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Problem-solving skills among students on the topic of derivatives: Differences in the changes of achievement emotions

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Abstract

Problem-solving, one of the crucial skills for student success in mathematics, has not been optimal, in which most of students have poor mathematical problem-solving skills. Emotional stability during mathematical tasks, particularly in solving derivatives, is believed to influence problem-solving skills outcomes. This study examines the link between achievement emotions and problem-solving skills among public middle school students in South Sumatera, Indonesia, focusing on the topic of derivatives. Using an explanatory sequential mixed-method approach, the research combined a non-experimental survey for quantitative data and grounded theory for qualitative insights. Data collection involved the Achievement Emotions Questionnaire in Mathematics (AEQ-M) and a problem-solving skills test on derivatives, analyzed through one-way MANOVA, Pearson correlation, and coding paradigms. Findings showed that students with heightened positive emotions and reduced negative emotions performed better in problem-solving skills, excelling in areas like data organization, problem identification, formula presentation, strategy selection, and generalization. Positive emotions correlated positively with problem-solving skills indicators, while negative emotions showed a negative correlation. Students with stable emotional states consistently demonstrated strong problem-solving skills, whereas those with fluctuating emotions struggled. These results highlight the need to create supportive learning environments and implement strategies to manage achievement emotions, enabling students to enhance their problem-solving skills in mathematics effectively.

Keywords: achievement emotions, derivatives, mathematics, middle school, problem-solving

INTRODUCTION

Mathematical problem-solving skills are fundamental to students' overall success in mathematics, particularly for middle school students who are building the foundation for advanced mathematical concept (Suparman & Juandi, 2022). These skills not only enhance students' understanding of mathematical concepts but also contribute significantly to their academic achievement (Ariani et al., 2024). In middle school, where mathematics curricula introduce essential topics like algebra, geometry, and calculus, strong problem-solving abilities can empower students to tackle complex problems with confidence. Furthermore, students proficient in problem-solving are better equipped to perform well in mathematics assessments, which in turn fosters positive attitudes toward the subject and boosts their overall academic self-concept (Garcia-Moya et al., 2024). The impact of mathematical problem-solving skills reaches beyond grades, as it encourages logical reasoning, critical thinking, and adaptability, all of which are essential skills for future academic and career success.

Despite the importance of problem-solving skills, many students struggle with mathematical problems, especially with more challenging topics such as derivatives (Bayaga, 2024; Lupiáñez et al., 2024). This struggle is often attributed to various factors, including the complexity of mathematical concepts and insufficient instructional support. Derivatives, for instance, are a critical concept in calculus but pose particular difficulties for middle school students due to the abstract nature of the topic and the analytical skills required. Empirical studies have highlighted that

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Contribution to the literature

- The main findings of this study support the existence of the Control-Value Theory of achievement emotions in educational settings of mathematics.
- Mathematics teachers can also incorporate reflective exercises, such as emotional journaling during problem-solving tasks, to help students develop self-awareness and emotional regulation skills.
- Educational policymakers should consider incorporating emotional well-being metrics into evaluations of teaching effectiveness and curriculum design.

students with low problem-solving skills in mathematics frequently experience frustration and anxiety, particularly when confronted with derivative problems (Just & Siller, 2024; Khusna et al., 2024; Ndiung & Menggo, 2024; Türkoğlu & Yalçınalp, 2024). One notable factor associated with these difficulties is the role of achievement emotions - emotions directly tied to success or failure in academic settings (Suparman et al., 2024). The challenge of mastering derivatives and other complex topics, coupled with negative emotions, can create a cycle where low problem-solving skills exacerbate feelings of inadequacy, which further hampers students' progress in mathematics.

Achievement emotions, such as anxiety, enjoyment, and pride, are influential factors affecting students' problem-solving skills in mathematics (Suparman et al., 2021). These emotions shape how students' approach and react to mathematical tasks, influencing their motivation, engagement, and ultimately, their performance. For instance, positive emotions like enjoyment and pride can enhance concentration and encourage persistence, leading students to approach problems with greater resilience and creativity (Sakaki et al., 2024). Conversely, negative emotions like anxiety and shame often result in avoidance behaviors, reducing students' willingness to engage with complex problems, such as those involving derivatives (Pekrun et al., 2023a). Achievement emotions, therefore, act as a critical lens through which students interpret their mathematical experiences, affecting both their immediate responses to problem-solving tasks and their long-term attitudes toward mathematics.

Previous studies have explored the relationship between problem-solving skills and achievement emotions in some mathematics contents, including: enumeration rules, linier equation system, 3D geometry, statistics, and probability (Caballero-Carrasco et al., 2021; Hanin & Van Nieuwenhoven, 2019; Merrick & Fyfe, 2023; Van der Beek et al., 2024; Yazgan & Ülger, 2023), yet there remains a notable gap in the research, particularly concerning students' emotional experiences while solving derivative-related problems. While much research has been conducted on general mathematics achievement, relatively there are no empirical studies which have specifically examined how positive and negative emotions fluctuate during the process of tackling derivative problems. Understanding these emotional shifts is essential because it sheds light on how students' attitudes and behaviors toward specific mathematical topics evolve over time (Putwain et al., 2021). This study seeks to address this gap by focusing on how achievement emotions specifically impact students' problem-solving skills in the context of derivatives, thereby contributing novel insights to the field of educational psychology.

The current study aims to examine the relationship between achieving emotions and mathematical problem-solving skills, focusing specifically on the topic of derivatives among middle school students. This study seeks to determine whether certain emotions-positive or negative-significantly influence students' skills to solve derivative problems. By investigating this relationship, this study makes a meaningful contribution to both educational psychology and mathematics education by identifying ways to improve student engagement and achievement in mathematics. The research questions guiding this study are:

(1) Is there any significant difference of mathematical problem-solving skills among middle school students in the changes of positive and negative emotions?

(2) How is the achievement of mathematical problem-solving skills among middle school students under reviewed from the stability of achievement emotions?

The findings of this study could inform teaching strategies that foster positive emotional responses to mathematics, ultimately helping students to develop stronger problem-solving skills and achieve greater success in their mathematical endeavors.

THEORETICAL FRAMEWORK

Problem-Solving Skills in Mathematics

Problem-solving skills in mathematics are defined by experts as a set of cognitive processes used to identify, analyze, and resolve mathematical challenges (Kain et al., 2024; Yilmaz & Griffiths, 2023). According to Polya, problem-solving involves understanding the problem, devising a plan, carrying out the plan, and reviewing the solution to evaluate its accuracy (Garcia-Moya et al., 2024; Rocha & Babo, 2024). Schoenfeld (2016) expands this view by emphasizing the role of strategic decision-making and metacognition in solving mathematical problems effectively. Problem-solving skills are critical for students because they encourage logical thinking, pattern recognition, and creativity, which are essential for success in mathematics (Torres-Peña et al., 2024). Through problem-solving, students learn to apply mathematical knowledge to real-world scenarios, bridging abstract concepts with practical applications (Muslim et al., 2024). Furthermore, problem-solving develops resilience and persistence, as students often need to attempt different approaches before arriving at a solution. Kilpatrick et al. (2001) highlights that strong problem-solving skills are foundational to deep mathematical understanding, enabling students to tackle increasingly complex topics as they progress. Out of these definitions, problem-solving skills in mathematics involve cognitive processes for identifying, analyzing, and resolving mathematics challenges, which foster logical thinking, creativity, and resilience, and enable students to apply mathematical knowledge to real-world context and develop a deep understanding of complex concepts. For educators, cultivating these skills is a priority, as they not only impact students' academic performance but also their overall approach to learning and critical thinking. Thus, fostering problem-solving skills in mathematics is key to equipping students with tools for lifelong learning and adaptability in diverse academic and real-life situations.

To measure problem-solving skills in mathematics, various indicators have been established by educational researchers and experts. Polya identifies four main indicators: problem understanding, strategy formulation, solution execution, and solution verification (Chacón-Castro et al., 2023). Each of these indicators reflects a stage in the problem-solving process, allowing educators to assess students' abilities at each step. Schoenfeld (2016) further includes aspects like resourcefulness and flexibility in approach, highlighting that proficient problem solvers can adapt their strategies when faced with unexpected challenges. Meyer and Norman (2020) emphasizes cognitive and metacognitive indicators, noting that students must monitor and regulate their thought processes to achieve success in complex problem-solving tasks. Indicators such as logical reasoning, mathematical communication, and creativity are also vital, as they demonstrate a student's ability to think critically and articulate their solutions effectively. Indicators like perseverance and confidence are often included as well, as they reflect a student's attitude and willingness to engage in difficult problems. These indicators offer a comprehensive view of students' problem-solving abilities, which encompass both cognitive and affective dimensions crucial for mathematics success. This current study, however, refers to the indicators of problem-solving skills in mathematics suggested by Polya but those are developed more to be five indicators, including:

(P1) Organizing the data and selecting relevant information in identifying problems,

(P2) Presenting the formulation of a mathematical problem in various forms,

(P3) Selecting and using the right approach or strategy to solve problems,

(P4) Solving problems, and

(P5) Generalizing solved problems.

Achievement Emotions

Achievement emotions are defined by researchers as emotions that are directly tied to success or failure in academic settings (Pekrun & Linnenbrink-Garcia, 2012; Pekrun & Stephens, 2012). Pekrun (2016) defines achievement emotions as emotional experiences that students encounter when engaged in activities with clear performance outcomes, such as completing tests or solving problems. These emotions include both positive emotions, such as pride and enjoyment, and negative emotions, such as anxiety and frustration. Achievement emotions are distinct from general emotions because they are specifically linked to individuals' evaluations of their performance in educational contexts (Suparman et al., 2024). According to Pekrun's Control-Value Theory, achievement emotions arise when students perceive control over their learning outcomes and place value on the task at hand (Lazarides & Raufelder, 2021). These emotions are crucial in academic settings as they influence students' motivation, focus, and resilience (Juandi & Suparman, 2024). Out of these explanations, achievement emotions are emotions tied to success or failure in academic settings, influencing students' motivation, focus, and resilience. Achievement emotions, therefore, play an essential role in shaping students' academic experiences and outcomes, particularly in subjects like mathematics.

Achievement emotions can be categorized based on three primary dimensions: valence, activation, and object focus (Pekrun et al., 2023a). Valence refers to whether the emotion is positive or negative; for example, pride is a positive emotion, whereas anxiety is negative. Activation denotes the level of arousal or intensity of emotion, with emotions like excitement being highly activated and boredom being low in activation. Object focus refers to the specific target of the emotion, which could be activity-related (e.g., enjoyment of the problem-solving process) or outcome-related (e.g., pride in a successful solution). This categorization allows for a nuanced understanding of how different emotions impact learning, as not all emotions have the same effect on students' motivation or performance (Schukajlow et al., 2017). For instance, high-activation emotions like anxiety can lead to avoidance behaviors, whereas positive, activity-related emotions like enjoyment can enhance engagement. This framework is useful in identifying the types of emotions students experience during challenging tasks, such as solving math problems, and understanding how these emotions influence their approach to learning. This present study involves positive emotions (e.g., enjoyment, pride, hope, contentment, and relaxation) and negative emotions (e.g., anxiety, anger, shame, hopelessness, and boredom).

Achievement emotions have a significant impact on students' problem-solving skills in mathematics (Suparman et al., 2021). Positive achievement emotions, such as enjoyment, often encourage students to engage actively with challenging problems, promoting persistence and creative thinking. In contrast, negative emotions like anxiety can undermine confidence, leading students to avoid mathematical tasks or adopt a fixed mindset. These emotions influence cognitive processes, as positive emotions can broaden thinking and facilitate flexible problem-solving, while negative emotions may restrict thinking and lead to a narrow focus (Putwain et al., 2021). Studies indicate that students experiencing positive emotions are more likely to use effective problem-solving strategies, while those with negative emotions may struggle with self-doubt and incomplete solutions (Camacho-Morles et al., 2021; Forsblom et al., 2022; Schukajlow et al., 2017). Achievement emotions also impact students' motivation, with positive emotions fostering an intrinsic interest in the subject and negative emotions resulting in extrinsic or avoidance motivations (Schukajlow et al., 2017). By influencing cognitive, motivational, and behavioral factors, achievement emotions significantly shape students' mathematical learning experiences and problem-solving outcomes.

Calculus and Derivatives

Calculus is a fundamental area of mathematics that plays a critical role in students' middle and high school education, as it provides the tools necessary for understanding change and motion (Hussain & ur Rehman, 2025). Calculus is often considered a gateway subject, as it forms the basis for advanced studies in mathematics, physics, engineering, and economics. For middle school students, calculus concepts are introduced in an accessible way to develop their foundational understanding. Understanding calculus prepares students for the study of dynamic systems and real-world applications, such as population growth and velocity (Bate et al., 2025). Given its complexity, calculus also reinforces essential mathematical skills, including algebraic manipulation and conceptual reasoning (Singh et al., 2025). Mastery of calculus concepts can greatly enhance students' academic progress in STEM fields, helping them build confidence in handling complex problems (Boruah & Hazarika, 2025). Overall, calculus serves as a bridge between basic mathematics and more specialized fields, encouraging students to engage deeply with mathematical principles.

Derivatives, a core concept within calculus, represent the rate at which a quantity changes and are introduced as an essential topic for understanding dynamic systems (Li, 2024). In middle school, the concept of derivatives may be presented in simplified form, such as understanding slopes of lines or rates of change in real-world contexts (Scholz & Berger, 2024). Derivatives provide a foundation for students to understand key calculus ideas, such as differentiation, which allows them to calculate instantaneous rates of change. Teachers often introduce basic derivatives concepts to help students comprehend linear functions, as well as applications like velocity in physics. The study of derivatives enhances students' analytical skills, as they learn to break down complex functions and interpret their behaviors (Santos-Trigo et al., 2024). Moreover, derivatives are foundational for students planning to advance in mathematics, as they are essential in calculus-based courses and real-world applications. By exploring derivatives early, students are better prepared for the rigorous demands of higher-level mathematics and applied sciences.

The study of derivatives offers numerous advantages for students, both academically and in everyday life. Understanding derivatives allows students to interpret real-world phenomena that involve rates of change, such as acceleration, growth trends, and economic shifts (Ruby & Mandal, 2024). In fields such as physics, biology, and economics, the ability to calculate and interpret derivatives is crucial for analyzing changes and predicting outcomes. In daily life, derivatives can help students make informed decisions, such as understanding interest rates, population trends, or even changes in personal finances (Ozkan et al., 2024). Developing skills in derivatives also fosters critical thinking, as students must interpret data, predict outcomes, and assess trends (Thabet et al., 2024). This knowledge gives students a toolkit for understanding dynamic systems and processes that shape their surroundings. By learning derivatives, students can connect mathematical concepts to practical applications, enriching their understanding of the world (Bragina et al., 2020). Ultimately, derivatives equip students with a skillset that is valuable not only in academics but also in a range of professional and personal contexts.

METHOD

Research Design

This study used an explanatory sequential mixed-method design, chosen to effectively explore both the quantitative and qualitative dimensions of problem-solving skills in mathematics and achievement emotions. This approach allowed for a comprehensive analysis by first examining broad patterns through quantitative data and then delving into the underlying experiences through qualitative inquiry (Creswell & Clark, 2011).

The initial quantitative phase examined the differences in problem-solving skills among middle school students as they experience shifts in positive and negative emotions, using a non-experimental survey design to gather data. A survey approach was selected as enables efficient collection of data from a larger sample, providing an overview of emotional trends and skill levels (Creswell, 2013). Following the quantitative phase, the study proceeded with a qualitative phase to gain deeper insight into how achievement emotions affect the achievement of problem-solving skills in mathematics among middle school students. For this phase, a grounded theory was applied to analyze qualitative data, seeking to construct a theory around how positive and negative emotions affect the achievement of mathematical problem-solving skills among students (Creswell, 2012). The qualitative insights provided context and explanation for the quantitative findings, enriching the overall understanding of the emotional dynamics in mathematical problem-solving skills. The use of this mixed-method design ensured that both statistical significance and personal experiences were captured, creating a holistic view of the research problem.

Participant

The participants were 30 twelfth-grade students from a public middle school in South Sumatera, selected through purposive sampling. They were chosen as they had a solid foundation in mathematics, and were at a developmental stage in which emotional responses could strongly affect academic performance. Purposive sampling was used to select participants who would likely demonstrate the variation in achievement emotions and problem-solving skills, thus ensuring meaningful data for the objectives of this study. This specific group was expected to provide insights into both high and low emotional responses to problem-solving tasks, particularly in calculus-related derivative topics. The focus on a single middle school allowed for a controlled context in examining the role of achievement emotions within the same educational setting. Limiting the sample to 30 students also enabled in-depth analysis while maintaining manageable data (Lipsey & Wilson, 2001). This participant selection method was designed to align with the mixed-method approach, providing diverse perspectives and experiences.

Instrument and Data Collection

The primary instrument for assessing problem-solving skills in mathematics was a test consisting of two essay-based problems related to derivative applications in daily life (see **Appendix A**). These problems were chosen for their relevance to real-world situations, encouraging students to apply theoretical knowledge practically. The test had been validated and deemed reliable, with a high correlation coefficient (r = 0.817 for 1st problem; r = 0.892 for 2nd problem) and Cronbach's alpha (α = 0.791), ensuring internal consistency. The problem-solving skills test was designed to assess five indicators consisting of:

(P1) organizing the data and selecting relevant information in identifying problems,

(P2) presenting the formulation of a mathematical problem in various forms,

(P3) selecting and using the right approach or strategy to solve problems,

(P4) solving problems, and

(P5) generalizing solved problems (Chacón-Castro et al., 2023).

Both the validity and reliability metrics demonstrated the test's ability to accurately measure problem-solving skills among students (Mohamad et al., 2015). Moreover, the essay format enabled students to articulate their thought processes, providing insights into their analytical and logical reasoning skills (Kadarisma et al., 2019). The results from this test formed the quantitative data used to analyze problem-solving skills in mathematics among middle school students.

The second instrument was an achievement emotions questionnaire tailored for mathematics (AEQ-M), comprising 25 statements rated on a 5-point Likert scale (see **Appendix B**), adapted by Bieleke et al. (2023) and Pekrun et al. (2023b). This questionnaire covered five positive emotions (e.g., enjoyment, pride, hope, contentment, relaxation) and five negative emotions (e.g., anxiety, anger, hopelessness, boredom, shame), allowing for a nuanced understanding of students' emotional responses to mathematics. Each statement had been rigorously valid, and the instrument had demonstrated high reliability, with a significant Cronbach's alpha value (α = 0.871; $p < 0.05$ for enjoyment, α = 0.912; $p < 0.01$ for pride, α = 0.856; $p < 0.05$ for hope, α = 0.819; $p < 0.05$ for contentment, α = 0.867; $p < 0.05$ for relaxation, α = 0.883; $p < 0.05$ for anxiety, α = 0.879; $p < 0.05$ for hopelessness, α = 0.901; $p < 0.01$ for shame, α = 0.827; $p < 0.05$ for boredom, α = 0.874; $p < 0.05$ for anger). The AEQ-M served as a key tool for measuring both the valence (positive or negative) and intensity of emotions related to problem-solving skills in mathematics (Bieleke et al., 2023). Data from this instrument contributed to understanding how emotional factors correlated with problem-solving skills in mathematics. This structured assessment ensured that the emotional aspect of the study was measured with precision and reliability.

In collecting the data, firstly, AEQ-M was administrated to 30 twelfth-grade students from a public middle school to collect the data regarding students' achievement emotions before conducting mathematics test. Secondly, a test of problem-solving skills in mathematics was administrated to collect the data regarding students' mathematical problem-solving

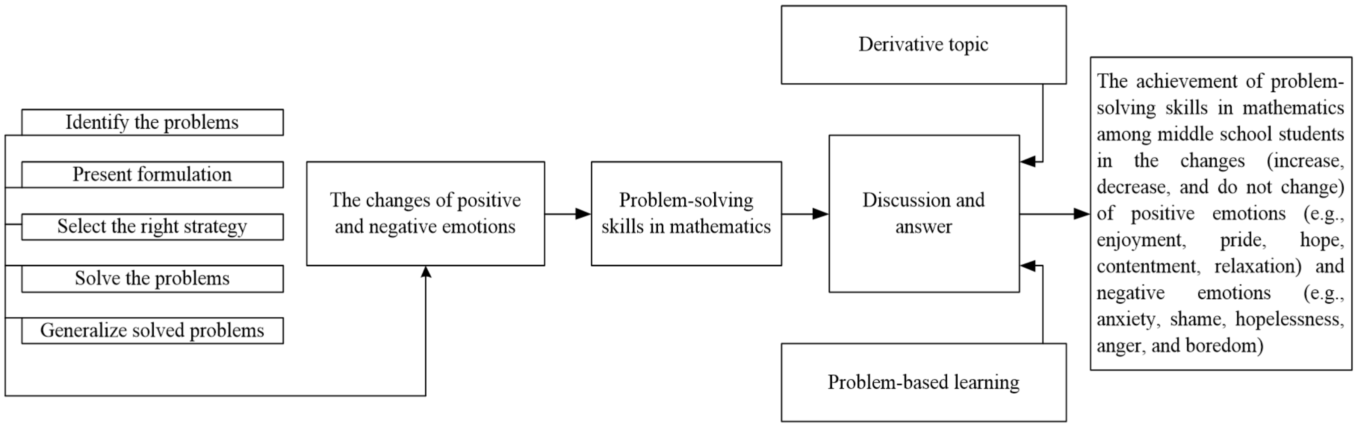


Figure 1. The illustration of coding process in this grounded theory (Source: Authors' own elaboration)

skills. Lastly, AEQ-M was repeatedly administrated to collect the data regarding students' achievement emotions after conducting mathematics test.

Data Analysis

To analyze the quantitative data, N-gain scores were calculated to describe changes in students' positive and negative emotions during solving the derivative problems. N-gain, or normalized gain, was particularly useful in this study as it reflected relative increase or decrease in emotions (Hake, 1998), allowing for comparisons among middle school students. Additionally, a one-way MANOVA (Multivariate Analysis of Variance) was employed to examine differences in problem-solving skills in mathematics based on the observed changes in positive and negative emotions. MANOVA was appropriate here because it could simultaneously assess multiple dependent variables, such as different skill levels across various emotional changes (Rutherford, 2011). This statistical approach provided insights into whether positive and negative emotions significantly affected students' problem-solving skills in mathematics. The combination of N-gain and MANOVA ensured both descriptive and inferential statistical analysis, covering both trends and causal relationships. These analyses provided a detailed quantitative understanding of the influence of emotions on problem-solving skills in mathematics.

For the qualitative data, a coding paradigm was used, consisting of open, axial, and selective coding stages to organize and interpret the data (Qureshi & Ünlü, 2020). In this grounded theory, the coding process was aimed at describing the achievement of problem-solving skills in mathematics in the changes of positive and negative emotions (see **Figure 1**). Open coding began the process by breaking down qualitative responses into distinct concepts and categories, enabling initial identification of patterns. Axial coding was then applied to link these categories, exploring relationships among concepts and deepening the understanding of emotional effects on problem-solving skills in mathematics.

Finally, selective coding integrated the findings into a coherent theory that described how achievement emotions affected students' problem-solving skills in mathematics. This coding process aligned with grounded theory principles, enabling the development of a theory grounded in students' experiences (Creswell, 2013). By combining quantitative and qualitative analysis, the study achieved a comprehensive view of the role of achieving emotions in problem-solving skills in mathematics, with each method providing complementary insights.

RESULTS

Descriptive Statistics

Descriptive statistics was used to describe the change of students' positive emotions (e.g., enjoyment, pride, hope, contentment, and relaxation) and negative emotions (e.g., anger, anxiety, shame, hopelessness, and boredom) (see **Table 1**), and students' problem-solving skills in mathematics (see **Table 2**).

As seen in **Table 1**, of 30 students surveyed in this study, positive emotions among 43.33% of students increased, followed by 43.33% of students decreased, and 13.34% of students did not change in positive emotions. Meanwhile, negative emotions among 43.33% of students decreased, followed by 43.33% of students increased, and 13.34% of students did not change in negative emotions.

As presented in **Table 2**, students' problem-solving skills who experienced an increase of positive emotions exceeded students' problem-solving skills who experienced the decrease and unchanging of positive emotions during solving math problems. On the other hand, students' problem-solving skills who experienced the decrease of negative emotions were greater than students' problem-solving skills who experienced the increase and unchanging of negative emotions.

Table 1. The change of positive and negative emotions

Participant	Positive Emotions (N-Gain Value)	The Change	Negative Emotions (N-Gain Value)	The Change
A1	-0.11	Decrease	0.15	Increase
A2	-0.31	Decrease	0.30	Increase
A3	-0.89	Decrease	0.22	Increase
A4	-2.40	Decrease	0.38	Increase
A5	0.27	Increase	-1.17	Decrease
A6	0.33	Increase	-1.50	Decrease
A7	-1.40	Decrease	0.16	Increase
A8	0.50	Increase	-0.02	Decrease
A9	0.50	Increase	-2.00	Decrease
A10	-0.89	Decrease	0.16	Increase
A11	-1.67	Decrease	0.29	Increase
A12	0.25	Increase	-0.13	Decrease
A13	-0.06	Decrease	0.10	Increase
A14	-0.47	Decrease	0.13	Increase
A15	0.00	Do not change	0.00	Do not change
A16	0.00	Do not change	0.00	Do not change
A17	-1.00	Decrease	0.28	Increase
A18	0.40	Increase	-0.20	Decrease
A19	-0.63	Decrease	0.32	Increase
A20	0.00	Do not change	0.00	Do not change
A21	0.74	Increase	-0.57	Decrease
A22	0.59	Increase	-0.26	Decrease
A23	-1.38	Decrease	0.19	Increase
A24	0.47	Increase	-0.03	Decrease
A25	0.25	Increase	-1.35	Decrease
A26	-0.20	Decrease	0.45	Increase
A27	0.50	Increase	-0.40	Decrease
A28	0.47	Increase	-0.13	Decrease
A29	0.00	Do not change	0.00	Do not change
A30	0.63	Increase	-0.24	Decrease

Table 2. Problem-solving skills in mathematics based on the change of achievement emotion

Indicators	Positive Emotions			Negative Emotions			Total
	Increase	Don't change	Decrease	Decrease	Don't change	Increase	
P1	7.77 (0.48)	4.25 (2.63)	3.62 (1.56)	7.77 (0.48)	4.25 (2.63)	3.62 (1.56)	5.50 (2.43)
P2	7.69 (0.75)	4.00 (2.71)	2.46 (1.81)	7.69 (0.75)	4.00 (2.71)	2.46 (1.81)	5.37 (2.58)
P3	7.08 (0.64)	4.75 (2.22)	2.23 (1.48)	7.08 (0.64)	4.75 (2.22)	2.23 (1.48)	4.67 (2.62)
P4	7.31 (0.75)	4.75 (2.50)	2.31 (1.55)	7.31 (0.75)	4.75 (2.50)	2.31 (1.55)	4.80 (2.73)
P5	6.38 (0.51)	2.50 (1.92)	1.77 (1.48)	6.38 (0.51)	2.50 (1.92)	1.77 (1.48)	3.87 (2.54)
Total	36.23 (2.01)	20.25 (11.09)	13.38 (5.58)	36.23 (2.01)	20.25 (11.09)	13.38 (5.58)	24.20 (12.11)

Table 3. The results of homogeneity test

Problem-Solving Skills in Mathematics	Positive Emotions		Negative Emotions	
	Levene Statistics	P-value	Levene Statistics	P-value
P1: Organizing the data	3.612	0.053	3.861	0.061
P2: Presenting the formulation	2.165	0.139	2.274	0.143
P3: Selecting the right approach	2.668	0.088	2.741	0.089
P4: Solving problems	3.240	0.065	3.567	0.072
P5: Generalizing solved problems	4.878	0.076	4.934	0.083
Total	3.390	0.075	3.476	0.079

Inferential Statistics

Inferential statistics was used to statistically analyze problem-solving skills in mathematics among students and the change of students' positive and negative emotions. Particularly, one-way MANOVA was performed to examine the difference of problem-solving skills in mathematics among students based on the change of students' positive and negative emotions (See Table 4). However, the assumption of homogeneity for each of the data regarding problem-solving skills in mathematics is extremely required. The results of homogeneity test for the data of problem-solving skills in mathematics are shown in **Table 3**.

As seen in **Table 3**, the homogeneity test shows that the data organizing the data, presenting the formulation, selecting the right approach, solving problems, and generalizing solved problems is homogeneous. Overall, the data of students' problem-solving skills in

Table 4. The results of one-way MANOVA

Positive and Negative Emotions	Effect	F-value	Partial Eta Squared
Multivariate Tests	Pilla's Trace	6.007**	0.556
	Wilks' Lambda	9.031**	0.663
	Hotelling's Trace	12.761**	0.744
	Roy's Largest Root	26.093**	0.845
Tests of Between-Subjects Effects	P1: Organizing the data	30.909**	0.696
	P2: Presenting the formulation	24.810**	0.648
	P3: Selecting the right approach	44.829**	0.768
	P4: Solving problems	40.412**	0.750
	P5: Generalizing solved problems	49.167**	0.785
	Problem-solving skills	59.196**	0.814

** $p < 0.001$

Table 5. The results of Shapiro-Wilk's normality test

Data	Statistics	df	Sig.	Conclusion
P1: Organizing the data	0.982	30	0.134	Normal
P2: Presenting the formulation	0.937	30	0.175	Normal
P3: Selecting the right approach	0.994	30	0.245	Normal
P4: Solving problems	0.945	30	0.367	Normal
P5: Generalizing solved problems	0.974	30	0.278	Normal
Overall: Problem-solving skills	0.912	30	0.185	Normal
Positive emotions	0.980	30	0.492	Normal
Negative emotions	0.938	30	0.341	Normal

Table 6. The results of Pearson correlation analysis

Indicator of Problem-Solving Skills	Positive Emotions	Negative Emotions
P1: Organizing the data	0.635**	-0.598**
P2: Presenting the formulation	0.633**	-0.560**
P3: Selecting the right approach	0.624**	-0.613**
P4: Solving problems	0.766**	-0.674**
P5: Generalizing solved problems	0.744**	-0.601**
Overall: Problem-solving skills	0.726**	-0.650**

** $p < 0.001$

mathematics is also homogeneous. This indicates that one-way MANOVA in examining the difference of problem-solving skills in mathematics among students based on the change of students' positive and negative emotions is required to do.

As seen in **Table 4**, there was a significant difference of problem-solving skills in mathematics among students based on the change of students' positive and negative emotions. Particularly, students' skills in organizing the data, presenting the formulation, selecting the right approach, solving problems, and generalizing solved problems were significant difference among them who experienced the increase, unchanging, and decrease of positive and negative emotions.

To apply the analysis of Pearson correlation, the normality assumption, including indicator of problem-solving skills, positive emotions, and negative emotions need to be verified (see **Table 5**).

The results of the Shapiro-Wilk normality test in **Table 5** indicate that all variables have a significance value (Sig.) greater than 0.05, meaning they follow a normal distribution. Each problem-solving skill component, including organizing data, presenting formulations, selecting approaches, solving problems, and generalizing solutions, was found to be normally distributed. The overall problem-solving skills variable also met the normality assumption, supporting the consistency of the data. Additionally, both positive and negative emotions were normally distributed, suggesting a balanced emotional response among participants. These findings confirm that parametric statistical tests can be appropriately applied to analyze relationships within the dataset.

Table 6 shows that there was a significant positive correlation between students' problem-solving skills in mathematics and the change of students' positive emotions. This finding indicates that the more increasingly the change of positive emotions experienced by students, the higher the achievement of students' problem-solving skills in mathematics. Additionally, there was a significant negative correlation between students' problem-solving skills in mathematics and the change of negative emotions. This finding interprets that the more decreasing the change of negative emotions experienced by students, the higher the achievement of students' problem-solving skills in mathematics.

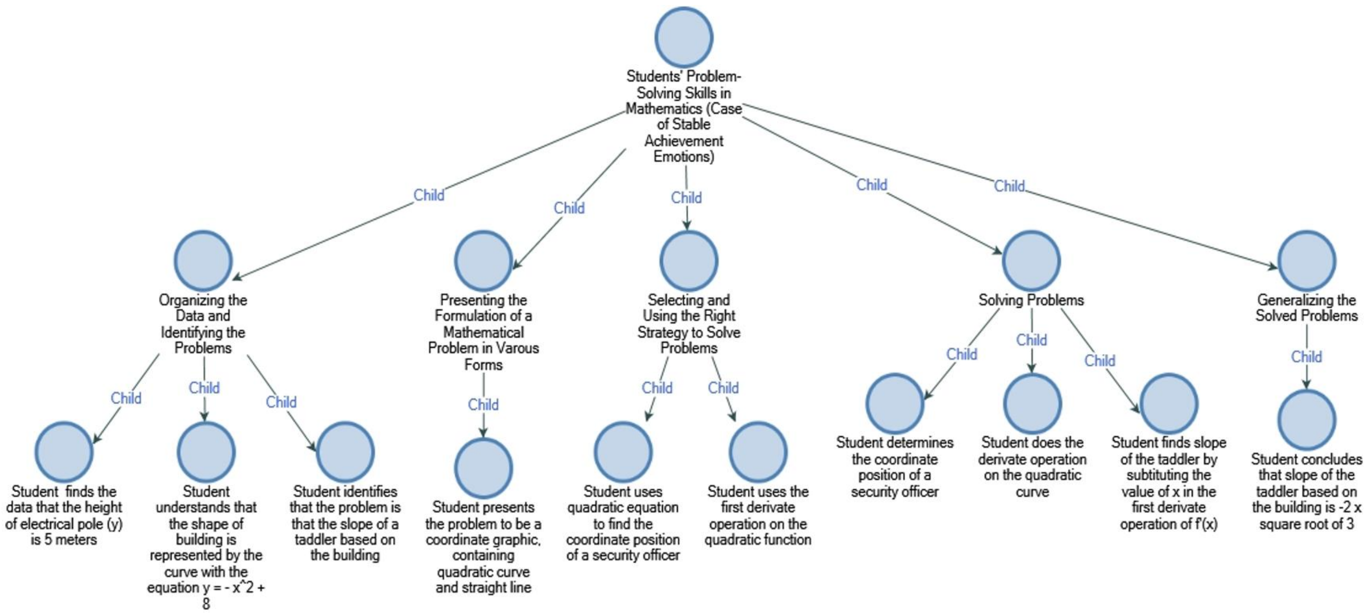


Figure 2. Student's mathematical problem-solving skills in the first problem (Source: Authors' own elaboration)

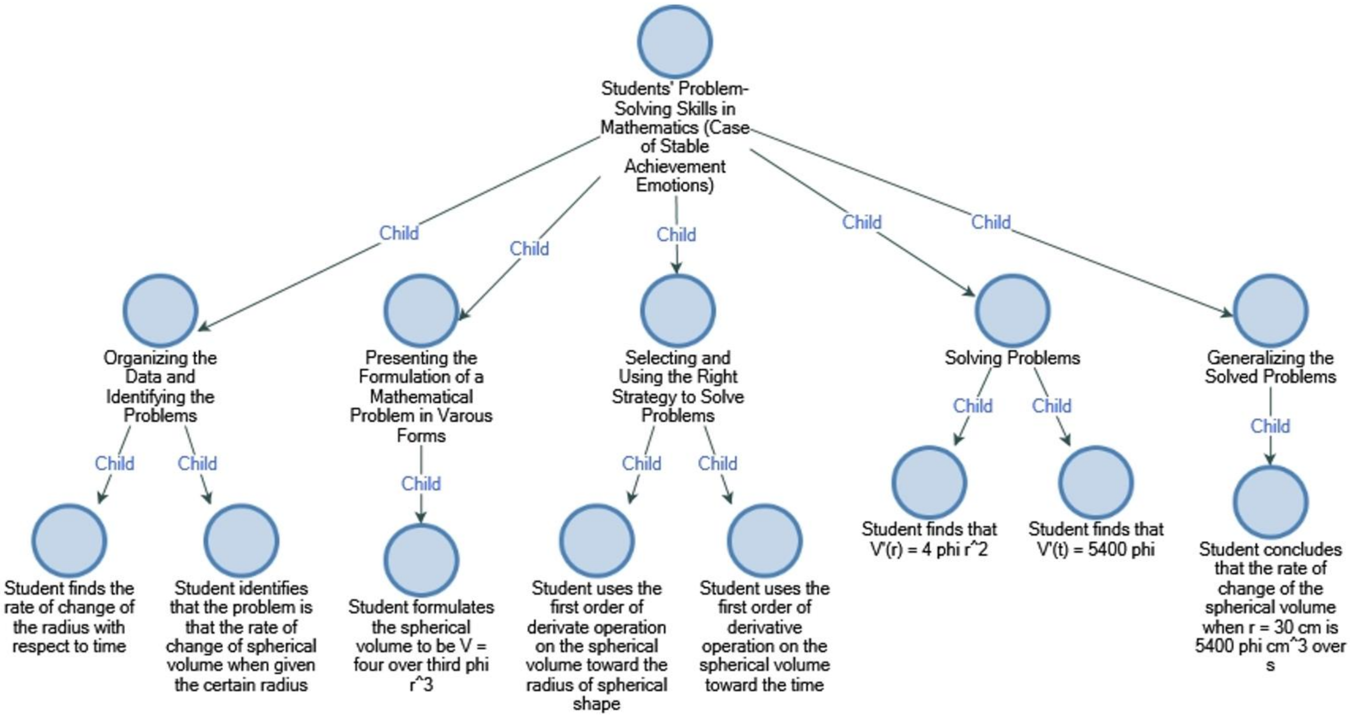


Figure 3. Student's mathematical problem-solving skills in the second problem (Source: Authors' own elaboration)

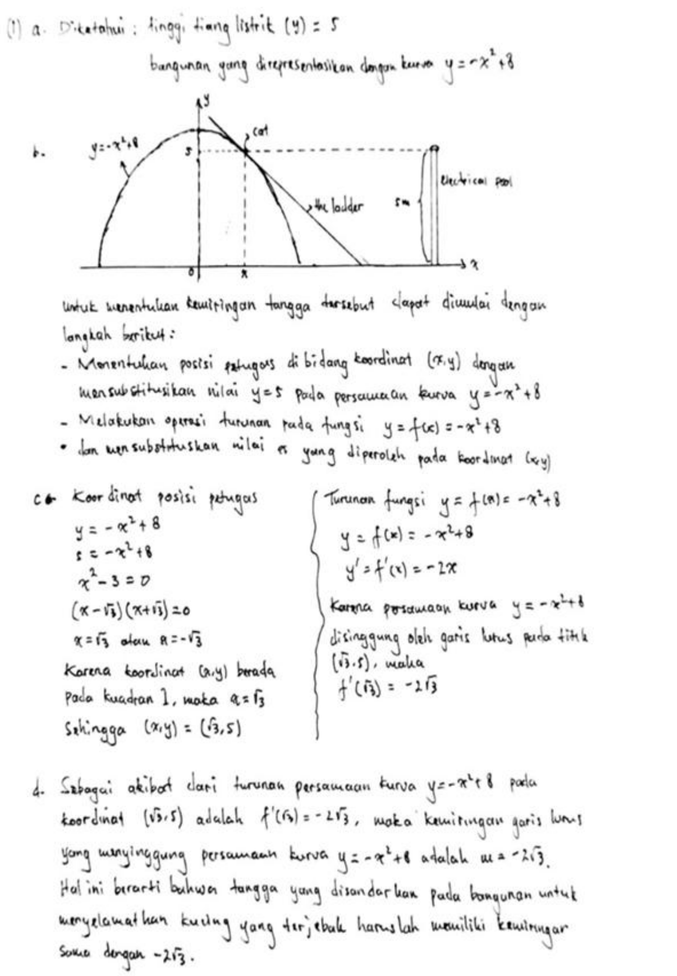
Coding Paradigm

This qualitative design, a grounded theory, was used to describe the achievement of students' problem-solving skills in mathematics analyzed by considering the change of students' positive and negative emotions during solving two derivative problems. Students who experienced the increase of positive emotions and the decrease of negative emotions can relatively achieve all of indicators of problem-solving skills (see **Figure 2** and **Figure 3**). The findings indicate that to have high problem-solving skills in mathematics, students' achievement emotions during solving math problems must be stable, in which their positive emotions increase, and their negative emotions decrease.

As seen in **Table 1a**, viewed by the first problem (see **Appendix 1**), students who experienced stable achievement emotions (positive emotions increase and negative emotions decrease), can organize the data, present the formulation, select the right approach, solve the problems, and generalize the solved problems. The detail of student's work in the first problem which described his/her problem-solving skill in derivative topic is presented in **Table 7**.

As seen in **Table 1a**, viewed by the second problem (see **Appendix 1**), students who experienced stable

Table 7. Student's work in the first problem (case of stable achievement emotions)

Indonesian Version	English Version
 (1) a. Diketahui : tinggi tiang listrik (y) = 5 bangunan yang direpresentasikan dengan kurva $y = -x^2 + 8$ b. $y = -x^2+8$ cat, electrical pool, the ladder, 5 m untuk menentukan kemiringan tangga tersebut dapat dimulai dengan langkah berikut : - Menentukan posisi petugas di bidang koordinat (x,y) dengan mensubstitusikan nilai y = 5 pada persamaan kurva $y = -x^2+8$ - Melakukan operasi turunan pada fungsi $y = f(x) = -x^2+8$ • dan mensubstitusikan nilai x yang diperoleh pada koordinat (x,y) c. Koordinat posisi petugas $y = -x^2+8$ $5 = -x^2+8$ $x^2-3=0$ $(x-\sqrt{3})(x+\sqrt{3})=0$ $x=\sqrt{3}$ atau $x=-\sqrt{3}$ Karena koordinat (x,y) berada pada kuadran I, maka $x=\sqrt{3}$ Sehingga $(x,y) = (\sqrt{3},5)$ Turunan fungsi $y = f(x) = -x^2+8$ $y = f(x) = -x^2+8$ $y' = f'(x) = -2x$ Karena persamaan kurva $y=-x^2+8$ disinggung oleh garis lurus pada titik $(\sqrt{3},5)$, maka $f'(\sqrt{3}) = -2\sqrt{3}$ d. Sebagai akibat dari turunan persamaan kurva $y=-x^2+8$ pada koordinat $(\sqrt{3},5)$ adalah $f'(\sqrt{3}) = -2\sqrt{3}$, maka kemiringan garis lurus yang menyinggung persamaan kurva $y=-x^2+8$ adalah $m = -2\sqrt{3}$. Hal ini berarti bahwa tangga yang disandarkan pada bangunan untuk menyelamatkan kucing yang terjebak haruslah memiliki kemiringan sama dengan $-2\sqrt{3}$.	**Given:** -The height of electric pole (y = 5 meters) -The building is represented by the curve $y = -x^2 + 8$ -The problem is slope of a ladder leaning on the curve **Diagram:** A sketch is drawn showing the curve $y = -x^2 + 8$, the pole at y = 5, and a ladder leaning on the curve **Steps to determine the slope of ladder learning** -Determine the position of a security officer on the coordinate plane (x,y) by substituting the value of y = 5 into the curve equation $y = -x^2 + 8$ -Perform differentiation on the function $y = f(x) = -x^2 + 8$ and substitute the x value obtained into the derivative equation **Coordinates of the security officer** $y = -x^2 + 8$ $5 = -x^2 + 8$ $x^2 - 3 = 0$ $x = \sqrt{3}$ or $x = -\sqrt{3}$ Since the security officer's coordinate (x,y) are in the first quadrant, $x = \sqrt{3}$ Thus, the coordinates are $(x, y) = (\sqrt{3}, 5)$ **Derivative of the curve $y = -x^2 + 8$** $y = f(x) = -x^2 + 8$ $f'(x) = -2x$ Since the curve $y = -x^2 + 8$ is tangent to the ladder at the point $= (\sqrt{3}, 5)$, we have: $f'(\sqrt{3}) = -2\sqrt{3}$ **Conclusion** This means the ladder placed on the building to reach the worker must have a slope equal to $-2\sqrt{3}$

achievement emotions (positive emotions increase and negative emotions decrease), can organize the data, present the formulation, select the right approach, solve the problems, and generalize the solved problems. The details of student's works in the second problem which described his/her problem-solving skill in derivative topic is presented in **Table 8**.

Additionally, students who experienced the decrease of positive emotions and the increase of negative emotions can achieve from two to three indicators of problem-solving skills (see **Figure 4** and **Figure 5**). The findings indicate that students' low achievement of problem-solving skills in mathematics can be caused by unstable achievement emotions of students during solving the derivative problems.

As seen in **Table 1a**, viewed by the first problem (see **Appendix 1**), student who experienced unstable achievement emotions (positive emotions decrease and negative emotions increase), only can organize the data & identify the problems, and present the formulation in various forms.

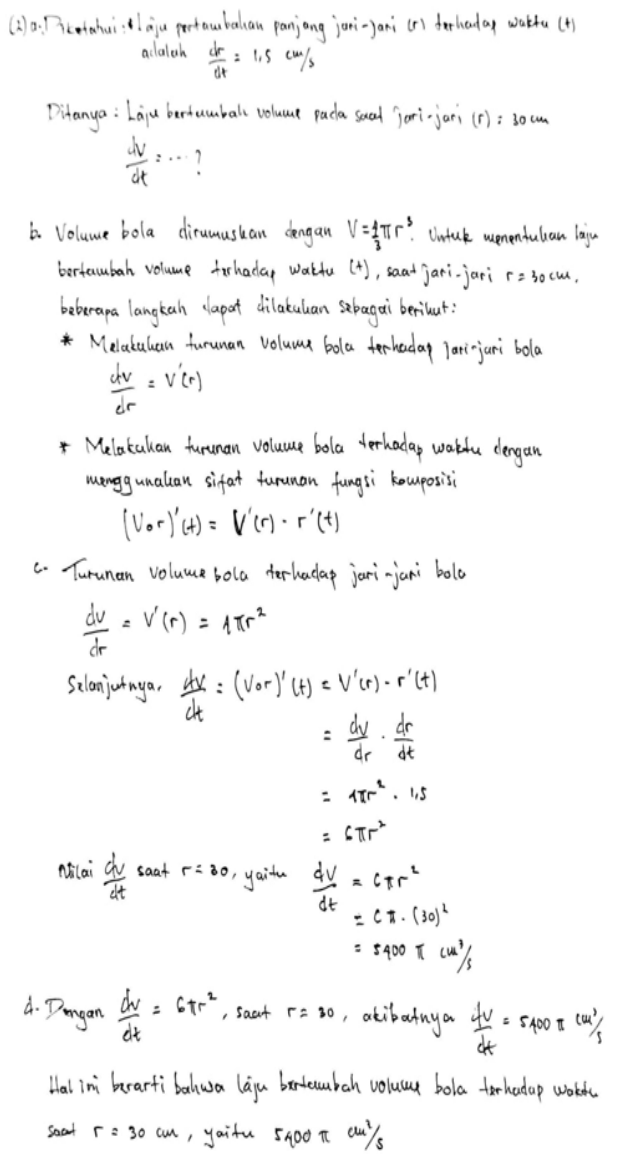
As seen in **Table 1a**, viewed by the second problem (see **Appendix 1**), student who experienced unstable achievement emotions (positive emotions decrease and negative emotions increase), only can organize the data & identify the problems, present the formulation in various forms, and select the right approach to solve the problems. The detail of student's work in the first and second problem which described his/her problem-solving skill in derivative topic is presented in **Table 9**.

DISCUSSION

The Difference of Students' Problem-Solving Skills in Mathematics Based on the Change of Positive and Negative Emotions

The results of the one-way MANOVA reveal significant differences in problem-solving skills among students based on the variation in their positive and negative emotions. This indicates that emotions play a pivotal role in mathematical problem-solving, particularly in the domain of derivatives. For instance, students who experienced an increase in positive emotions demonstrated superior abilities in organizing data, presenting formulations, selecting the appropriate approach, solving problems, and generalizing solutions.

Table 8. Student's work in the second problem (case of stable achievement emotions)

Indonesian Version	English Version
 (2) a. Diketahui: Laju pertambahan panjang jari-jari (r) terhadap waktu (t) adalah $\frac{dr}{dt} = 1{,}5$ cm/s Ditanya: Laju bertambah volume pada saat jari-jari (r) = 30 cm $\frac{dV}{dt} = \ldots ?$ b. Volume bola dirumuskan dengan $V = \frac{4}{3}\pi r^3$. Untuk menentukan laju bertambah volume terhadap waktu (t), saat jari-jari r = 30 cm, beberapa langkah dapat dilakukan sebagai berikut: * Melakukan turunan volume bola terhadap jari-jari bola $\frac{dV}{dr} = V'(r)$ * Melakukan turunan volume bola terhadap waktu dengan menggunakan sifat turunan fungsi komposisi $(V \circ r)'(t) = V'(r) \cdot r'(t)$ c. Turunan volume bola terhadap jari-jari bola $\frac{dV}{dr} = V'(r) = 4\pi r^2$ Selanjutnya, $\frac{dV}{dt} = (V \circ r)'(t) = V'(r) \cdot r'(t) = \frac{dV}{dr} \cdot \frac{dr}{dt} = 4\pi r^2 \cdot 1{,}5 = 6\pi r^2$ Nilai $\frac{dV}{dt}$ saat r = 30, yaitu $\frac{dV}{dt} = 6\pi r^2 = 6\pi \cdot (30)^2 = 5400\pi$ cm³/s d. Dengan $\frac{dV}{dt} = 6\pi r^2$, saat r = 30, akibatnya $\frac{dV}{dt} = 5400\pi$ cm³/s Hal ini berarti bahwa laju bertambah volume bola terhadap waktu saat r = 30 cm, yaitu 5400π cm³/s	**Given:** The rate of change of the radius (r) with respect to time (t) is $\frac{dr}{dt} = 1.5\ cm/s$ **Question:** What is the rate of change of volume now when the radius (r) = 30 cm? $\frac{dV}{dt} = ?$ **The formula for a sphere is given by:** $V = \frac{4}{3}\pi r^3$ **The steps to determine the rate of change of the volume (V) with respect to time (t) when the radius (r) = 30 cm** The following steps can be taken: -Differentiate the sphere's volume equation with respect to its radius (r) $\frac{dV}{dr} = V'(r)$ -Differentiate the volume equation with respect to time using the chain rule: $\frac{dV}{dt} = (V \circ r)' = V'(r) \times r'(t)$ **Differentiating the sphere's volume with respect to its radius (r):** $\frac{dV}{dr} = V'(r) = 4\pi r^2$ Next, the rate of change of volume $\left(\frac{dV}{dt}\right)$ is given by: $\frac{dV}{dt} = \frac{dV}{dr} \times \frac{dr}{dt}$ $\frac{dV}{dt} = 4\pi r^2 \times 1.5 = 6\pi r^2$ The value of $\frac{dV}{dt}$ when r = 30 cm is: $\frac{dV}{dt} = 6\pi(30)^2 = 5400\pi$ **Conclusion** This means the rate of change of the sphere's volume with respect to time when r = 30 cm is $5400\pi\ {cm^3}/{s}$

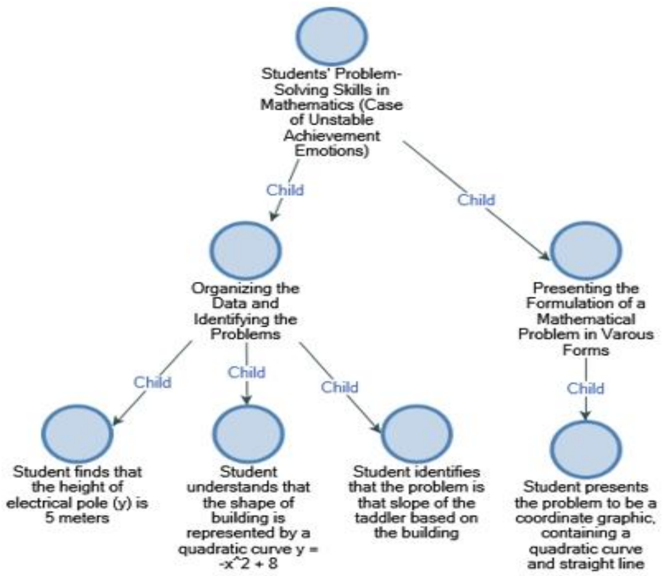


Figure 4. Student's mathematical problem-solving skills in the first problem (Source: Authors' own elaboration)

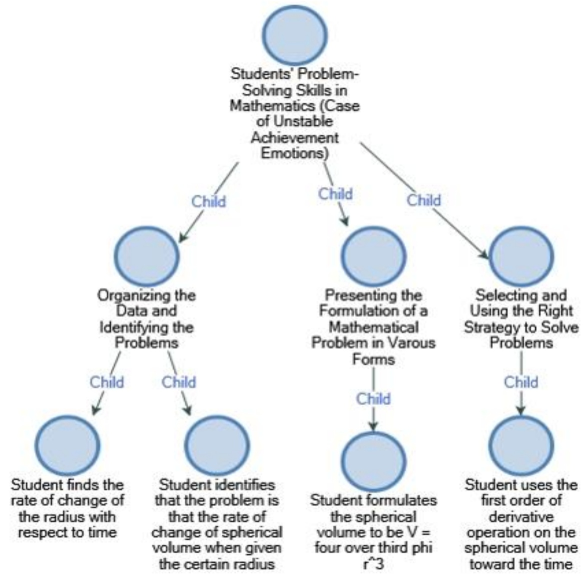
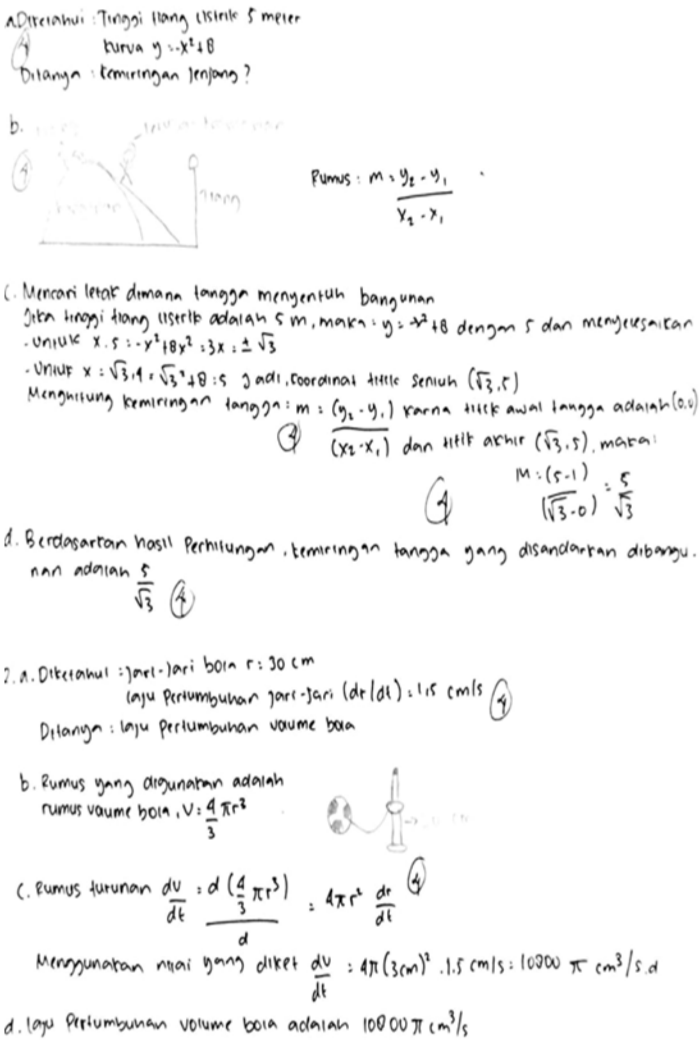


Figure 5. Student's mathematical problem-solving skills in the second problem (Source: Authors' own elaboration)

Table 9. Student's work in the first and second problem (case of unstable achievement emotion)

Indonesian Version	English Version
 a. Diketahui : Tinggi tiang listrik 5 meter kurva $y = -x^2 + 8$ Ditanya : kemiringan jenjang ? b. Rumus : $m = \frac{y_2 - y_1}{x_2 - x_1}$ c. Mencari letak dimana tangga menyentuh bangunan Jika tinggi tiang listrik adalah 5 m, maka : $y = -x^2 + 8$ dengan 5 dan menyelesaikan - Untuk $x . 5 = -x^2 + 8x^2 = 3x = \pm\sqrt{3}$ - Untuk $x = \sqrt{3}, 4 = \sqrt{3}^2 + 8 = 5$ Jadi, coordinat titik sentuh $(\sqrt{3}, 5)$ Menghitung kemiringan tangga : $m = \frac{(y_2 - y_1)}{(x_2 - x_1)}$ karna titik awal tangga adalah (0,0) dan titik akhir $(\sqrt{3}, 5)$, maka : $M = \frac{(5-1)}{(\sqrt{3}-0)} = \frac{5}{\sqrt{3}}$ d. Berdasarkan hasil perhitungan, kemiringan tangga yang disandarkan dibangunan adalah $\frac{5}{\sqrt{3}}$ 2. a. Diketahui : Jari-Jari bola r = 30 cm laju pertumbuhan jari-jari (dr/dt) = 1.5 cm/s Ditanya : laju pertumbuhan vaume bola b. Rumus yang digunakan adalah rumus vaume bola, $V = \frac{4}{3}\pi r^3$ c. Rumus turunan $\frac{dV}{dt} = \frac{d(\frac{4}{3}\pi r^3)}{d} = 4\pi r^2 \frac{dr}{dt}$ Menggunakan nilai yang diket $\frac{dV}{dt} = 4\pi(3cm)^2 . 1.5\ cm/s = 10000\pi\ cm^3/s.d$ d. laju pertumbuhan volume bola adalah $10000\pi\ cm^3/s$	**The First Problem** Given: -The height of the electrical pole is 5 meters -The curve is $y = -x^2 + 8$ Questions: What is the slope of the ladder? Formula for slope $$m = \frac{y_2 - y_1}{x_2 - x_1}$$ Steps to determine where the ladder touches the building: When the heigh of the electric pole is 5 meters, substitute $y = 5$ into $y = -x^2 + 8$, $5 = -x^2 + 8$ $x^2 - 3 = 0$ $(x + \sqrt{3})(x - \sqrt{3}) = 0$ $x = \sqrt{3}$ or $x = -\sqrt{3}$ Since the position of the ladder is in the first quadrant, $x = \sqrt{3}$. The coordinate of the point of contact are $(\sqrt{3}, 5)$. Calculating the slope (m) of the ladder: The ladder's starting point is (0,0), and the endpoint of the ladder on the curve is $(\sqrt{3}, 5)$. Using the slope formula: $$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{5 - 0}{\sqrt{3} - 0} = \frac{5}{\sqrt{3}}$$ Conclusion Based on the calculation, the slope of the ladder resting on the building is $\frac{5}{\sqrt{3}}$. **The Second Problem** Given: -The radius of the sphere (r) is 30 cm -The rate of change of the radius is $\frac{dr}{dt} = 1.5\ cm/s$ Question What is the rate of change of the sphere's volume? Formula used: The formula for the volume of a sphere: $$V = \frac{4}{3}\pi r^3$$ Derivative formula: Differentiating the volume with respect to time: $$\frac{dV}{dt} = \frac{d}{dt}\left(\frac{4}{3}\pi r^3\right) = 4\pi r^2 \times \frac{dr}{dt}$$ Substituting the known values: $$\frac{dV}{dt} = 4\pi(3)^2 \times 1.5 = 1000\pi\ cm^3/s$$ Conclusion The rate of change of the sphere's volume is $1000\pi\ cm^3/s$

These abilities are critical in mathematics as they reflect the hierarchical and interconnected nature of mathematical reasoning (Pekrun et al., 2017). The findings are further supported by significant F-values and high partial eta-squared values, particularly for tasks like generalizing solved problems (F = 49.167, η2 = 0.785) and overall problem-solving skills (F = 59.196, η2 = 0.814), which underscore the importance of emotional states in academic performance. Students with stable emotional states showed moderate problem-solving skills, implying that consistent emotional states are beneficial but not as impactful as the active increase of positive emotions. Conversely, students experiencing a decline in positive emotions or an increase in negative emotions exhibited significantly lower performance across all problem-solving indicators. This disparity suggests that negative emotions might hinder the cognitive processes essential for mathematical problem-solving, such as working memory and attention (Muis et al., 2015; Tornare et al., 2015). Moreover, the results indicate that fluctuations in emotions directly affect problem-solving efficiency, emphasizing the need for emotional regulation in academic settings (Di Leo et al., 2019).

Pearson correlation analysis demonstrates a strong relationship between students' problem-solving skills and their emotional changes. Positive emotions, such as enjoyment and interest, are positively correlated with problem-solving indicators, with coefficients ranging from $r = 0.624$ for selecting the right approach to $r = 0.766$ for solving problems. These findings suggest that positive emotions enhance students' motivation and cognitive engagement, leading to improved mathematical performance (Winberg et al., 2014). The total correlation ($r = 0.726$) reinforces the notion that positive emotional changes are critical to achieving high problem-solving proficiency. On the other hand, negative emotions, such as anxiety and frustration, are negatively correlated with problem-solving skills, with coefficients ranging from $r = -0.560$ for presenting formulations to $r = -0.674$ for solving problems. These results highlight the detrimental impact of negative emotions on cognitive performance, particularly in tasks requiring complex reasoning and sustained attention (Greensfeld & Deutsch, 2022). The overall negative correlation ($r = -0.650$) confirms that reducing negative emotional experiences is equally important for enhancing mathematical problem-solving abilities. These findings emphasize the dual role of emotions in either facilitating or impeding academic success. Positive emotions act as enablers of deeper cognitive processing and resilience, while negative emotions can obstruct problem-solving by increasing cognitive load and reducing working memory capacity (Pekrun & Linnenbrink-Garcia, 2012). Interventions aimed at promoting positive emotions and reducing anxiety, such as mindfulness practices and adaptive feedback, could be particularly effective in supporting students' problem-solving skills. Consequently, addressing both positive and negative emotional dynamics is essential for fostering academic success in mathematics.

The study's findings underscore the critical role of achieving emotions, including both positive and negative emotions, as predictors of students' problem-solving skills in mathematics. Positive emotions, such as enjoyment and pride, have been shown to enhance intrinsic motivation and self-efficacy, which are essential for effective problem-solving (de Corte et al., 2011). The strong correlations observed between positive emotions and problem-solving skills highlight the potential of these emotions to drive academic achievement. Moreover, students experiencing a positive shift in emotions are better equipped to handle complex mathematical tasks, as positive emotions broaden cognitive flexibility and foster creative thinking (Zhou, 2013). Conversely, negative emotions, such as anxiety, act as significant barriers to academic success. These emotions often trigger avoidance behaviors and decrease persistence, leading to lower problem-solving performance. The observed negative correlations suggest that as negative emotions increase, students' cognitive resources are diverted towards emotion regulation rather than task execution (Passolunghi et al., 2019). Thus, reducing negative emotions through targeted interventions is critical for improving mathematical achievement. Overall, the findings align with the control-value theory of achievement emotions, which posits that emotions significantly influence learning outcomes by shaping motivation, attention, and cognitive processes (Pekrun, 2006). Effective strategies for fostering positive emotions include creating mastery-oriented learning environments, using praise to reinforce effort, and providing opportunities for collaborative problem-solving. Similarly, addressing negative emotions requires strategies such as anxiety-reduction workshops, goal setting, and encouraging a growth mindset (Villavicencio & Bernardo, 2015). By integrating emotional regulation techniques into instructional design, educators can significantly enhance students' problem-solving abilities and overall academic success in mathematics.

The Achievement of Students' Problem-Solving Skills in Mathematics Referring to the Stability of Achievement Emotions

The results highlight that student who experienced stable achievement emotions-characterized by an increase in positive emotions and a decrease in negative emotions-demonstrated high levels of proficiency across all indicators of problem-solving skills in mathematics, particularly in the derivative topic. In the first problem, such students excelled in organizing data, presenting formulations, selecting the correct approach, solving problems, and generalizing solved problems. For example, as shown in **Figure 2** and **Table 5**, a student successfully calculated the slope of a ladder leaning on a curved building by accurately differentiating the curve equation and substituting the coordinates to determine the slope. This thorough problem-solving process exemplifies the link between emotional stability and cognitive performance in mathematics (Pekrun et al., 2017). Similarly, in the second problem, students derived the rate of change of a sphere's volume using proper differentiation techniques and chain rule applications, as outlined in **Figure 3** and **Table 6**. Stable achievement emotions provide a supportive cognitive environment, allowing students to focus, engage with the problem systematically, and persist through challenges

(Abdullah et al., 2022). Positive emotions such as curiosity and satisfaction bolster intrinsic motivation, enabling students to actively explore and internalize mathematical concepts (Winberg et al., 2014). Conversely, the decrease in negative emotions minimizes distractions and cognitive interference, such as test anxiety, which can impair problem-solving abilities (Greensfeld & Deutsch, 2022). The results affirm that the consistent interplay of rising positive emotions and diminishing negative emotions optimizes problem-solving efficacy, supporting theories that link emotional regulation to academic achievement.

These findings underscore the necessity for educators to foster stable achievement emotions in classrooms. Strategies such as integrating collaborative learning, encouraging constructive feedback, and incorporating mindfulness practices can enhance emotional regulation and problem-solving outcomes. By fostering an emotionally supportive learning environment, educators can empower students to achieve comprehensive proficiency in mathematics, especially in complex topics like derivatives (Suparman et al., 2024).

Meanwhile, student experiencing unstable achievement emotions, marked by a decrease in positive emotions and an increase in negative emotions, displayed limited problem-solving capabilities. As shown in **Figure 4** and **Figure 5**, such students could only achieve between two and three problem-solving indicators.

For the first problem, as documented in **Table 7**, these students managed to organize the data and present the formulation but struggled to select the appropriate approach, solve the problem effectively, or generalize solutions. For example, while they correctly identified the coordinates where the ladder meets the curve, they incorrectly calculated the slope using incomplete differentiation steps, leading to suboptimal results.

In the second problem, students with unstable emotions demonstrated similar limitations. Although they correctly organized given data and presented formulations, they faltered when applying the chain rule to calculate the rate of change of the sphere's volume. Their partial success can be attributed to the inhibitory effects of heightened negative emotions, such as anxiety and frustration, which compromise working memory and attention (Passolunghi et al., 2019).

Furthermore, the decline in positive emotions reduces persistence and curiosity, leading to premature disengagement from problem-solving tasks (de Corte et al., 2011). The poor performance of these students highlights the adverse impact of emotional instability on mathematical cognition. Negative emotions create a cognitive load that interferes with logical reasoning and error detection, while a lack of positive reinforcement diminishes students' motivation to tackle challenging problems. These findings align with research suggesting that emotional instability is a significant predictor of underachievement in mathematics (Pekrun, 2006). To mitigate these effects, interventions such as anxiety-reduction workshops, goal setting, and fostering a growth mindset can help stabilize achievement emotions and improve students' mathematical proficiency (Putwain et al., 2021).

The qualitative findings demonstrate a clear relationship between students' mathematical problem-solving skills and the stability of their achievement emotions. Students with stable achievement emotions consistently outperformed their peers, achieving all problem-solving indicators, as observed in their ability to generalize solutions and make connections between problems. This suggests that stable emotions are essential for accessing higher-order cognitive functions, such as abstraction and generalization, which are integral to solving complex mathematical problems (Putwain & Wood, 2023). In contrast, students with unstable emotions displayed fragmented problem-solving skills, often failing to progress beyond data organization and basic formulation, highlighting the detrimental effects of emotional instability on cognitive engagement. The grounded theory approach emphasizes that emotional stability acts as a crucial mediator of mathematical performance. Positive emotions foster a state of cognitive readiness, enhancing students' ability to navigate challenging problems and maintain resilience in the face of difficulties (Alcaraz-Muñoz et al., 2020). Conversely, the increase in negative emotions disrupts cognitive processing by narrowing students' attention and inducing avoidance behaviors, which undermine problem-solving outcomes (Basarkod et al., 2023). These observations align with the control-value theory of achievement emotions, which posits that emotions significantly influence students' engagement, persistence, and academic success (Pekrun et al., 2023b). These findings extend to classroom practices, where fostering emotional stability should be prioritized as part of instructional strategies.

Implications to the Field of Mathematics Education

The findings of this study provide critical theoretical contributions to understanding the role of achieving emotions in mathematics education, particularly in problem-solving contexts. By highlighting the significance of stable achievement emotions-characterized by increasing positive emotions and decreasing negative emotions-the study supports and extends the control-value theory of achievement emotions (Pekrun et al., 2023b). This theory posits that emotions influence cognitive engagement, motivation, and academic performance, which is reinforced by the observed link between emotional stability and mathematical problem-solving proficiency. Moreover, the study emphasizes the interplay between cognitive and emotional domains, suggesting that effective problem-solving requires not only cognitive strategies but also emotional regulation skills. This aligns with Fredrickson's broaden-and-build theory, which proposes that positive emotions enhance cognitive flexibility and creativity, which is critical for solving complex mathematical problems. Additionally, the findings provide evidence for integrating emotional factors into mathematical learning models, underscoring the need for an expanded framework that includes emotional stability as a determinant of academic success. These insights advance theoretical discussions about the multifaceted nature of mathematical problem-solving, bridging gaps between emotional and cognitive perspectives in educational research. Furthermore, the findings suggest that emotional dynamics influence not only immediate problem-solving outcomes but also the long-term development of mathematical reasoning and resilience. By focusing on the derivative topic as a complex cognitive task, this study underscores the importance of analyzing domain-specific emotional impacts. Overall, this research highlights the necessity of reconceptualizing mathematics education theories to include emotions as pivotal components of learning processes.

The study's findings offer valuable practical implications for improving instructional practices and fostering emotional well-being in mathematics education. First, educators should prioritize creating emotionally supportive learning environments that promote positive emotions such as curiosity, enjoyment, and confidence while reducing negative emotions like anxiety and frustration. Strategies such as collaborative learning, gamification, and mindfulness practices can help stabilize students' achievement emotions, thereby enhancing their problem-solving skills. Teachers can also incorporate reflective exercises, such as emotional journaling during problem-solving tasks, to help students develop self-awareness and emotional regulation skills. Providing immediate and constructive feedback can further strengthen students' confidence and intrinsic motivation to engage with challenging mathematical concepts. Moreover, integrating emotional education into mathematics curricula can equip students with tools to manage their emotions, fostering resilience and persistence in problem-solving. The study also calls for targeted interventions for students with unstable achievement emotions, such as anxiety-reduction programs and fostering a growth mindset through goal setting and encouragement. Professional development programs for teachers should include training on recognizing and addressing students' emotional states during lessons. Finally, education policymakers should consider incorporating emotional well-being metrics into evaluations of teaching effectiveness and curriculum design. By addressing both cognitive and emotional aspects of learning, these practical applications can improve students' overall mathematical performance and long-term academic success.

LIMITATIONS AND SUGGESTIONS

This study, while providing valuable insights into the relationship between achievement emotions and problem-solving skills in mathematics, has several limitations that should be acknowledged. First, the sample size and scope of participants were not specified, which may limit the generalizability of the findings to diverse student populations. Future studies should aim to include larger and more diverse samples to examine whether the observed relationships are held across different age groups, cultural contexts, and levels of mathematical proficiency. Second, the study focused solely on the derivative topic, which, while complex, may not fully represent the broad spectrum of mathematical problem-solving skills. Expanding future research to include other mathematical topics, such as algebra or geometry, could provide a more comprehensive understanding of how emotions influence problem-solving.

Additionally, this study employed a qualitative grounded theory design, which provides in-depth insights but lacks the robustness of mixed methods approaches for validating findings. Future research should combine qualitative and quantitative methods to triangulate data and strengthen the validity of emotional-cognitive correlations. The reliance on self-reported data regarding emotions is another limitation, as students may inaccurately recall or express their emotional states. Employing physiological measures, such as heart rate variability or skin conductance, alongside self-reports could enhance the accuracy of emotional assessments. Moreover, the study did not account for external factors, such as classroom environment or teacher behavior, which may influence students' emotions during problem-solving. Future studies should control these variables to isolate the specific impact of achievement emotions on mathematical performance.

Finally, the cross-sectional nature of the study limits its ability to infer causal relationships between emotional stability and problem-solving skills. Longitudinal designs are suggested for future research to examine how changes in emotions over time impact the development of mathematical skills. The study also did not explore individual differences in emotional regulation strategies, which could moderate the relationship between emotions and problem-solving. Future research could investigate the role of personality traits, such as grit or resilience, in shaping these dynamics. By addressing these limitations, future studies can provide a deeper and more nuanced understanding of the interplay between emotions and cognitive performance in mathematics education.

CONCLUSION

This study demonstrates the integral role of achievement emotions in influencing students' problem-solving skills in mathematics, combining insights from both quantitative and qualitative analyses. Quantitatively, the findings reveal that positive emotions are significantly positively correlated with all indicators of problem-solving skills, while negative emotions are significantly negatively correlated. The one-way MANOVA results further highlight that students with increased positive emotions and decreased negative emotions excel in problem-solving tasks, achieving higher scores across all indicators such as organizing data, selecting the right approach, and generalizing solutions. Qualitative findings corroborate these results, showing that students with stable achievement emotions consistently demonstrated comprehensive problem-solving skills in derivative problems, while those with unstable emotions achieved limited success.

These results underscore the dual impact of emotions, where positive emotions enhance cognitive engagement and persistence, while negative emotions hinder problem-solving by increasing cognitive load. The integration of quantitative and qualitative evidence strengthens the theoretical understanding of how emotional stability fosters mathematical proficiency. Practically, these findings emphasize the importance of fostering supportive learning environments and implementing interventions that regulate emotions to optimize problem-solving performance. Future research should explore these dynamics across broader mathematical topics and diverse student populations to enhance generalizability. Overall, this study highlights the necessity of addressing both cognitive and emotional factors in mathematics education to cultivate well-rounded problem-solving capabilities.

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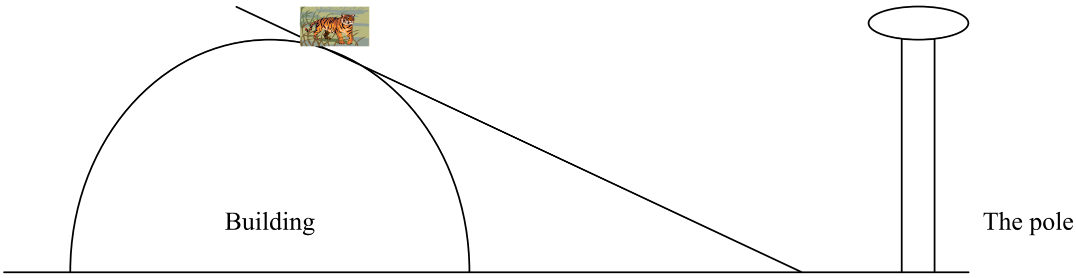
APPENDIX A

Table 1a. Test of problem-solving skills in mathematics

No	Problems
1	A security officer wants to save a cat trapped in a building (See the Figure). He climbs a ladder leaning against the building.  When taking the cat, he notices that his position is at the same height as an electric pole next to the building. If the height of the electric pole is 5 meters and the surface of the building is shaped like the curve $y = -x^2 + 8$, determine the slope of the ladder by answering the following questions: a) What information is known and asked in the question? b) Create a sketch of the situation and determine the formula that will be used to solve this problem. c) Solve the problem using the selected formula. Based on the results obtained, what conclusion can you draw?
2	Randi is inflating a soccer ball. He observes that the radius of the ball increases at a rate of 1.5 cm per second. When the radius of the ball is 30 cm, determine the rate of change of the ball's volume with respect to time by answering the following questions: (a) What information is known and asked in the question? (b) Create a sketch of the situation and determine the formula that will be used to solve this problem. (c) Solve the problem using the selected formula. Based on the results obtained, what conclusion can you draw?

APPENDIX B

Table 1b. Achievement Emotions Questionnaire in Mathematics (AEQ-M)

Full Name:
Age:
Gender:
Class:
School:

Instructions for Filling Out the Questionnaire

1) This achievement emotion questionnaire consists of ten components: enjoyment, pride, hope, satisfaction, relaxation, anger, anxiety, shame, hopelessness, and boredom.
2) Each statement for all components can be rated on a scale of 1–5, with each scale described as follows:
   (1) = Strongly Disagree
   (2) = Disagree
   (3) = Neutral
   (4) = Agree
   (5) = Strongly Agree
3) Select one scale from 1–5 for each statement by marking a checkmark (✓) in the space provided.
4) Fill out this questionnaire as truthfully as possible to reflect the achievement emotions you experience or feel during mathematical activities, such as attending math classes, doing math homework, or taking math tests.

Table 2b. Achievement Emotions in Solving Mathematical Problems

No	Statement	Scale				
		1	2	3	4	5
1	I enjoy taking math tests					
2	I study hard for math tests to get good grades					
3	I smile with joy when a math test goes well					
4	I feel proud of myself after a math test					
5	I feel proud of how well I performed on a math test					
6	I want to tear the math test paper into pieces					
7	I feel upset because the teacher asked difficult questions on the math test					
8	I feel tense and nervous while taking a math test					
9	I can not fully concentrate during a math test because of anxiety					
10	I worry about getting a bad grade while taking a math test					
11	I worry about failing before the math test even starts					
12	I choose not to take the math test because I feel very anxious					
13	I feel nauseous about the upcoming math test					
14	I feel ashamed after taking the math test					
15	I start sweating because my performance on the math test makes me feel embarrassed					
16	I feel hopeless during the math test					
17	I keep thinking I will never get a good grade in math tests					
18	I find math tests very boring					
19	I don't care much about the given math test because it's boring					
20	I hope to solve math problems successfully during the test					
21	I keep thinking I will get a good grade on the math test					
22	I feel satisfied completing the math test independently					
23	I fell satisfied doing the math test to best of my ability					
24	I feel calm while taking the math test					
25	I feel more relaxed when the math test is going well					