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INVESTIGATING STUDENTS' MATHEMATICAL LITERACY PERFORMANCE IN PISA QUESTIONS: INFORMATION PROCESSING THEORY

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Abstract— The theory of information processing examines how individuals process information in their minds, which is essential for students in solving problems, including PISA tasks. This study explores students' mathematical performance in solving PISA tasks through the lens of information processing theory. A qualitative approach was employed, involving three research subjects with varying levels of mathematical literacy: level 2 (low), level 3 (medium), and level 5 (high). Data were collected through task analysis and semi-structured interviews. The analysis involved data reduction, presentation, and conclusion drawing. The study adopted the Atkinson-Shiffrin information processing model, which comprises sensory register, working (short-term) memory, and long-term memory. Cognitive processes analyzed included attention, perception, rehearsal, retrieval, and coding. The findings revealed that cognitive processes occurred at all students, but their effectiveness varied by task complexity. Level 2 students exhibited cognitive processes primarily in problems characterized by the use of basic arithmetic calculations. The cognitive difficulties encountered by these students occurred during the attention phase, where they struggled to comprehend problems involving models, resulting in errors during the encoding process. Level 3 students demonstrated cognitive processing in problems characterized by the use of explicit models. Cognitive challenges included issues in the attention phase, as students had difficulty understanding problems with complex characteristics, disruptions in the perception phase, where they experienced cognitive lapses in concept application, and obstacles in the encoding process. Level 5 students engaged in cognitive processing for problems of higher complexity, but faced challenges with tasks requiring mathematical model development and implicit concept integration. These findings indicate the necessity for collaborative learning in classrooms to accommodate diverse cognitive abilities, bridging differences, fostering interaction, and encouraging peer support, leading effectively foster and improve students' problem-solving abilities.

Index Terms— Cognitive processes, mathematical performance, literacy skill level, PISA questions, information processing theory.

I. INTRODUCTION

Mathematical literacy is considered an essential ability for persons in the 21st century. The Sustainable Development Goals (SDGs) established by the United Nations endorse the objective of attaining well-being by 2030 [1]. Quality education constitutes a fundamental objective of sustainable development [2]. The United Nations assesses excellent education using factors including the attainment of functional literacy and numeracy [3]. The Programme for International Student Assessment (PISA) further underlines that mathematics literacy is a crucial metric of a nation's educational achievement [4].

Mathematics education in Indonesia encounters numerous learning obstacles. Results from the PISA assessments administered by the Organisation for Economic Co-operation and Development (OECD) from 2000 to 2022 indicate that Indonesian pupils regularly exhibit inadequate performance in mathematical literacy. In 2022, Indonesia achieved a score of 366, which is below the global average of 472 [4]. The PISA results show the necessity of enhancing students' mathematics literacy, including the cognitive processes [4].

Problem-solving cognition provides an aspect of mathematical ability evaluated in PISA [4]. Thinking is the cognitive process of leveraging the mind to create judgments informed by facts and experience [5].

Investigations into human memory [6], [7], [8] assist researchers in comprehending the mechanisms of information retention and loss. Students do not simply listen, write, or complete assignments during learning; they engage in cognitive processes within the brain, rendering learning a mental activity [9]. The cognitive process in mathematics education emphasizes discovering answers rather than only memorizing processes, investigating patterns instead of solely recalling formulas, and developing hypotheses rather than simply doing tasks [10].

The learning of mathematics has transitioned from an emphasis on theoretical understanding to a focus on practical application. This transition is underpinned by the belief that students can proficiently acquire mathematics by actively constructing their own mathematical comprehension. This comprehension necessitates that students examine, represent, transform, solve, apply, prove, and communicate concepts proficiently [11]. The abilities to formulate, apply, and understand are fundamental components of mathematical literacy [12]. Mathematical literacy encompasses not only memorization but also the application of knowledge in practical situations [13].

The correlation between cognitive processes and mathematical literacy can be observed through the information processing conducted by students. Information processing theory is a cognitive learning framework that elucidates the mechanisms of knowledge processing, storage, and retrieval inside the mind [14]. Information processing theory analyzes the cognitive mechanisms individuals employ to interpret information within the brain. The information processing theory has two main components, namely a component of information storage and cognitive processes [14]. The components of information storage consist of: 1) sensory register, the initial element of the memory system that acquires information from the senses; 2) short-term (working) memory (STM), where a limited amount of information is processed and loaded for a few seconds; 3) long-term memory (LTM), the memory component where information is preserved for prolonged durations [14], [15]. Slavin [14] defines cognitive processes in information processing as follows: 1) attention, the concentrating of the active mind on certain information by eliminating other information; 2) perception, interpreting the received information; 3) rehearsal, mentally reiterating information to improve recall; 4) retrieval, accessing information retained in long-term memory; 5) coding, archiving information obtained from long-term memory. This study employs the Atkinson-Shiffrin information processing model [15]. Figure 1 illustrates this type of information processing.

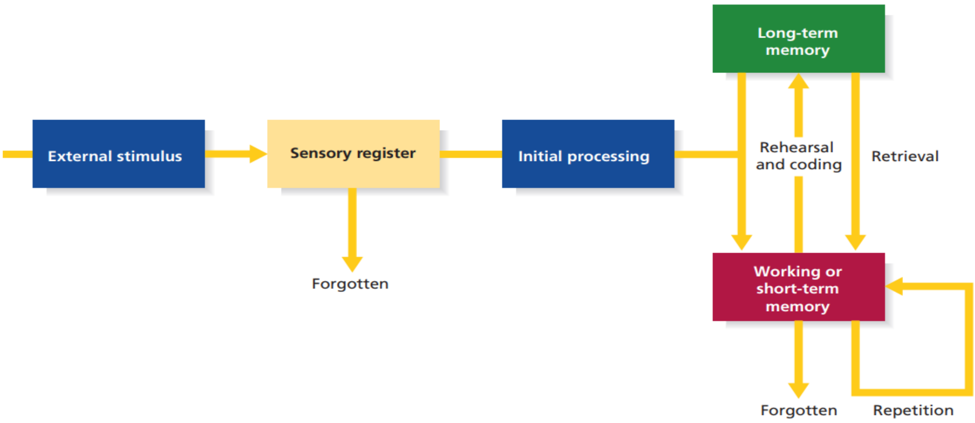


Figure 1. Information Processing Model

Numerous research have associated information processing theory with mathematical proficiency. Investigations on mathematical aptitude and information processing have primarily focused on the elementary school level [16], [17], [18], [19], with comparatively less research at the junior high school level [20], [21]. A study by Wang and Carr [22] examines the correlation between spatial aptitude and mathematical performance through the lens of information processing theory. Further study investigated information processing theory in the context of vector [23] and proportion learning [24]. Currently, few research investigates mathematical literacy in addressing PISA tasks from the perspective of information processing.

The capacity for information processing is essential for pupils in addressing challenges, particularly PISA inquiries. The mathematical literacy performance of students is evidenced by their capacity to solve PISA problems. This study attempts to examine students' mathematical literacy performance in addressing PISA tasks through the lens of information processing theory.

II. METHODOLOGY

(a). Research Design

This study employs a qualitative method, adopting a case study design. A case study aims to create a comprehensive description by thorough analysis of a particular situation [25]. This study examines students' mathematical literacy proficiency in addressing PISA problems.

(b). Research Subjects

The research covers 57 pupils in the ninth grade. The selection of ninth-grade pupils is predicated on criteria for assessing mathematical literacy, notably focusing on individuals under the age of 15 [4]. The students were categorized based on their mathematical proficiency, as determined by a summative assessment. Mathematical proficiency was classified into three levels: low, medium, and high.

Data collected by administering PISA problems, encompassing mathematical literacy questions from level 1c to level 6, to the intended research participants. The procedure of solving these PISA questions was directly observed. The students were classified based on their ability in mathematical literacy. Individuals with outstanding ability in each category of mathematical aptitude were chosen as possible subjects. The subsequent decision was predicated on the students communication abilities and endorsements from their maths teachers. Three students were selected as research subjects, reflecting mathematical literacy level 2, level 3, and level 5. Subsequently, the participants were subjected to comprehensive interviews concerning their problem-solving process in relation to the PISA questions. The research participants can be seen in Table 1.

Table 1. Research Subjects

Subject	Mathematics Ability Level	Mathematical Literacy Skill Level
MIR	Low	Level 2
ADE	Medium	Level 3
AMR	High	Level 5

(c). Research Instruments

This study used instruments that include PISA questions, ranging levels 1c to 6, to evaluate mathematical literacy proficiency, and an interview guide. The PISA questions are utilized to assess mathematical literacy while considering the cognitive processes that occur as students process information. The interview guide is another tool employed to gather comprehensive insights into the reasoning behind the problem-solving procedures undertaken. A description of the types of PISA questions is presented in Table 2.

Table 2. Types of PISA Questions

Level	Description
6	Solving abstract problems, deep understanding of mathematical concepts, and evaluating the suitability of the solutions in relation to the initial situation.
5	Creating and using models in complex situations, applying challenging problem-solving strategies, combining implicit mathematical knowledge, and relating solutions to real-world situations.
4	Using explicit models for complex concrete situations, employing computational thinking, constructing and presenting arguments based on reasoning.
3	Designing strategies involving step-by-step decision-making, beginning to use computational thinking skills, using multiple calculations and information from various sources.
2	Extracting relevant information from sources, designing simple strategies, applying basic understanding, and making direct interpretations from results.
1a	Questions with readily available and clear information, using basic understanding, and performing simple routine procedures as instructed.
1b	Questions where required information is clearly presented, recognizing irrelevant information and disregarding it.
1c	Questions where all relevant information is clearly presented, using short and easy-to-understand texts.

(d). Data Analysis

The data analysis process in this study involves data reduction, data presentation, and conclusion drawing [26]. Data reduction includes the processes of selecting, summarizing, explaining, and transforming the data collected and recorded in written form, including transcripts and student solution documents. The collected data is described in the form of explanations and accompanied by illustrations. Subsequently, conclusions are drawn from the gathered data and verified against the formulated conclusions.

Information processing commences upon the entry of data through the senses. Information that lacks full attention will be eliminated from memory, while information that is focused on is transferred to another component, namely long-term memory. Information that is consistently processed will be stored in long-term memory. Indicators of the thinking process are presented in Table 3.

Table 3. Indicators of the Thinking Process Based on Information Processing Theory

Thinking Process Component	Description	Indicator
Attention	Focusing on reading the question carefully and thoroughly regarding the information obtained.	Selecting relevant information in the question: • The student writes or states what is known and what is being asked in the question.

Thinking Process Component	Description	Indicator
Perception	The student's interpretation of the received information in the form of a problem-solving plan.	Choosing a problem-solving strategy: • The student writes or expresses a problem-solving strategy using formulas.
Retrieval	The process of recalling information from long-term memory (LTM) that is needed in short-term memory (STM) to process information.	Recalling previous information: • The student recalls formulas from concepts previously learned.
Rehearsal	The process of repeating information over time, leading to its retention in memory.	Repetition: • The student repeats previously given information and re-applies concepts that were previously used in STM.
Coding	The process of storing new information in long-term memory.	Drawing conclusions: • The student explains each completed step and summarizes the solution process.

III. RESULTS

Based on the students' problem-solving results, it was found that the students received information in the form of PISA questions and processed that information. The data, including work results and interview responses, were used to explore the students' mathematical literacy performance in solving PISA questions. The analysis revealed that the students' problem-solving abilities were classified into three different levels: literacy level 2, level 3, and level 5.

(a). Description of Mathematical Literacy Performance of Level 2 Student

MIR begins the process of storing information after reading and reviewing the question within the sensory register. During the attention process, MIR understands that the truck used for delivery measures 4 meters in length, 2 meters in width, and 2 meters in height, while the medium-sized boxes have dimensions of 0.5 meters in length, 0.5 meters in width, and 0.5 meters in height. The inquiry concerns the truck's capacity to accommodate medium-sized cargo. MIR analyzes the problem-solving technique through a backward approach in the perception process. MIR explains that result of multiplying the size of the box by a number obtained the size of the truck. For example, the product of the box's length and a certain number is equivalent to the truck's length. During the retrieval process, MIR extracts information from LTM to STM concerning numerical operations, as evidenced by the identification of the multiplier for the box size that corresponds to the truck's dimensions. However, MIR experiences forgotten loss, where in information previously retained in LTM concerning the concept of the volume of three-dimensional shapes is lost. This arises from inadequate access to obtain the notion when required. Despite the information remaining in memory, it is inaccessible due to infrequent utilization. In contrast, the concept of numerical operations is effectively retained in LTM, enabling effortless recall of that information. MIR illustrates the problem-solving processes in the coding process, asserting that the formula for multiplying the box size by a factor produces the truck's dimensions. The quantity of boxes is calculated by multiplying the figures obtained during the retrieval operation. MIR determines that the outcome is 128 medium-sized boxes that can be accommodated in the truck. The mathematical literacy performance of MIR is illustrated in Figure 2.

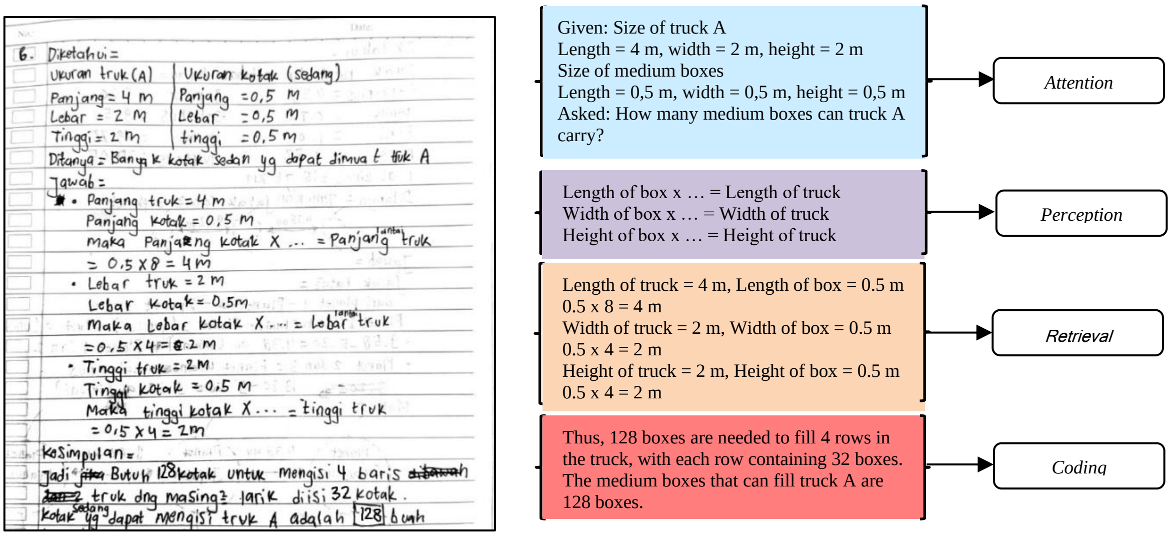


Figure 2. MIR's mathematical literacy performance on level 2

The process of mathematical literacy thinking by MIR in solving the level 2 PISA problem is supported by interview data. The interview results with MIR are presented as follows:

Researcher : Do you understand the question in the problem you read?
MIR : Yes, I do.
Researcher : Based on the question, what do you understand?
MIR : The dimensions of truck A are given: length = 4 meters, width = 2 meters, height = 2 meters. The medium-sized box dimensions are: length = 0.5 meters, width = 0.5 meters, height = 0.5 meters.
Researcher : What is the question asking about?
MIR : The number of medium-sized boxes that can fit in truck A.
Researcher : What is your plan for solving this problem?
MIR : I will calculate the number of boxes in arrangement. The length of the box multiplied by a certain number equals the length of the truck's floor. The width of the box multiplied by a certain number equals the width of the truck's floor. The height of the box multiplied by a certain number equals the height of the truck.
Researcher : What is the next step you take after that?
MIR : I calculate the number of boxes in the truck. There are 32 boxes in one layer, and the height of the truck can fit 4 boxes. The total number of boxes that can fill the truck is 128.
Researcher : What conclusion did you draw from the steps you took to reach the result?
MIR : The number of medium-sized boxes that can fill truck A is 128 boxes.

MIR successfully resolved the level 2 challenge, which entails basic arithmetic calculations. However, MIR encountered challenges in addressing a level 3 literacy issue. MIR was incapable of resolving the issue that necessitated the application of explicit models. The cognitive process of MIR is illustrated in Figure 3.

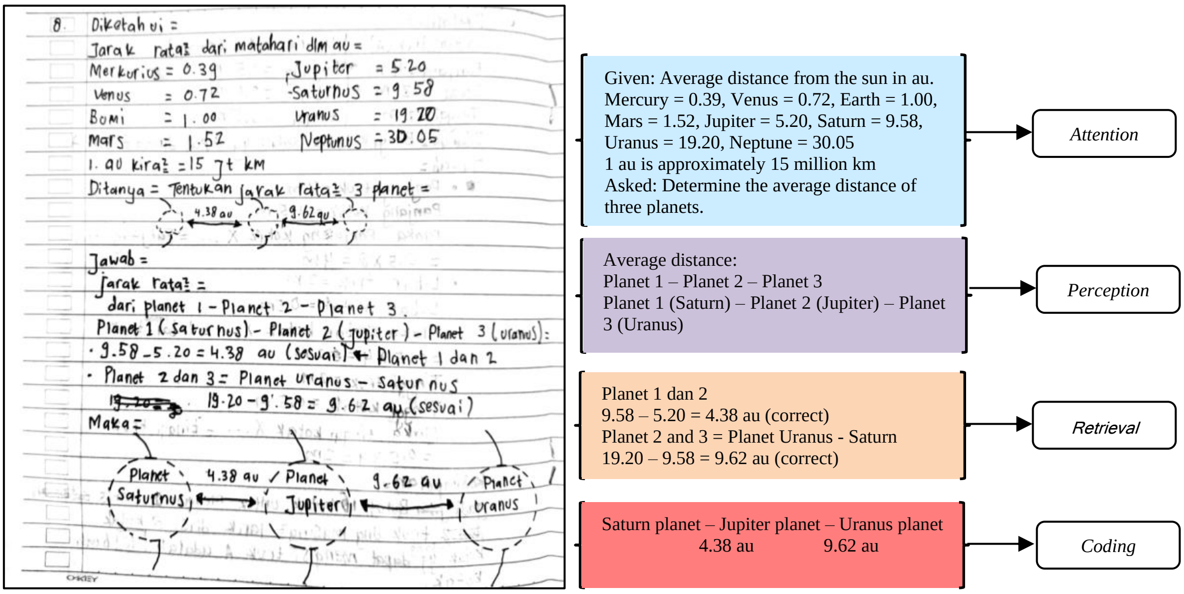


Figure 3. MIR's mathematical literacy performance on level 3

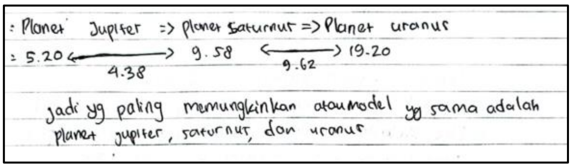
The thinking process of MIR in solving the level 3 problem is supported by the following interview:

Researcher : Based on the question, what do you understand?
MIR : The average distance of planets from the Sun is in AU. 1 AU is approximately equal to 15 million kilometers.
Researcher : What is the question asking?
MIR : Determine the average distance of three planets.
Researcher : What is your plan for solving this problem?
MIR : First, I will identify planets 1 and 2, which are 4.38 AU apart. Then, I will find the distance between planet 2 and planet 3, which is 9.62 AU.
Researcher : How did you determine planets 1, 2, and 3?
MIR : I just chose planet 1 (Saturn), planet 2 (Jupiter), and planet 3 (Uranus).
Researcher : Why did you choose these three planets?
MIR : The distance between Saturn and Jupiter is 9.58 AU minus 5.20 AU, which equals 4.38 AU, so it fits. Then, the distance between Jupiter and Uranus is 19.20 AU minus 9.58 AU, which equals 9.62 AU, so it fits.
Researcher : Based on the results you have obtained, what conclusion did you draw?
MIR : The order of the three planets is Saturn, Jupiter, and Uranus.
Researcher : Is it acceptable to swap the planets?
MIR : No, it is not.

The data from the level 3 challenge was acquired by MIR and recorded in the sensory register. During the attention process, MIR retrieved familiar information, including the average distance of planets from the Sun in astronomical units (AU) and the conversion of 1 AU to 15 million kilometres. MIR reaffirmed the inquiry concerning the distance among the three planets. In the perception process, MIR interpreted the problem-solving strategy by identifying the planets that corresponded to the specified distances. MIR established the sequence of the planets as Saturn (planet 1), Jupiter (planet 2), and Uranus (planet 3). During the retrieval process, MIR transferred information about the notion of subtraction from LTM to STM. The subtraction operation of 9.58 minus 5.20 resulted in 4.38, which matched the distance between planets 1 and 2. MIR employed the same procedure to verify the distance between planets 2 and 3, calculating 19.20 minus 9.58, which equated to 9.62, consistent with the distance between the two planets. The coding procedure, MIR highlighted the actions undertaken, indicating that the planets were initially arranged and subsequently verified in accordance with the model. MIR determined that the sequence of the planets from left to right was Saturn, Jupiter, and Uranus. However, an error occurred in the conclusion of the answer. This error resulted from MIR's incomplete comprehension of the query, leading to an erroneous solution. MIR concentrated on the distances between the planets that aligned with the problem but failed to accurately account for the correct sequence of the planets. MIR experienced a challenge during the attention phase due to difficulty in comprehending the situation, which involved using of an explicit model, resulting in an error during the coding process.

(b). Description of Mathematical Literacy Performance of Level 3 Student

In the sensory register, ADE observed and processed the material alongside the question from the level 3 literacy problems. Throughout the attention process, ADE comprehended the provided information, which encompassed the planets' distances from the Sun in astronomical units (AU), the conversion of AU to million kilometres, and the model illustrating the distances among three planets. ADE identified the inquiry as requesting the sequence of the three planets. During the perception process, ADE delineated the approach for establishing the sequence of the three planets by directly selecting those that closely correspond to the distances depicted in the model. ADE interpreted the planetary arrangement from left to right as Jupiter, Saturn, and Uranus. During the retrieval process, ADE extracted information from LTM to STM by calculating the distances between the planets using subtraction. ADE calculated the distance between Jupiter and Saturn, subtracting the distance of Saturn from Jupiter, resulting in 4.38 AU, which was correct. ADE subsequently estimated the distance differential between Uranus and Saturn, obtaining 9.62 AU, which was also correct. The coding procedure, ADE catalogued the planetary sequence by initially selecting the planets and subsequently validating the distance for each one. ADE determined that the accurate sequence of the planets, according to the model, was Jupiter, Saturn, and Uranus. The cognitive process of ADE in addressing the level 3 challenge is depicted in Figure 4.



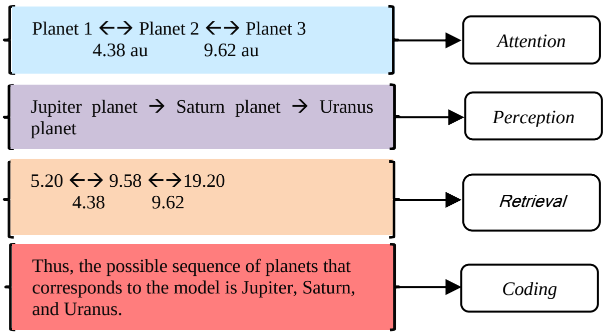


Figure 4. ADE's mathematical literacy performance on level 3

The cognitive process of ADE is demonstrated in the following interview results:

Researcher : Based on the question, what is it related to?
ADE : The order of three planets.
Researcher : What do you understand from the question?
ADE : The distance of the planets from the Sun in AU. One AU is approximately 150 million kilometres. The planet model shows the average distance between the three planets.
Researcher : What is the question asking?
ADE : Determine the three planets in the correct order.
Researcher : What is your plan for solving this problem?
ADE : First, I will find the planets with a distance difference of 4.38 AU, which are Jupiter and Saturn. Subtracting the distance of Saturn from Jupiter gives 4.38 AU. Then, I will find the planets with a distance difference of 9.62 AU, which are Saturn and Uranus.
Researcher : Based on the steps you took to reach the result, what conclusion did you draw?
ADE : Therefore, the order of the planets according to the model is Jupiter, Saturn, and Uranus.
Researcher : Is it acceptable to swap the planets? Explain your reasoning.
ADE : No, because the distance difference between the two planets would be inconsistent with the problem.

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However, ADE encountered challenges in solving the level 5 literacy problem. The cognitive process employed by ADE to address the level 5 problem is illustrated in Figure 5.

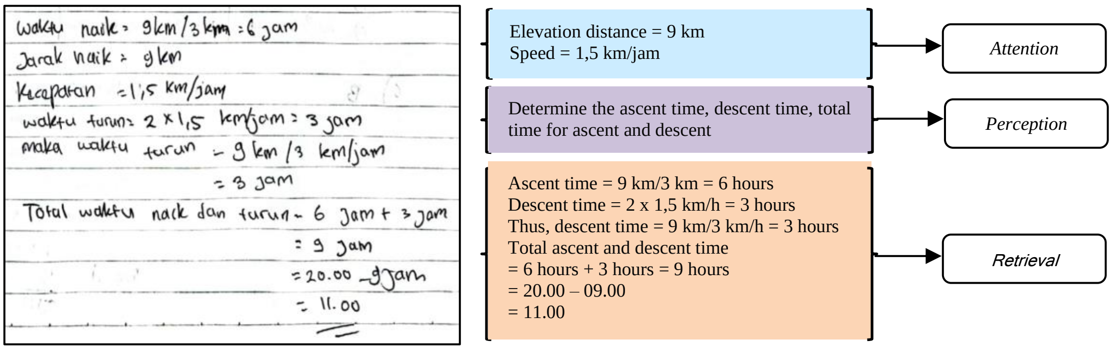

Figure 5. ADE's mathematical literacy performance on level 5

The cognitive process of ADE in addressing the level 5 challenge is supported by the following interview findings:

Researcher : Based on the question, what information is provided in the problem?
ADE : The distance to climb the mountain is 9 km, the average speed is 1.5 km/h, and the descent speed is twice as fast as the ascent speed.
Researcher : What is the question asking?
ADE : What is the latest time Toshi can start climbing so that he can return by 8:00 PM?
Researcher : What is your plan for solving this problem?
ADE : I will determine the ascent time, descent time, and total time for both ascent and descent.
Researcher : How did you determine the ascent and descent times?
ADE : The descent time is 9 km divided by 3 km/h, which equals 6 hours. The ascent time is 2 times 1.5 km/h, which equals 3 hours, so the descent time is 9 km divided by 3 km/h, which equals 3 hours.
Researcher : Further, what formula did you use to calculate the ascent time?
ADE : I don't know, I forgot the formula.
Researcher : There are two calculations for the descent time. Why are there two different calculations?
ADE : The problem states that the descent speed is twice as fast as the ascent, so I calculated it as 2 times 1.5 km/h, which equals 3 hours. Then I calculated the descent time as 9 km divided by 3 km/h, which equals 3 hours.
Researcher : Based on the results you obtained, what conclusion did you draw?
ADE : I concluded that the climb should start at 11:00 AM.
Researcher : Are you confident that your answer is correct?
ADE : I am not sure, no.

During the attention process, ADE perceived the elevation distance as 9 km and the ascending velocity as 1.5 km/h. Nevertheless, ADE did not entirely comprehend the material in the inquiry, as not all relevant information were provided. The perception process, ADE revealed the strategy of problem-solving by determining the ascent time, descent time, and overall time for climbing. ADE experienced confusion in the perception process, which was marked by a disruption in thinking; the problem should have been solved using the concept of speed, yet ADE resorted to a numerical operation that occurred to them. This indicates that ADE has forgotten lost the concept of speed. The retrieval process, ADE obtained information and calculated the ascent time as 6 hours, although the calculation was erroneous. The identical error occurred in calculating the descent duration, as ADE employed two different calculations. During the coding process, ADE failed to exhibit the retention of new information in LTM. ADE documented the end result as 11:00 AM but conveyed ambiguity on the answer, indicating a deficiency in comprehension of the problem. ADE encountered challenges in the attention process due to the complexity of the situation, resulting in a disturbance in cognitive processing during perception in the form of forgotten lost on the concept of speed. Furthermore, the problem-solving approach lacked a coding procedure.

(c). Description of Mathematical Literacy Performance of Level 5 Student

Information processing commences at the sensory register, where AMR observes and interprets the presented question. In the attention process, AMR comprehends the issue, which encompasses a climbing distance of 18 km, an average ascent velocity of 1.5 km/h, and an average descent velocity of 3 km/h. AMR presents the inquiry on the latest time Toshi may begin climbing to ensure a return by 8:00 PM. In the perception process, AMR formulates a strategy for solving the problem based on the speed formula. The ascension duration is determined by dividing the climbing distance by the ascent speed. During the retrieval process, AMR extracts information from LTM to STM, utilizing the speed formula and numerical computations. The ascension duration is determined by dividing the elevation distance of 9 km by the ascending velocity of 1.5 km/h, yielding a total of 6 hours. AMR employs the identical methodology to compute the descent duration, resulting in 3 hours. AMR calculates the overall climbing duration by summing the ascent and descending times: 6 hours plus 3 hours, resulting in 9 hours. AMR calculates the commencement time for the ascent by deducting 9 hours from 8:00 PM, yielding 11:00 AM. During the coding process, AMR successively records the procedures for ascertaining the ascent's commencement time and finalizes the problem-solving procedure. The cognitive process employed by AMR to address the level 5 challenge is illustrated in Figure 6.

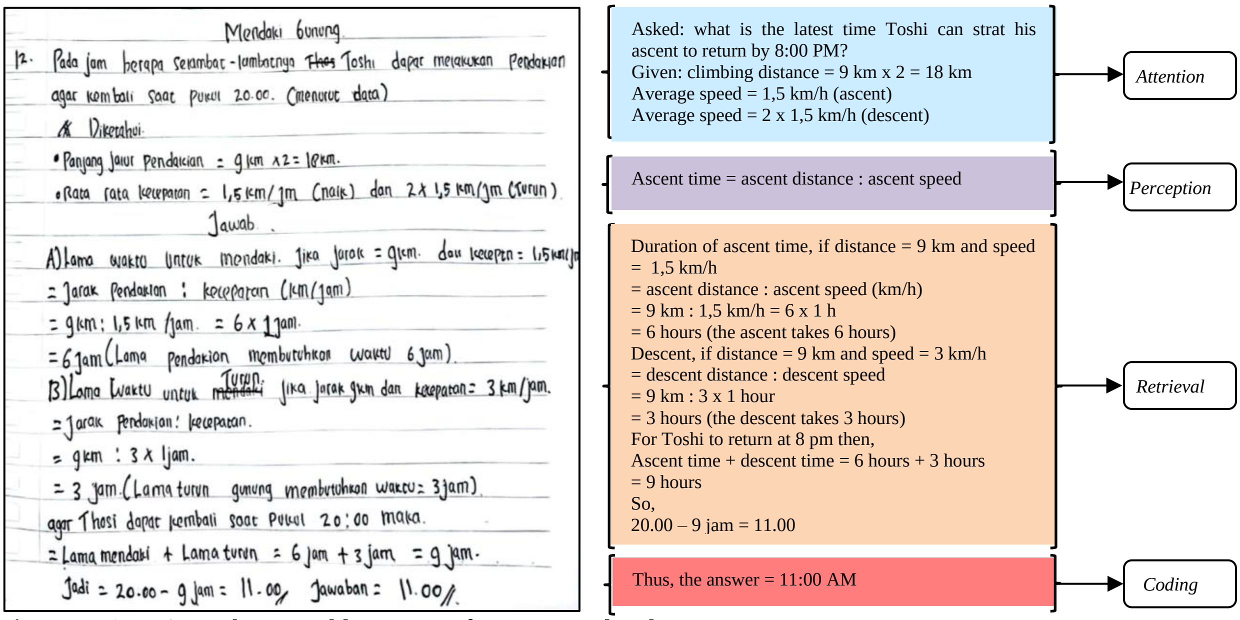

Figure 6. AMR’s mathematical literacy performance on level 5

The cognitive process of AMR in addressing the level 5 issue can be discerned from the subsequent interview findings:

Researcher : Based on the question, what do you understand?
AMR : The climbing distance of 9 km multiplied by 2 equals 18 km. The average ascent speed is 1.5 km/h. The average descent speed is twice the ascent speed, which is 3 km/h.
Researcher : What is the question asking?
AMR : What is the latest time Toshi can start climbing in order to return by 8:00 PM?
Researcher : What is your plan for solving this problem?
AMR : I will calculate the ascent and descent times using the formula distance divided by speed to find the ascent time. I will calculate the descent time in the same way, dividing the distance by the descent speed.
Researcher : What is the next step you take after that?
AMR : I will calculate the total climbing time by adding the ascent and descent times. After obtaining the climbing time, I will calculate the start time by subtracting the total climbing time from 8:00 PM.
Researcher : Based on the results you have obtained, what conclusion did you draw?
AMR : Therefore, Toshi can start climbing at 11:00 AM to return by 8:00 PM.

AMR's memory effectively stores the knowledge required to process the information. AMR accurately implements concepts and calculations. This is due to AMR's capacity to retrieve the necessary concepts for problem-solving, which are effectively maintained in LTM, resulting in a precise answer. AMR exhibits cognitive processes when addressing a challenge with increased complexity.

AMR faced challenges in addressing level 6 literacy issues. During the attention process, AMR identified the problem's inquiry regarding the year when DVD sales first declined below 1 million units, with the information indicating that DVD sales totaled 254 million units. During the perception process, AMR analyzed the problem-solving method by employing the equation $d = 254 - 22n$ provided in the problem. During the retrieval process, AMR shifted information from LTM to STM utilizing the established equation. AMR recorded $d = 254$ (2008) and inferred that in the 22nd year following 2008, DVD sales will total -1 million. This result was obtained by substituting the value of n into the equation. During the coding procedure, AMR highlighted the processes undertaken, namely employing the equation and directly replacing the number $n = 22$. AMR determined that DVD sales initially fell below 1 million in 2030. However, an error transpired in reaching the conclusion. This error occurred because to AMR's difficulties in comprehending the problem's input, resulting in an erroneous solution and inaccurate application of the given equation model. AMR encountered difficulties in attention, retrieval, and coding processes, particularly in comprehending the problem's attributes, which entailed the formulation of a mathematical model. The cognitive process employed by AMR in addressing the level 6 challenge is illustrate in Figure 7.

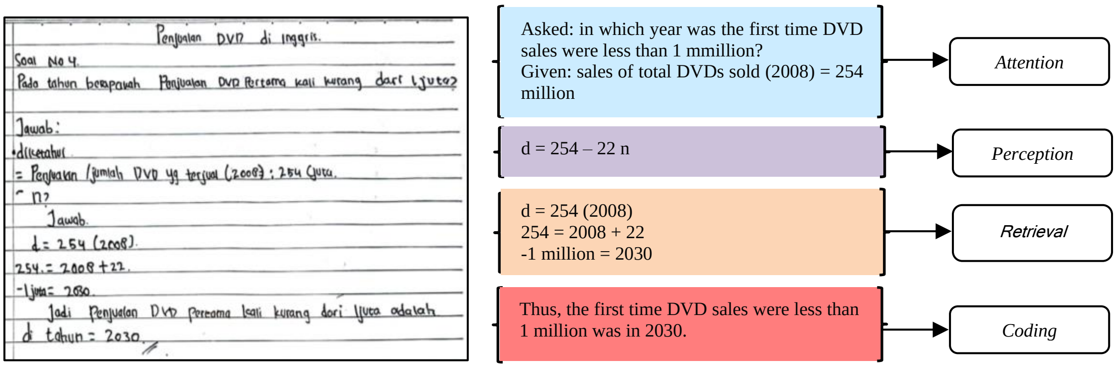

Figure 7. AMR's mathematical literacy performance on level 6

The cognitive process of AMR in addressing the level 6 challenge is supported by the following interview findings:

Researcher : Based on the question, what do you understand?
AMR : The total number of DVDs sold is 254 million, and the equation of the line is $d = 254 - 22n$
Researcher : What is being asked in the problem?
AMR : In which year did DVD sales first fall below 1 million?
Researcher : What is your plan to solve this problem?
AMR : I will use the equation of the line, $d = 254 - 22n$.
Researcher : Then, what is the next step you take?
AMR : I chose $n = 22$, and the result is that DVD sales would be negative 1 million. 2008 plus 22 equals 2030.
Researcher : Based on the results obtained, what conclusion can you draw?
AMR : Therefore, DVD sales first dropped below 1 million in 2030.

The analysis indicates that AMR had challenges in the attention process, particularly in comprehending the problem's attributes related to the formulation of a mathematical model and the incorporation of implicitly conveyed mathematical notions. Moreover, AMR encountered obstacles throughout the retrieval process, resulting in complications in the coding process when addressing the issue.

IV. DISCUSSION

The analysis of problem-solving in students with a mathematical literacy level 2 begins with the presentation of a PISA question. MIR, reads the information and stores it in the sensory register. Slavin [14] asserts that the sensory register operates to acquire information from the senses and retain it for a very brief period. The information ultimately moves into the attention process. Attention involves selecting relevant and irrelevant information for further processing [27]. In the level 2 question, MIR understands the established data concerning the dimensions of the truck utilized for transportation and the measurements of the medium-sized box. MIR determines that the question refers to the number of medium-sized boxes that can be accommodated in the truck. MIR outlines the problem-solving method employed in the perception process. The implementation of techniques is essential in mathematical problem-solving [28]. MIR employs a backward-working strategy, wherein the multiplication of the box size by a specific factor determines the truck's dimensions. Turkmen Dural & Dede [28] indicate that backward-working tactics are among the least frequently employed. During the retrieval process, information is extracted from LTM and STM [27]. During the retrieval process, MIR experiences forgotten loss with the concept of rectangular prism volume. Forgotten lost implies a failure of memory resulting from associative disruption and the absence of retrieval cues related to the target memory [29]. MIR employs multiplication ideas that are effectively retained in LTM, facilitating successful retrieval of this information. MIR demonstrates each stage in the coding process and concludes the solution. MIR displays cognitive thinking in addressing the PISA problem through basic arithmetic calculations.
MIR faced challenges while addressing the level 3 mathematics literacy problem. The research reveals that, during the coding process, MIR derived a conclusion from the outlined stages [27]. The conclusion regarding the planetary order Saturn, Jupiter, and Uranus was erroneous, despite the employed approach being accurate. This error resulted from MIR's misinterpretation of the inquiry, leading to complications in the attention process. MIR concentrated on the selection of planets but did not accurately arrange them. The cognitive difficulty in addressing the level 3 literacy issue arose during the attention phase, where comprehension of the problem was hindered, which required an explicit model. This problem resulted in errors during the coding process.
In addressing the level 3 literacy issue, ADE comprehended the question and preserved it in the sensory register. The attention process, ADE determined the distances of the planets from the Sun, the conversion of 1 AU to million kilometers and the planetary model, alongside the inquiry regarding the sequence of the three planets. During the perception process, ADE constructed a mechanism for determining the accurate sequence of the planets. ADE assessed the distances between planets 1 and 2, and planets 2 and 3, utilizing the principle of subtraction during the retrieval process. During the coding procedure, ADE recorded the data for identifying the

planets by initially selecting them and subsequently verifying the distances for each. ADE determined that the planetary sequence according to the model was Jupiter, Saturn, and Uranus. Cognitive processes were evident in ADE's solution to a problem involving the use of an explicit model.

ADE found difficulties in addressing the level 5 literacy issue. The level 5 PISA problem posed a more complex challenge. During the attention process, ADE comprehended the 9 km distance to ascent and the elevation rate of 1.5 km/h, but other details were not entirely comprehended. In the perception process, ADE articulated a problem-solving strategy but became confused, experiencing a disruption in thinking. The cognitive disruption arose because the issue, which ought to have been resolved through the principle of speed, was instead tackled with an idea that emerged spontaneously. ADE's misunderstanding of the appropriate concept and the forgotten lost of the speed concept considerably impeded problem-solving. Cheng [30] asserts that forgetting or inadequate retention of learnt material can hinder pupils' problem-solving capabilities. During the retrieval process, ADE obtained information and concluded that the ascension necessitated 6 hours. However, the calculations were erroneous. The identical error transpired in the computation of descent time, as ADE employed two distinct methodologies for the calculation. Nur et al. [24] argue that errors in students' work arise from structural similarities between two problems. Lu et al. [29] state that memory storage disruptions exist when tasks have characteristics within the same domain. During the coding process, ADE failed to exhibit the retention of new information in LTM. The conclusive outcome, 11:00 AM, was achieved. However, ADE expressed uncertainty on the answer due to inadequate comprehension of the problem. ADE encountered cognitive difficulties in attention, perception, and coding processing. During the attention step, ADE discovered problems comprehending the more complicated topic, in the perception process, cognitive disruption in the form of forgotten lost on the concept of speed. During the coding process, there was an absence of new knowledge retention in LTM and no resolution was attained from the problem-solving process.

The level 5 PISA problem-solving process started with AMR interpreting and comprehending the question while keeping it in the sensory register. The sensory register is essential, as attention to information is necessary for retention [14]. During the attention process, AMR recognized the data concerning the climbing distance, the average ascent and descent speeds, the inquiry regarding the latest time to commence ascending to ensure a return by 8:00 PM. In the perception process, AMR created a way to resolve the issue utilizing the speed formula to calculate the climbing duration. During the retrieval process, AMR obtained information regarding the speed formula and numerical operation. Ultimately, throughout the coding process, AMR documented the information regarding the sequential method for establishing the initial time and finalized the resolution. AMR’s memory effectively stored the knowledge needed for processing the information. This achievement resulted from AMR's capacity to recall the required concepts, which were effectively retained in LTM, leading to the accurate solution. Cognitive processes were seen in AMR's management of a more intricate problem. Concurrently, AMR had challenges in addressing PISA level 6 problems related to attention, retrieval, and coding processes, specifically in comprehending problems that require the development of mathematical models.

V. CONCLUSION

The data analysis indicates that students' cognitive processes in solving PISA issues vary according to their levels of mathematical literacy. Cognitive processes manifest in all pupils, although exhibit unique traits based on the problem's complexity. Level 2 students demonstrate cognitive processes in problem-solving that involve basic arithmetic calculations. The cognitive issues faced by these pupils show throughout the attention phase, where obstacles in comprehending problems that require model utilization result in errors in the coding process. Level 3 students demonstrated cognitive processes in addressing challenges that necessitate the application of explicit models. The cognitive challenges include difficulties in the attention process, where students struggle to understand more complex problems, disruptions in the perception process due to forgotten lost when applying concepts, and challenges in the coding process. Level 5 students express cognitive processes in addressing situations of increased complexity. Students encounter difficulties in formulating mathematical models and integrating implicit mathematical principles. Students deal with cognitive process restrictions related to attention in issue comprehension, information retrieval, and coding.

The results of this study have implications for classroom instructional methods. Teachers can create activities that support students with varying cognitive abilities through collaborative learning. Collaborative learning may address these disparities by fostering engagement and assistance among students.

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REFERENCES

[1] UNESCO, *Education for sustainable development goals : learning objectives*. Paris: UNESCO, 2017.

[2] E. Boeren, “Understanding Sustainable Development Goal (SDG) 4 on ‘quality education’ from micro, meso and macro perspectives,” *International Review of Education*, vol. 65, no. 2, pp. 277–294, Apr. 2019, doi: 10.1007/s11159-

019-09772-7.

[3] S. Getenet and H. Getnet, “Investigating the use of the National Assessment Program – Literacy and Numeracy (NAPLAN) test results,” *Studies in Educational Evaluation*, vol. 78, Sep. 2023, doi: 10.1016/j.stueduc.2023.101277.

[4] OECD, *PISA 2022 Assessment and Analytical Framework*. in PISA. Paris: OECD Publishing, 2023. doi: 10.1787/dfe0bf9c-en.

[5] M. Nor Bin Bakar, “The Process of Thinking among Junior High School Students in Solving HOTS Question,” *International Journal of Evaluation and Research in Education (IJERE)*, vol. 4, no. 3, pp. 138–145, 2015, doi: http://doi.org/10.11591/ijere.v4i3.4504.

[6] M. A. Conway and M. L. Howe, “On the nature of human memory,” 2022, *Routledge*. doi: 10.1080/09658211.2021.1931738.

[7] A. I. Ferreira, L. S. Almeida, and G. Prieto, “The role of processes and contents in human memory: An item response theory approach,” *Journal of Cognitive Psychology*, vol. 23, no. 7, pp. 873–885, Nov. 2011, doi: 10.1080/20445911.2011.584692.

[8] C. Hulme and P. Dalloz, *Mathematical and Connectionist Models of Human Memory: A Comparison*, vol. 3, no. 2. 1995. doi: 10.1080/09658219508258962.

[9] J. A. Van de Walle, *Elementary and middle school mathematics: teaching developmentally*, Sixth Edition. Pearson Education, Inc, 2007.

[10] A. H. Schoenfeld, “Learning to Think Mathematically: Problem Solving, Metacognition, and Sense Making in Mathematics (Reprint),” *Journal of Education*, vol. 196(2), p. 1, 2016, doi: https://doi.org/10.1177/002205741619600202.

[11] K. Hirschfeld-Cotton, “Mathematical communication, conceptual understanding, and students’ attitudes toward mathematics,” *Action Research Projects*, 2008.

[12] OECD, *PISA 2022 Results (Volume I): The State of Learning and Equity in Education*. in PISA. Paris: OECD Publishing, 2023. doi: 10.1787/53f23881-en.

[13] Z. R. Mevarech and L. Fan, “Cognition, Metacognition, and Mathematics Literacy,” Cham Springer, 2018, pp. 261–278. doi: 10.1007/978-3-319-66659-4_12.

[14] R. E. . Slavin, *Educational psychology : theory and practice*, Tenth Editions. London: Pearson, 2014.

[15] R. C. Atkinson and R. M. Shiffrin, *Human Memory: A Proposed System and Its Control Processes*. California: Standford University, 1968.

[16] D. H. Berg, “Working memory and arithmetic calculation in children: The contributory roles of processing speed, short-term memory, and reading,” *J Exp Child Psychol*, vol. 99, no. 4, pp. 288–308, Apr. 2008, doi: 10.1016/j.jecp.2007.12.002.

[17] H. Lee Swanson, G. D. Arizmendi, and J. T. Li, “Working memory growth predicts mathematical problem-solving growth among emergent bilingual children,” *J Exp Child Psychol*, vol. 201, p. 104988, Jan. 2021, doi: 10.1016/J.JECP.2020.104988.

[18] Y. Qi, Y. Chen, X. Yu, X. Yang, X. He, and X. Ma, “The relationships among working memory, inhibitory control, and mathematical skills in primary school children: Analogical reasoning matters,” *Cogn Dev*, vol. 70, p. 101437, Apr. 2024, doi: 10.1016/J.COGDEV.2024.101437.

[19] H. L. Swanson and M. Beebe-Frankenberger, “The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties,” *J Educ Psychol*, vol. 96, no. 3, pp. 471–491, Sep. 2004, doi: 10.1037/0022-0663.96.3.471.

[20] M. H. Yen *et al.*, “The influence of memory updating and number sense on junior high school math attainment,” *Learn Individ Differ*, vol. 54, pp. 30–40, Feb. 2017, doi: 10.1016/j.lindif.2017.01.012.

[21] D. Cheng, K. Shi, N. Wang, X. Miao, and X. Zhou, “Examining the differential role of general and specific processing speed in predicting mathematical achievement in junior high school,” *J Intell*, vol. 10, no. 1, Mar. 2022, doi: 10.3390/jintelligence10010001.

[22] L. Wang and M. Carr, “Understanding the relationship between spatial ability and mathematics achievement through the lens of information processing theory,” *N Am J Psychol*, pp. 173–192, Jan. 2020, doi: 10.13140/RG.2.2.20223.15524.

[23] N. Phu Loc, D. Huu Tong, and V. Khuong Duy, “Using the Information Processing Theory into Teaching Mathematics: A Case Study of ‘Vector’ Concept,” *Article in International Journal of Scientific & Technology Research*, vol. 8, 2019, [Online]. Available: www.ijstr.org

[24] I. M. Nur, C. Sa’dijah, S. Irawati, and Subanji, “Student’s thinking process in solving proportions based on information processing theory,” *Pegem journal of Education and Instruction*, vol. 14, no. 2, Jan. 2024, doi: 10.47750/pegegog.14.02.25.

[25] R. K. Yin, *Case Study Research : Design and Methods*, 5th ed. Thousand Oaks, California: SAGE, 2014.

[26] M. B. Miles, A. M. Huberman, and J. Saldana, *Qualitative Data Analysis: A Methods Sourcebook*, 3rd ed. London: SAGE Publication, 2014.

[27] T. Gurbin, “Enlivening the machinist perspective: Humanising the information processing theory with social and cultural influences,” *Procedia Soc Behav Sci*, vol. 197, pp. 2331–2338, Jul. 2015, doi: 10.1016/j.sbspro.2015.07.263.

[28] S. Türkmen Dural and Y. Dede, “Problem solving strategies used in mathematics textbooks for Turkish middle schools,” *Asian Education and Development Studies*, vol. 13, no. 5, pp. 444–459, Jul. 2024, doi: 10.1108/AEDS-02-2024-0050.

[29] R. R. Miller, “Failures of memory and the fate of forgotten memories,” *Neurobiol Learn Mem*, vol. 181, p. 107426, May 2021, doi: 10.1016/J.NLM.2021.107426.

[30] V. M. Y. Cheng, “Understanding and enhancing personal transfer of creative learning,” *Think Skills Creat*, vol. 22, pp. 58–73, Dec. 2016, doi: 10.1016/j.tsc.2016.09.001.