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The Relationship between Cognitive Flexibility and Mathematical Literacy: Insights from Indonesian Elementary Students

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Abstract

This study investigates the relationship between mathematical literacy and cognitive flexibility in solving complex problems among Indonesian elementary school students aged 9–10 $n = 78$. Utilizing a mixed-methods approach, the research combined quantitative testing and qualitative interviews to provide a comprehensive understanding of this relationship. The findings indicate that students with higher levels of both literacy and flexibility performed significantly better in problem-solving. However, students with high flexibility but low literacy struggled to grasp mathematical concepts while those with high literacy but low flexibility showed rigid problem-solving approaches. Despite these differences, all students demonstrated potential for improvement with adequate teacher support. These results emphasize the importance of tailored educational strategies to enhance both mathematical literacy and cognitive flexibility especially in developing countries like Indonesia.

Keywords:

Cognitive Flexibility, Mathematical Literacy, Problem-Solving Skills

Introduction

Mathematical problem-solving and reading difficulties throughout childhood have significant long-term effects on educational achievement, income wealth and health outcomes in adulthood (Baumann et al., 2024). Therefore, concerns over mathematical literacy have been growing considerably (Baumann et al., 2024; Cordova Jr et al., 2024; Sitopu et al., 2024; Ureña et al., 2024). In today's culture there is an increasing need for individuals to possess the ability to comprehend and analyze mathematical concepts to effectively apply knowledge. The application of mathematical literacy in understanding mathematical concepts requires more than just knowledge of "school" mathematics (Abbas et al., 2024).

Besides mathematical literacy, cognitive flexibility is also crucial in mathematics learning. Learners need cognitive flexibility to navigate life challenges in the information age. Prior studies have investigated cognitive flexibility of elementary school students (Rahayuningsih et al., 2020), devised open-ended tools to examine students' cognitive flexibility (Rahayuningsih et al., 2021) and examined the cognitive flexibility of prospective teachers in conducting learning during the COVID-19 pandemic (Muzaini et al., 2021). Other research explored the relationship between elementary school students' cognitive flexibility and self-efficacy and scrutinized cognitive flexibility in relation to geometrical figure apprehension with the help of new auxiliary elements (Muzaini et al., 2023). However previous studies have predominantly examined cognitive flexibility and mathematical literacy as separate constructs. The interplay between these two cognitive attributes remains unexplored particularly in the Indonesian context where mathematical literacy continues to pose significant challenges. This is evidenced by consistently low PISA scores in mathematics highlighting a critical need for interventions to enhance both mathematical literacy and cognitive flexibility among Indonesian students (Stacey et al., 2011; Fadlila et al., 2021; Machromah et al., 2020). This study aims to address this gap by examining the relationship between cognitive flexibility and mathematical literacy providing insights to inform educational practices in Indonesia.

Past studies have not yet investigated the correlation between cognitive flexibility and the mathematical literacy of elementary school students. Hence, it is imperative to conduct a new study to demonstrate diverse attributes of students' cognitive abilities in comprehending intricate mathematical concepts. To address the issue, the current study was conducted to reveal the correlation between elementary school students' cognitive flexibility and mathematical literacy using literacy-based problem-solving tasks. This study answered two research questions as follows:

- What is the correlation between elementary students' cognitive flexibility and mathematical literacy?
- What are the attributes of students' cognitive flexibility when addressing mathematics problems that involve literacy?

Literature Review

Cognitive Flexibility

Working memory capacity (WMC) helps to keep cognitive processes memory and attention organized based on information relevant to the task at hand (Awh & Vogel, 2008; Conway et al., 2001). WMC differences enable multiple and varied cognitive abilities (Gruszka & Nęcka, 2017; Hambrick & Meinz, 2011; Hicks et al., 2015). Individuals with higher WMC have greater fluid intelligence which is the ability to solve new reasoning problems (Kane et al., 2005). They also exhibit superior ability to execute intricate cognitively challenging procedures in comparison to those with lower working memory capacity (Barrett et al., 2004; Thomassin et al., 2015). An individual with a larger WMC is more adept at adapting to new tasks and can modify their cognitive framework more effectively (Colflesh & Conway, 2007; Rummel & Boywitt, 2014; Weldon et al., 2013) which is a characteristic of cognitive flexibility (Ionescu, 2012).

Cognitive flexibility is the capacity to adapt one's work methods to changing task requirements (Pelczer et al., 2013). Cognitive flexibility can be understood through the lens of three main constructs: cognitive variety, cognitive novelty and change in cognitive framing (Furr, 2009; Spiro et al., 1992). Cognitive variety is the diversity of problem-solving thinking patterns in a group (Eisenhardt et al., 2010) or the diversity of cognitive patterns or views (Furr, 2009). Cognitive novelty relates to ideas connected to learning content and students' overall mastery of the content (Orion & Hofstein, 1994) or the addition of an external perspective (Furr, 2009). Change in cognitive framing is a phenomenon that may occur from the influence of an external perspective such as previous contextual experience. Cognitive framing attempts to address new problems using previously used solutions (Goncalo et al., 2010). Cognitive flexibility is a viable alternative for identifying specific qualities of high achieving mathematical creative abilities for the reasons outlined above. In this research, students' mathematical cognitive flexibility was measured using indicators of cognitive variety, cognitive novelty and change in cognitive framing. Figure 1 presents the indicators used to examine students' mathematical cognitive flexibility, adopted from Rahayuningsih (2023).

Table 1
Indicators of mathematical cognitive flexibility Rahayuningsih et al. (2023)

No	Indicators of mathematical creative thinking ability	Operational Definition
1	Cognitive novelty	Find new strategies for solving a problem. Display a new mindset
2	Cognitive variety	Plan and use various resolution strategies when faced with complex problems and deadlocks. Change the problem-solving strategy when faced with deadlocks Think of different ways to solve the problem. Provide a variety of ways to solve the problem
3	Cognitive framing	Take detailed steps to find a deeper meaning for the answer or solution to the problem.

Mathematical Literacy

To address the 21st century needs, learners need to improve their literacy skills (Haara et al., 2017; Hayati & Kamid, 2019; Manfreda et al., 2021). Mathematical literacy refers to an individual's capacity to utilize mathematical concepts, methods, facts and instruments to describe explain and predict a phenomenon (Slyamkhan et al., 2022). When it comes to learning particularly mathematics learning, the desired outcome for pupils is not only to possess the ability to count but also to use mathematical concepts in addressing real-life issues.

Mathematical literacy plays a critical role in education as it helps students develop the ability to analyze, justify and express creative solutions to problems in various situations and contexts (Liu et al., 2018). The problem-solving process in mathematical literacy goes beyond routine mathematical tasks encompassing the resolution of contextual problems. Context-based exemplary problems can stimulate students to acquire knowledge, enhance perseverance and foster creativity in finding appropriate problem-solving strategies.

Moreover, research highlights a strong relationship between mathematical literacy and cognitive flexibility, a core executive function that refers to the ability to adapt to varying tasks perspectives or rules when solving problems. According to Magalhães et al. (2020), cognitive flexibility significantly contributes to academic achievement particularly in literacy and mathematics even after controlling for variables such as fluid intelligence inhibitory control working memory and planning. This suggests that students with strong cognitive flexibility skills are better equipped to comprehend and apply mathematics across different contexts.

Cognitive flexibility enables students to switch focus between different dimensions of mathematical problems, integrate new information, and apply adaptive problem-solving strategies. This capability is crucial for mathematical literacy as it allows students to:

1. Formulate Problems: Transform real-world situations into mathematically relevant representations.

2. Apply Mathematical Concepts: Flexibly utilize mathematical procedures and concepts to derive solutions.

3. Interpret Results: Relate mathematical outcomes back to the original problem context.

The development of mathematical literacy and cognitive flexibility is interconnected and mutually reinforcing. Cognitive flexibility enhances students' ability to tackle complex problems and make decisions in dynamic contexts a skill essential for mathematical literacy (Diamond, 2013). Magalhães et al. (2020) further emphasize that the impact of cognitive flexibility becomes more pronounced in older students, grades 4 and 6, compared to younger ones. This underscores the growing reliance on advanced executive functions as tasks in mathematical literacy increase in complexity.

Methods

Design and Research Setting

This study employed an exploratory mixed methods research design as described by Vimala Judy Kamalodeen (2016). This approach was selected to comprehensively explore the correlation between mathematical literacy and cognitive flexibility as well as to examine students' cognitive traits when solving literacy-based mathematical problems. The exploratory mixed methods design combines quantitative and qualitative data collection and analysis enabling a nuanced understanding of the relationship between the two variables.

The research was conducted sequentially over a period of 12 months from January to December in five public elementary schools located in Malang Indonesia. At the start of the school term, mathematical literacy and cognitive flexibility tasks were distributed to assess the abilities of the participants. A 4-week observation period was conducted to evaluate students' engagement and clarify task comprehension. The quantitative phase of the study analyzed test scores to establish the relationship between mathematical literacy and cognitive flexibility. In the qualitative phase, interviews were conducted with 14 students representing four categories of cognitive and mathematical literacy profiles: TT High Cognitive Flexibility and High Mathematical Literacy; TR High Cognitive Flexibility and Low Mathematical Literacy; RT Low Cognitive Flexibility and High Mathematical Literacy and RR Low Cognitive Flexibility and Low Mathematical Literacy. This sequential design ensured a robust examination of trends within each group while integrating the findings from both quantitative and qualitative data.

Participants

A total of 78 elementary school students aged 9–10 years were purposively selected as participants. These students represented a diverse socioeconomic background from five public schools in Malang. Inclusion criteria ensured that all participants possessed basic reading and arithmetic skills necessary for engaging with the literacy-based mathematical tasks. Exclusion criteria included students with cognitive impairments or significant learning difficulties as identified by their teachers. For the qualitative phase 14 participants were selected based on their test performance to represent each of the four cognitive and mathematical literacy categories TT TR RT RR. Demographic data including gender, age, socioeconomic status, family income, parental occupation and education and religion were also collected to contextualize the analysis.

Data Collection

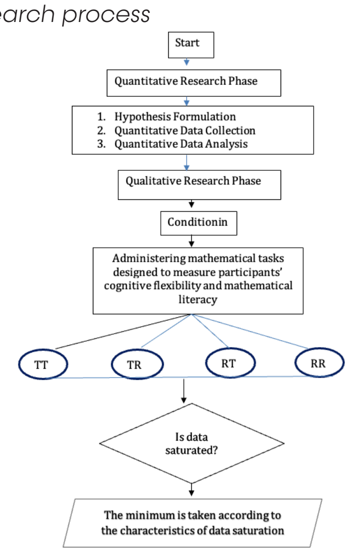
The study utilized four mathematical tasks to assess students' mathematical literacy and four cognitive flexibility tasks to measure their adaptive thinking capabilities. These tasks were distributed during a structured classroom session under the supervision of trained proctors. The tasks were designed to capture both problem-solving accuracy and the strategies employed by students.

1. Mathematical Literacy Tasks
   The mathematical literacy tasks emphasized real-world problem-solving, requiring students to interpret data and apply mathematical concepts. For example: Calculating the number of trees in a park based on given percentages; Determining the volume of water needed to fill a swimming pool; Estimating travel time between two cities based on a map scale and a given speed; Interpreting a bar chart to draw conclusions about students' interest in mathematics at different schools.

2. Cognitive Flexibility Tasks
   The cognitive flexibility tasks challenged students to adapt strategies and think creatively. Examples include: Developing a strategy to win a mathematical game with specified rules; Exploring multiple methods to calculate areas of geometric shapes; Solving a logical problem involving prime numbers; Analyzing height-weight data to create and interpret graphs; The sessions were supplemented with video recordings and interview transcripts to document the students' problem-solving approaches and rationale.

Figura 1.

Flowchart of the exploratory mixed methods research design research process



Research Instruments

In this study two instruments were used: Test 1; 4 test items to measure mathematical literacy skills and Test 2; 4 test items to measure cognitive flexibility. All instruments are valid according to Matteson (2006). Relevant content has been evaluated by experts using content validation procedures (Yusoff, 2019), a common procedure for assessing validity (Huang et al., 2019). The reliability coefficient of the instruments was estimated using the Cronbach Alpha formula. This is the most common internal measure of consistency in social, behavioral and educational sciences and is usually interpreted as the average of all possible split-half coefficients (Mohajan, 2017). The tests were used to measure the subjects' mathematical literacy and cognitive flexibility. The mathematical literacy test consists of four items with a reliability coefficient of 0.59. The cognitive flexibility test also consists of four items with a reliability coefficient of 0.55.

Data collection was carried out by administering the tests to students. The students then completed the tests. Subsequently, the scores from both tests were analyzed using descriptive statistics; mean, mode, median and variance and inferential statistics. Descriptive statistics were used to describe the data while inferential statistics were used to determine whether there were significant differences in the effects of mathematical literacy skills on cognitive flexibility among students. Analysis was performed using the SPSS software package. One of the instruments used is presented below; for further details readers can refer to the appendix of this article.

Mathematical Literacy Tasks

- There are 200 trees in the park. 40% of the trees are mango trees, 30% are coconut trees, and the rest are other trees. How many other trees are there in the park?

- A rectangular swimming pool is 20 meters long and 15 meters wide. If the pool is to be filled with water to a depth of 1 meter, how many liters of water will be needed?

- On a map with a scale of 1:500,000, the distance between two cities is 4 cm. How long does it take to travel between the two cities at 60 km/hour?

- The number of students attending multiple institutions who have an affinity for mathematics subjects is represented in a bar chart. 60% of students attend School A, 50% attend School B, 40% attend School C, and 30% attend School D. Draw a conclusion regarding the interest of students in mathematics at each of the four institutions using this information.

Cognitive Flexibility Tasks

- In a math game, there are 10 cards with numbers 1 to 10. Two players take turns taking one card from the pile of cards. The player who first reaches a total value of 15 by adding up the values of the cards they take will be the winner. Make a strategy to win this game.

- In a geometric drawing, there are several triangles, rectangles, and circles. Calculate the total area of all the flat shapes in different ways.
- A number X is a positive odd number. If X is multiplied by 2 and subtracted by 3, the result is a prime even number. Find the value of X.
- In a data table, there is information about the height and weight of students in a class. Make a graph showing the relationship between the student's height and weight. Give an interpretation of the graph.

Two validated instruments were used to measure the study variables:

1. Mathematical Literacy Test: Consisted of 4 items with a reliability coefficient Cronbach Alpha of 0.59.
2. Cognitive Flexibility Test: Consisted of 4 items, measuring cognitive novelty, variety, and framing, with a reliability coefficient of 0.55.

The validation process involved expert reviews from two mathematics education specialists. They evaluated the content alignment with the curriculum the clarity of instructions and the relevance of the test items. Pilot testing on a small group of students n = 10 was conducted to refine the tasks further.

The scores from these instruments were analyzed using descriptive statistics; mean, mode ,median and variance and inferential statistics to examine the relationship between the variables. The analysis was performed using SPSS with normality and linearity tests confirming the suitability of the data for regression analysis. Results revealed a strong correlation between mathematical literacy and cognitive flexibility.

The research followed a systematic flow:

1. Quantitative Phase: Assessment of mathematical literacy and cognitive flexibility using structured tasks. Scores were analyzed statistically to establish correlations.
2. Qualitative Phase: In-depth interviews were conducted with selected participants to explore their cognitive traits and problem-solving strategies.

Integration: Findings from both phases were triangulated to provide a comprehensive understanding of students' abilities.

The mixed methods approach enabled the integration of quantitative results and qualitative insights, offering a detailed perspective on how mathematical literacy and cognitive flexibility interact in elementary school contexts.

Results

Quantitative Findings

Descriptive Statistics

Table 2
Descriptive Statistics of Participants' Mathematical Literacy

Statistical Data	Score
Mean	75.96
Median	80.00
Modus	90.00
Standard Deviation	12.48
Minimum	50.00
Maximum	90.00
Number of Samples	78

Mathematical Literacy Data Interpretation:

The statistical analysis in Table 2 revealed that the majority of students in the sample possessed commendable mathematical literacy, as indicated by a mean of 75.96. This finding suggested that these students already had the capacity to effectively adjust to unfamiliar circumstances, employ diverse problem-solving approaches, and demonstrate mathematical literacy when resolving mathematical issues. However, there existed a range of skill levels across pupils, as seen by a standard deviation of 12.48. A median score of 80.00 signified that 50% of the sample possessed skills that were superior to the norm, while the remaining 50% had abilities that were below average. Notably, a mode of 90.00 indicated the presence of a distinct cluster of individuals in the sample who possessed exceptional mathematical literacy.

Table 3
Descriptive Statistics of Participants' Cognitive Flexibility

Statistical Data	Score
Mean	84.81
Median	85.00
Modus	85.00
Standard Deviation	7.45
Minimum	70.00
Maximum	95.00
Number of Samples	78

Cognitive Flexibility Data Interpretation:

According to the descriptive statistics in Table 3, the average student in the sample demonstrated excellent

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mathematical cognitive flexibility, with a mean score of 84.81. This finding indicated that students in this study possessed a high level of proficiency in adjusting to unfamiliar circumstances, employing diverse problem-solving techniques, and demonstrating cognitive flexibility when tackling mathematical problems. The students in this sample demonstrated a high level of ability, as indicated by the median value of 85.00. This showed that half of the students possessed above average ability, while the other half had below average ability. Notably, the mode value of 85.00 indicated the presence of a substantial cluster of individuals in the sample who possessed exceptional mathematical cognitive flexibility. While there was some variance in students' cognitive flexibility, as evidenced by the standard deviation of 7.45, this variation was rather little when compared to the average ability. These findings indicated that most pupils in the sample demonstrated advanced mathematics cognitive flexibility skills.

Inferential Statistics

Table 4

Residual Normality Test Result

Data	P Sig	Conclusion
Mathematical literacy on cognitive flexibility	0.051	Normal

The Kolmogorov-Smirnov test was used to assess the normality of residuals in relation to participants' mathematical literacy and cognitive flexibility. The test result in Table 4 yielded a value of 0.051 indicating that the residual data for these two variables followed a normal distribution as Sig. was greater > than 0.05. Subsequently another statistical test was conducted. The linearity test was done to determine the presence of linearity between the two datasets.

Table 5

Linearity Test Result

Data	Deviation from Linearity
Mathematical literacy on cognitive flexibility	0.61

Table 5 shows that the deviation from linearity between mathematical literacy and cognitive flexibility was 0.61, exceeding the threshold of 0.05. The test result suggested a strong correlation between the participants' mathematical literacy and cognitive flexibility.

Table 6

R-Square Analysis Result

Data	R Square	Adjusted R Square
Mathematical literacy on cognitive flexibility	0.631	0.626

According to Table 6 the R-Square value was 0.631 or 63.1%. This figure indicated that 63.1% of the variation in cognitive flexibility dependent variable can be explained by mathematical literacy independent variable whereas the remaining variation was impacted by other variables not considered in the study. Based on the R-Square value it can be inferred that cognitive flexibility strongly affected the mathematical literacy of elementary school students as indicated by an R-Square value ranging from 0.600 to 0.799.

Table 7

Hypothesis Testing

Data	Constant	Regression Coefficient	P Sig.
Mathematical literacy and cognitive flexibility	48.802	0.474	0.000

According to Table 7 the constant value a was 48.802 suggesting that when mathematical literacy was zero the cognitive flexibility remained consistent at 48.802. The regression coefficient b was 0.474 indicating that a 1% improvement in mathematical literacy was associated with a 0.474 increase in cognitive flexibility. If plugged into the equation $Y = a + bx$ the equation $Y = 48.802 + 0.474x$ was obtained. The significance value was 0.000 showing that the alternative hypothesis H1 was accepted and the null hypothesis H0 was rejected as the significance value was less than 0.05. Therefore, it may be concluded that mathematical literacy had an impact on the cognitive flexibility of elementary school students.

Qualitative Findings

Students' cognitive characteristics are categorized into four groups namely: 1 individuals with both high cognitive flexibility and high mathematical literacy TT; 2 individuals with high cognitive flexibility but low mathematical literacy TR; 3 individuals with low cognitive flexibility but high mathematical literacy RT; 4 individuals with both low cognitive flexibility and low mathematical literacy RR. The following sections provide an account of the findings pertaining to each category of students' cognitive characteristics.

Individuals with both high cognitive flexibility and high mathematical literacy represented by TT

The qualitative data analysis results revealed intriguing findings concerning students' cognitive attributes when addressing mathematical literacy issues. These findings offer a more comprehensive understanding of students' cognitive processes and learning strategies when engaging in intricate tasks. A notable attribute is the students' ability to tackle difficulties in unconventional and inventive manners.

This demonstrates that these students possessed a strong capacity for cognitive flexibility and were unafraid to experiment with novel problem-solving strategies. Cognitive flexibility plays a crucial role in solving mathematical literacy problems, as these problems typically lack a single definitive solution. Consequently, students must identify the most suitable method for the situation. The following excerpts of interviews with research participants corroborate the findings.

Interview with Student 1:

Interviewer: "Can you tell me about how you solved math problem No. 1 while pointing at the question sheet yesterday?"

Students 1: "At first I tried using the method I used to apply in this situation, but it didn't work. Then I tried several other ways, and finally I found a new and easier way to solve it."

Interview with Student 2:

Interviewer: "What made you confident that your answer to question No. 1 was correct?" pointing to the question sheet

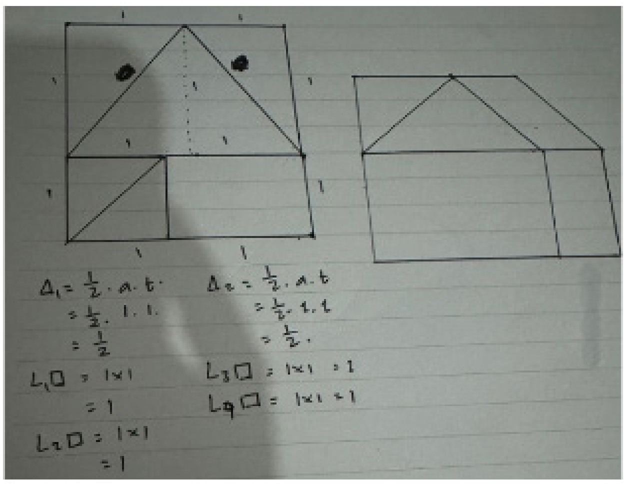
Student 2: "I was convinced it was correct because I've tried several different ways to solve it, and they all produced the same answer. Apart from that, I can also explain clearly how I got the answer."

Interview with a Mathematics Teacher:

Interviewer: " What do you think makes your students so creative in solving math problems?"

Teacher: "I think they are used to student-centered learning, where they are encouraged to try new ideas and learn from their mistakes. This helps them develop cognitive flexibility and the confidence to try unusual approaches to solving a problem in math."

Figure 2
Student worksheet



*Desp*ite employing diverse approaches, students in this study consistently exhibited a strong comprehension of the fundamental mathematical principles. This demonstrates that their creativity was not solely reliant on intuition but was also bolstered by extensive knowledge. A skilled problem solver is characterized by their capacity to effectively utilize information in many contexts. In addition to individual cognitive capacities, this investigation also demonstrated the significance of communication skills in resolving mathematical literacy problems. Participants who possessed the capability to elucidate their reasoning and methods in a coherent and organized fashion seemed to have commendable communication aptitude and the proficiency to express their concepts with efficacy. Proficiency in this skill is crucial for effective teamwork and cooperative learning, both of which play a significant role in the problem-solving process. The following sections contain interview excerpts and a student's work result to support the findings.

Interview with Student 4:

Interviewer: "Can you tell me about how you learned to solve math problems in a different way?"

Student 4: "I learn from my friends. When they do math problems in different ways, I try to understand it and apply it to other problems. I also like looking for online tutorials and watching YouTube videos about creative ways to solve math problems."

Interview with Student 5:

Interviewer: " Have you ever had difficulty solving math problems? How did you handle it?"

Student 5: " Yes of course. Sometimes I feel frustrated when I can't solve math problems the way I usually do. But I always try to find another solution. I usually ask my teacher or my friends, or I look for the information on the internet."

Mathematics Teachers:

Interview with Teacher 1:

Interviewer: "What do you think is the most important thing in mathematics instruction?"

Teacher 1: "In my opinion, mathematics instruction should help students develop critical and creative thinking skills. I want them to not only be able to solve math problems the right way, but also be able to understand the underlying concepts and apply their knowledge in different situations."

Interview with Teacher 2:

Interviewer: "How do you encourage your students to dare to try different ways of solving math problems?"

Teacher 2: " I provide them with open-ended math assignments, where students don't have just one correct answer. I also encourage them to collaborate with their friends and share ideas with each other. This helps them to learn from each other and develops their confidence to try new things.

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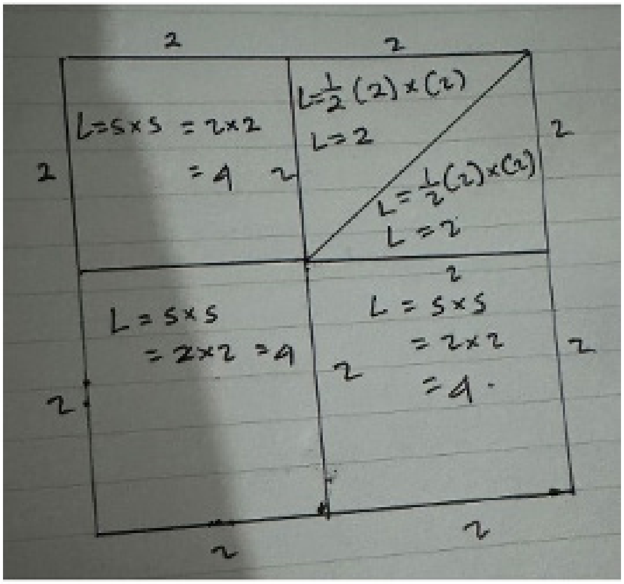
Figure 3
Student worksheet



Individuals with high cognitive flexibility but low mathematical literacy TR

Individuals in the TR group category exhibited strong abilities in adapting to new situations and using various strategies to solve mathematical problems. They possessed the ability to think creatively and come up with novel solutions. They also demonstrated a great level of cognitive flexibility when it came to thinking mathematically. Despite having a high degree of cognitive flexibility, students in the TR category nevertheless struggled to grasp basic mathematical ideas. They found some difficulties in making the connection between the fundamental principles and their problem-solving methods and knowledge as a result. They might therefore occasionally be unable to perform arithmetic problems correctly and consistently.

Interview with Student 7 Category TR:

Interview: "Can you tell us about how you solved math problem no. 4? I noticed you used a different method than most of your friends."

Student 7: "Yes, I like trying different ways to solve math problems. I think it's more interesting and challenging. Sometimes I find a way that is easier and faster than the usual way."

Interview: " Have you ever had difficulty solving math problems?"

Student 7: "Yes, sometimes I am confused by the concepts taught in class. I understand how to solve the problem, but I don't always understand why it works."

Interview: " How did you overcome these difficulties?"

Student 7: "Usually I ask my teacher or my friend who is smarter in mathematics. I also look for explanations on the internet or from math books."

Interview with Teacher:

Interview: "Can you describe the math skills possessed by the student named Reid using a pseudonym Student 7?"

Teacher: "Reid has a unique ability to solve mathematical problems. He always finds new and creative ways to solve problems. But he also often makes mistakes because he doesn't always understand the underlying concepts."

Interview: "What would you do to help Reid improve his understanding of math concepts?"

Teacher: " I would provide him with more varied math assignments, and I would also help him connect math concepts to concrete, real-life examples. I hope that this way he can understand mathematics better and reach his potential."

Students in the TR group exhibited variability in their ability to articulate their problem-solving strategies in mathematics. Certain pupils possessed the ability to express their thoughts coherently and methodically, whereas others struggled to communicate their ideas with proficiency. This demonstrates that their capacity for communication did not consistently align with their cognitive capacities. Students classified as TR typically had a diminished sense of self-assurance in their mathematical aptitude. This can be attributed to adverse learning experiences in the past or to their struggle in comprehending key mathematical ideas. A lack of self-assurance may impede their motivation to acquire mathematical knowledge and engage in problem-solving activities.

Interview with Student 8 Category TR:

Interviewer: " Can you explain how you solved problem number 3?"

Student 8: " I first tried ... , but it didn't work. Then I tried ... , and finally I found an easier way with ... ."

Interview with Student 9 Category TR:

Interviewer: "Can you explain why you chose this method to solve problem No. 4?"

Student 9: "I'm not sure, but I think this is the easiest and fastest way. I don't really understand the concepts used in this problem."

Interview with Student 10 Category TR:

Interviewer: "How do you feel about your math skills?"

Student 10: "I don't think I'm very good at math. I often make mistakes and don't always understand what is taught in class."

Interview with Student 11 Category TR:

Interviewer: " Do you like solving math problems?"

Student 11: "Not really. I feel frustrated when I can't solve math problems correctly. I'd rather do other easier subjects."

Individuals with low cognitive flexibility but high mathematical literacy RT

Several intriguing cognitive traits were discovered in pupils in the RT category, as indicated by the findings of the qualitative study. Students classified in the RT category exhibited a proficient comprehension of fundamental mathematical principles and possessed the ability to accurately employ mathematical terminology. They possessed the ability to carefully comprehend and analyze mathematical problems, effectively identifying pertinent information required to solve them. Although possessing a solid grasp of mathematical principles, students in the RT category struggled with adjusting to unfamiliar scenarios and devising innovative approaches to problem-solving. They exhibited a tendency to adhere to the ways they learned previously and encountered challenges in formulating novel strategies to tackle intricate problems.

Interviewer: "Can you try to explain how you would solve this problem? About 10 circles and triangles?"

Student 12: "Okay. First of all, I need to understand the information given in the problem. There are 10 circles arranged into 5 large triangles and 5 small triangles. Then, I need to know what the problem is asking about, namely the total number of triangles."

Interviewer: "How would you calculate the total number of triangles?"

Student 12: "I remember that the total number of triangles is the sum of the number of large triangles and the number of small triangles. So, I need to calculate the number separately."

Interviewer: "How do you count the number of large triangles and small triangles?"

Student 12: "From the information given in the problem, we know that there are 5 large triangles and 5 small triangles. So, the number of large triangles is 5 and the number of small triangles is 5."

Interviewer: "Good. Then, how do you get the total number of triangles?"

Student 12: "To get the total number of triangles, I need to add the number of large triangles and the number of small triangles. So, 5 large triangles + 5 small triangles = 10 total triangles."

Based on the interview excerpts it can be concluded that: 1) the student comprehended the concept of addition and the correlation between the quantity of large and small triangles and the total number of triangles; 2) the student could identify pertinent information in the problem specifically the number of circles large triangles and small triangles; 3) the student was focused on the learned addition method and did not attempt alternative problem-solving strategies and 4) the student was capable of articulating their reasoning and the sequential steps taken to solve the problem in a clear and organized manner.

Students classified as RT typically possessed proficient communication skills, especially in articulating their reasoning and strategies for resolving mathematical problems. They possessed the ability to express their views with clarity and organization and were capable of offering coherent justifications for their actions. Students in this category also had a strong sense of self-confidence in their capacity to solve mathematical issues, however they might require assistance in identifying the appropriate problem-solving. Although pupils in the RT group showed several restrictions, they demonstrated the capacity to enhance their mathematical skills. Their strong mathematical literacy is a valuable advantage that, with appropriate assistance, can facilitate their comprehension and acquisition of mathematical concepts.

Interviewer: "Can you tell me about what you see in this bar chart?"

Student 13: "This diagram shows the percentage of students in four schools who like mathematics. School A has the highest percentage, namely 60%, followed by School B with 50%, School C with 40%, and School D with 30%."

Interviewer: "Based on this information, what is your conclusion about students' interest in mathematics at these four schools?"

Student 13: "In general, students' interest in mathematics in the four schools varies. School A has the highest interest, followed by School B, School C, and School D which has the lowest interest."

Interviewer: "Can you provide further explanation about the differences in student interests in mathematics among the four schools?"

Student 13: "There may be several factors that cause these differences in student interest. It could be due to different teaching methods, the school learning environment, or even the student's personal interest in mathematics."

Interviewer: "In your opinion, what can be done to increase students' interest in mathematics in these schools?"

Student 13: "Perhaps teachers can use more interesting and interactive teaching methods, such as using games or examples that are relevant to everyday life. Apart from that, schools can also hold extracurricular activities related to mathematics."

Individuals with low cognitive flexibility and low mathematical literacy RR

Several noteworthy cognitive traits were discovered in students in the RR group, as indicated by the findings of the qualitative study. Students classified in the RR category encountered substantial challenges in comprehending fundamental mathematical concepts and resolving mathematical issues. They were often confused by mathematical terms and symbols, and they did not have a solid groundwork on which to build a more complex understanding. As a result, their ability to solve even the most basic mathematical issues was hindered.

> *Interviewer: "Can you try to explain this?"*
>
> *Student 14: "I don't really understand this problem. This problem uses a lot of math terms that I haven't learned."*
>
> *Interviewer: "Can you explain what you understand from this problem?"*
>
> *Student 14: "I know that X is a positive odd number. If this number is multiplied by 2 and subtracted by 3, the result is a prime even number. But I don't know how to solve the problem."*
>
> *Interviewer: "What do you usually do when you don't understand a math problem?"*
>
> *Student 14: "I usually try to memorize the formulas in the textbook, but I don't always understand how to use them."*
>
> *Interviewer: "How do you usually study mathematics?"*
>
> *Student 14: "I usually memorize formulas and example questions from textbooks. I also often ask my teacher or friends when I don't understand a math problem."*
>
> *Students in the RR category demonstrated low cognitive flexibility in mathematics. They got stuck to the methods they learned in class and thus faced difficulty developing new approaches to solving complex problems. This caused them to become easily frustrated and give up when faced with challenging math problems.*
>
> *Interviewer: "Can you explain how you would solve this problem?"*
>
> *Student 14: "I remember that the formula for calculating time is distance divided by speed. So, I will use that formula to solve this problem."*
>
> *Interviewer: "How did you figure out the distance between two cities on a map?"*
>
> *Student 14: "I measured the distance with a ruler and got 4 cm."*
>
> *Interviewer: "How did you know the speed?"*
>
> *Student 14: "The question states that the speed is 60 km/hour."*
>
> *Interviewer: "How did you convert distance from cm to km?"*
>
> *Student 14: "I didn't know how."*
>
> *Interviewer: "Did you try to remember the formula or other way to convert cm to km?"*
>
> *Student 14: "No, I didn't remember the formula."*
>
> *Interviewer: "How do you usually solve difficult math problems?"*
>
> *Student 14: "I usually try to find examples of similar problems and use the same method to solve them."*

Students in the RR category experienced challenges in effectively expressing their thoughts and strategies when solving mathematical problems. Frequently, they struggled to articulate the sequential process they followed in a lucid and organized fashion, and they encountered challenges in offering coherent justifications for their solutions. This hindered their ability to learn from their errors and seek assistance from others.

> *Interviewer: "Can you explain how you got the answer of 6 hours for the time it takes to travel between two cities?"*
>
> *Student 15: "I used the formula distance divided by speed, and I got 4 cm divided by 60 km/h. Then, I converted cm to km by multiplying it by 0.01."*
>
> *Interviewer: "How did you know that you should multiply 4 cm by 0.01?"*
>
> *Student 16: "I recalled that 1 cm is equal to 0.01 km. So, I had to convert cm to km so that the unit is the same as speed."*
>
> *Interviewer: "Are you sure that your answer was correct?"*
>
> *Student 16: "I'm not sure. I don't really understand how to convert cm to km."*
>
> *Interviewer: "Try explaining again the steps you took to solve this problem."*
>
> *Student 16: "I... I don't remember the steps anymore."*

Students classified into the RR group typically had a diminished sense of self-confidence regarding their mathematical skills. They hold the belief that they lacked proficiency in mathematics and lacked the drive to engage in studying and exerting effort in this subject. This belief may be a substantial hindrance to their progress in mathematics. Although students in the RR group had many constraints, they nonetheless demonstrated the potential for growth in mathematics. Given appropriate assistance, these individuals can acquire and comprehend essential mathematical principles, cultivate more efficient approaches to problem-solving, and enhance their self-confidence in their mathematical aptitude.

> *Student 16: "I'm not good at math. I always get poor scores on math tests."*
>
> *Interviewer: "Have you ever tried to improve your math skills?"*
>
> *Student 16: "I don't know how. I've tried to study it more, but I still don't get it."*
>
> *Interviewer: "Have you ever asked your teacher or friends for help when you were having difficulty in math?"*
>
> *Student 16: "Sometimes. But they can't help me either."*

Interviewer: "What do you like about math?"

Student 16: "I don't like math. I prefer other subjects."

Discussion

This study investigated the cognitive abilities of elementary school students in addressing mathematical literacy problems, focusing on cognitive flexibility and mathematical literacy. The quantitative data from this study demonstrated that mathematical literacy had a significant impact on mathematical cognitive flexibility. Additionally, the qualitative data uncovered several distinct findings concerning students' cognitive traits across different categories.

One intriguing discovery is that students who possessed both advanced cognitive flexibility and strong mathematical literacy demonstrated many cognitive benefits. They were able to generate imaginative and groundbreaking ideas to resolve issues comprehend essential mathematical principles and effectively apply them into the problem-solving process. Additionally, they possessed great communication skills enabling them to articulate their thoughts and strategies in a coherent and organized fashion. Having a strong sense of self-confidence is a crucial advantage for them when it comes to solving mathematical problems. Atagi and Sandhofer (2015) suggests that cognitive flexibility is the ability to adapt to new situations and use various strategies to solve problems. This ability is important in solving mathematical problems because it allows students to find creative and innovative solutions to the problems (Liu et al., 2018).

These findings highlight the importance of integrating educational strategies that foster cognitive flexibility and mathematical literacy in classroom practices. For example, open-ended mathematical tasks can encourage students to explore diverse problem-solving methods (Liljedahl et al., 2016). Collaborative learning where students share and compare problem-solving strategies can also enrich their flexibility and adaptive thinking (Rahayuningsih et al., 2020). These practices are particularly relevant in addressing 21st-century learning demands where problem-solving and adaptability are critical skills.

These findings further suggest that possessing cognitive flexibility and strong mathematical literacy is an optimal combination for becoming a proficient mathematical problem solver. Students possessing these attributes have the capacity to attain exceptional levels of accomplishment in mathematics. This study offers significant understanding into the diverse cognitive attributes that pupils possess when addressing mathematical literacy issues. These findings can assist instructors and educators in comprehending the diverse learning requirements of elementary school students and formulating more efficient learning approaches to enable all pupils to achieve their maximum potential in mathematics.

Students falling into the TR high cognitive flexibility and low mathematical literacy category demonstrated distinct aptitude in solving mathematical issues. These students had the capacity to discover inventive and groundbreaking solutions demonstrating the potential to evolve into adaptable individuals who can effectively address problems. However, they might encounter difficulties in comprehending essential mathematical principles which would frequently hinder their ability to apply their knowledge to problem-solving situations. Consistent with the viewpoint of Rahayuningsih et al. (2020), students with high cognitive flexibility are better at solving complex and non-routine mathematical problems compared to students with low cognitive flexibility. The pupils' communication skills exhibited a range of proficiency with certain individuals demonstrating adeptness in articulating their thoughts while others encountered challenges in doing so. Liljedahl et al. (2016) found that a lack of comprehension of basic mathematical concepts can impede students' ability to apply their knowledge to problem-solving procedures.

Educational strategies must be tailored to address these gaps. Teachers can focus on strengthening mathematical literacy by providing concrete real-world examples that bridge the gap between concepts and their application. Moreover, fostering a growth mindset among TR students is essential. Research shows that students with a growth mindset are more likely to experiment with new strategies and overcome challenges (Rege et al., 2021).

Students' poor confidence in their mathematical skills can serve as an additional obstacle to solving math problems effectively. Gunawan and Muflihati (2022) elucidated that a lack of self-assurance can provide an extra hindrance for individuals when it comes to successfully resolving mathematics issues. Despite their various restrictions pupils classified under the TR category possessed the capacity to enhance their mathematical abilities given appropriate assistance. By imparting a deep understanding of essential mathematical concepts and fostering the acquisition of efficient problem-solving skills one can enhance their self-confidence in mathematics hence facilitating their success in this discipline.

Students classified in the RT category characterized by low cognitive flexibility and strong mathematical literacy exhibited a fascinating amalgamation of skills. They demonstrated a robust comprehension of mathematical concepts and exhibited advanced mathematical literacy skills. Consequently, they were adept at comprehending mathematical difficulties and discerning pertinent information. In addition, they had strong communication skills which enabled them to articulate their problem-solving strategies with clarity and organization. Possessing a strong sense of self-assurance in one's mathematical skills is a valuable advantage when it comes to problem-solving. Students in the RT category however exhibited limited cognitive flexibility. This indicates these individuals would tend to adhere to the techniques they acquired at school and encounter challenges when attempting to discover novel approaches to resolve intricate situations. This inadequacy can impede their ability to tackle complex and unconventional mathematical tasks. The study conducted by Mariano-Dolesh et al. (2022) revealed that students possessing a robust comprehension of mathematical concepts exhibited superior problem-solving skills in complicated and non-routine mathematical tasks in contrast to students having a limited grasp of mathematical concepts. The study conducted by Rege et al. (2021) also showed that students with a growth mindset demonstrated a higher inclination to experiment with novel strategies and push their limits when it came to studying mathematics as opposed to students with a static mindset fixed mindset.

Teachers can support RT students by gradually introducing tasks that challenge their cognitive flexibility such as open-ended questions or multiple-solution problems. By encouraging students to step out of their comfort zone, teachers can foster adaptive thinking and problem-solving capabilities (Newton et al., 2020).

Despite their cognitive inflexibility, students in the RT group would be able to excel in mathematics given appropriate assistance. By facilitating the development of adaptable and innovative problem-solving techniques, individuals can acquire the skills necessary to surmount obstacles and achieve their maximum potential in the field of mathematics. Ismail et al. (2017) discovered that the brain possesses the capacity to undergo changes and growth particularly during critical developmental stages like schooling. By promoting neurogenesis and synaptic plasticity in the brain, individuals with restricted cognitive flexibility like RT students might enhance their mathematical aptitude. Moreover, according to Newton et al. (2020) it is crucial to establish a connection between learning content and personal experience as well as prior knowledge. By instructing pupils in mathematics using circumstances that are pertinent and significant to them they can more readily assimilate these concepts despite their restricted cognitive flexibility.

Conclusion

This study has demonstrated that cognitive flexibility and mathematical literacy significantly influence elementary school students' ability to solve mathematical literacy problems. By answering the research questions, this study confirms that students with advanced cognitive flexibility and a deep understanding of mathematical concepts excel as effective mathematical problem solvers. Specifically, the quantitative findings revealed a strong correlation between mathematical literacy and cognitive flexibility as shown by the R-Square value of 63.1%. Additionally, qualitative findings uncovered distinct cognitive traits across four student categories TT TR RT and RR providing valuable insights into how these traits impact problem-solving performance.

Students with high cognitive flexibility and mathematical literacy TT exhibited exceptional problem-solving abilities and creativity while those with high flexibility but low literacy TR demonstrated innovative thinking but struggled with foundational concepts. Conversely, students with high literacy but low flexibility RT excelled in routine problems but faced challenges adapting to novel situations. Students with low flexibility and literacy RR encountered the most significant obstacles including low confidence and limited comprehension of mathematical concepts. These findings validate the need for tailored instructional approaches to meet the diverse cognitive and learning needs of students.

The study's findings address the first research question by establishing the relationship between cognitive flexibility and mathematical literacy, while the second research question is addressed through a detailed analysis of the unique cognitive attributes of students in each category. This comprehensive understanding underscores the importance of integrating teaching strategies that promote both cognitive flexibility and mathematical literacy in elementary school settings. For example, incorporating open-ended tasks and collaborative problem-solving can foster adaptive thinking and creativity in students.

The implications of this study are particularly significant for educators and curriculum developers. By understanding the diverse cognitive traits of students, educators can design more effective instructional strategies, such as real-world problem-solving tasks and personalized support, to optimize each student's potential. For example, students in the TR group may benefit from focused interventions to strengthen their mathematical foundation, while RT students require opportunities to develop adaptive problem-solving skills. Furthermore, RR students require comprehensive support to build confidence and foundational knowledge.

Future research should explore alternative methodologies, such as experimental designs, to assess the impact of specific teaching interventions on cognitive flexibility and mathematical literacy. Additionally, extending the study to different age groups or educational contexts could provide a broader understanding of how these attributes evolve over time and influence learning outcomes.

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Ethical Considerations

The studies involving human participants were reviewed and approved by Universitas Negeri Malang. The participants provided their written informed consent to participate in this study

Conflict Of Interest

All "The authors declare no conflicts of interest".

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