding of differentiation concepts. Teacher insights further illuminated the underlying issues contributing to students' struggles. Teachers noted that students often lacked a deep conceptual understanding, relying heavily on memorized procedures rather than engaging with the material more meaningfully. The students struggled to apply these strategies effectively in unfamiliar contexts. The reliance on traditional instructional methods, such as direct instruction and worked examples, may not be sufficient to bridge this gap.

In alignment with teacher recommendations, there is a pressing need to introduce more dynamic and engaging instructional approaches to address these deficiencies. This study suggests integrating real-world applications as a potential strategy to make learning differentiation more meaningful. Real-world applications such as analyzing rates of change in physics, economics, and biology can help students recognize the relevance of differentiation concepts to real-life situations. Additionally, the use of technological tools, such as dynamic mathematics software and graphing calculators, can aid students in visualizing functions and their derivatives more effectively, thereby enhancing their understanding. Teachers can also employ differentiated instruction to tailor teaching methods to students' abilities, offering additional practice for weaker students while challenging advanced students with more complex problems. Despite challenges such as time and resource constraints, teachers expressed interest in adopting more interactive and innovative teaching strategies. Approaches like scaffolding can provide structured guidance to students, beginning with simpler problems and gradually progressing to more complex ones. By implementing these strategies, teachers can not only enhance students' achievement in differentiation but also equip them with problem-solving skills that are essential for higher education and future careers. These instructional changes, supported by research literature, offer a pathway for enhancing both teaching practices and student outcomes in mathematics.

5.1 Limitation and future direction

Despite the valuable insights gained, this study has several limitations. The study was conducted with a sample of 30 students from one district, which may limit the generalizability of the findings. The results may not fully represent the broader population of Malaysian secondary school students. The study focused solely on differentiation within the mathematics curriculum, which limits its application to other areas of mathematics. Future research could explore whether similar challenges exist in other complex mathematical topics, such as integration or trigonometry. While the study collected teacher perspectives on student challenges and current strategies, it did not experimentally test the effectiveness of proposed instructional interventions such as scaffolding or technology integration. This limits the ability to draw concrete conclusions about the impact of these strategies.

Future research should involve a larger and more diverse sample of students across multiple regions to ensure more generalizable results. This would allow for a broader understanding of the challenges faced by students across Malaysia and could highlight regional differences in performance and instructional needs. While this study focused on differentiation, future research could explore problem-solving challenges in other areas of mathematics, such as integration, trigonometry, or calculus more broadly. Comparing student difficulties across different mathematical domains could provide further insights into the underlying factors affecting problem-solving skills. Experimental research is needed to test the effectiveness of teachers proposed instructional strategies and supported by literature, such as scaffolding, technology-enhanced learning, and real-world applications. By implementing these interventions in classroom settings and measuring their impact on student performance, future studies could provide more concrete evidence on how best to improve problem-solving skills in differentiation. Since teachers expressed a need for more resources and training in innovative instructional methods, future studies could investigate how professional development programs can equip teachers with the skills and tools needed to implement these strategies effectively. Research in this area could explore the long-term effects of teacher training on both instructional practices and student outcomes.

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Conflicts of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Considerations This study involved human participants and used a mixed-methods design, comprising a problem-solving test administered to students and semi-structured interviews with mathematics teachers. Participation was voluntary, and all participants were informed about the study's purpose and procedures before data collection. The test was conducted solely for research purposes and did not affect students' academic evaluation. We obtained informed consent from all participants and secured school permission where required. Participants' identities were kept confidential, and all collected data were anonymised and used exclusively for research purposes.

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