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Students' Mathematical Literacy within a Problem-Based Learning (PBL) Model Integrating the Indonesian Realistic Mathematics Education (IRME) Approach and Math Trail

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Abstract

This study was motivated by the low levels of mathematical literacy achievement among eighth-grade students in Cirebon Regency. To address this issue, a Problem-Based Learning (PBL) model was implemented that integrated the Indonesian Realistic Mathematics Education (IRME) approach and the Math Trail framework. The study aimed to analyze: 1) the quality of the Math Trail-based PBL model (incorporating the IRME approach) regarding the mathematical literacy of eighth-grade students at SMPN 1 Depok, and 2) the students' mathematical literacy levels following the model's implementation. A mixed-methods research design, specifically an explanatory sequential design, was employed. The study was conducted at SMP Negeri 1 Depok, Cirebon Regency. The results indicate that the Math Trail-based PBL model (integrating the IRME approach) is highly effective at developing eighth-grade students' mathematical literacy. Analysis of student responses and interviews revealed that students in the High Mathematical Literacy (LMT) category were able to meet all six mathematical literacy indicators: identifying mathematical aspects within a problem, translating the problem into mathematical language, formulating a solution strategy, applying mathematical concepts, interpreting the solution, and explaining the reasoning behind the result. Students in the Moderate Mathematical Literacy (LMS) category met three indicators: identifying mathematical aspects within a problem, translating the problem into mathematical language, and formulating a solution strategy. Meanwhile, students in the Low Mathematical Literacy (LMR) category were able to meet only one indicator correctly: identifying mathematical aspects within a problem.

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INTRODUCTION

As we enter the 21st century, competition across various fields has intensified. Improving the quality of education is one way to address the challenges of this competitive era. Educational quality often serves as a benchmark for a nation's progress. Students' abilities in mathematics, science, and reading literacy, along with their capacity to apply these skills in daily life, are used as indicators of educational quality. 21st-century education is characterized by the "4C" concept: creativity and innovation, critical thinking and problem-solving, communication, and collaboration. Mathematical literacy is defined as an individual's capacity to reason mathematically and to formulate, employ, and interpret mathematics to solve problems in a variety of real-world contexts; this encompasses the concepts, procedures, facts, and tools used to describe, explain, and predict phenomena (OECD, 2021).

An individual is considered mathematically literate if they can understand the role and utility of mathematics in daily life and use it to make sound decisions as a constructive, caring, and wise 21st-century citizen. Mathematical literacy is characterized by the ability to: (1) formulate situations mathematically; (2) employ mathematical concepts, facts, procedures, and reasoning; and (3) interpret, apply, and evaluate mathematical outcomes (OECD, 2021). Consequently, educators and students are expected to possess mathematical literacy skills and the ability to adapt to advancements in communication technology.

Mathematical literacy is a vital skill for both current and future generations (Nurlaili et al., 2022). It is crucial for students as it aids in understanding the concepts being studied; the practical benefits of these concepts include the ability to use efficient problem-solving methods, assess the rationality of results, and analyze situations to draw conclusions (Genc & Erbas, 2019). Understanding the role of mathematics in real life is crucial for every individual, as it enables them to become constructive, caring, and logical members of society who can accurately evaluate and apply mathematics (Agusdianita & Karjiyati, 2021). Consequently, mathematics is one of the subjects assessed to determine student competence.

Under the Regulation of the Minister of Education, Culture, Research, and Technology Number 17 of 2021, the Minimum Competency Assessment (AKM) measures the reading literacy and numeracy (mathematical literacy) competencies that students must possess. Numeracy, or mathematical literacy, is the ability to think using mathematical concepts, procedures, facts, and tools to solve everyday problems across various contexts relevant to individuals as citizens of both Indonesia and the world.

The government has implemented several new policies in the education sector, ranging from differentiated instruction and the Kurikulum Merdeka to the Project to Strengthen the Pancasila Student Profile (P5). Furthermore, the government has developed the Minimum Competency Assessment (AKM) and accompanying training modules to enhance teachers' numeracy skills, as well as guidelines for strengthening literacy and numeracy in schools all aimed at improving the quality of education in Indonesia. However, student literacy achievement, as evidenced by Indonesia's participation in international comparative studies, remains lower than that of students in other countries. This is reflected in student mathematical literacy performance based on results from the Programme for International Student Assessment (PISA), as presented in the following table.

Table 1 Student Mathematical Literacy Achievement Based on PISA Results

Year	Field of Study	Indonesia's Rank	Number of Participating Countries	Score
2000	Math	39	41	367
2003	Math	38	40	360
2006	Math	50	57	391
2009	Math	61	65	371
2012	Math	64	65	375
2015	Math	63	70	386
2018	Math	73	79	379

In mathematics, Indonesian students' average PISA test scores have fluctuated. The lowest average score was recorded in PISA 2003 at 360, while the highest was achieved in PISA 2006 at 391 (Educational Assessment Research Agency et al., n.d.). Recent data from the PISA 2018 survey ranked Indonesia 73rd out of 79 participating countries with a score of 379 well below the OECD average of 489. This indicates that Indonesia's performance in the PISA survey remains suboptimal; the recurrence of such results suggests that the country consistently ranks at the lower end of the performance spectrum.

A similar situation was observed among students at SMP Negeri 1 Depok, Cirebon Regency, during lessons on sets and relations: 53 of the 58 students observed struggled to solve the problems, while only a small number were able to complete the tasks, as shown in the following figure.

Baskara mengambil 5 nomor kupon undian berupa 5 angka pertama bilangan asli. Fahmi mengambil 10 nomor kupon undian berupa 10 angka pertama bilangan genap. Tentukan bentuk relasi seperti apa yang dapat dibuat? Sajikan relasi tersebut dalam bentuk diagram panah, lalu tentukan: domain, kodomain dan range!

Figure 1. Initial Observation Question

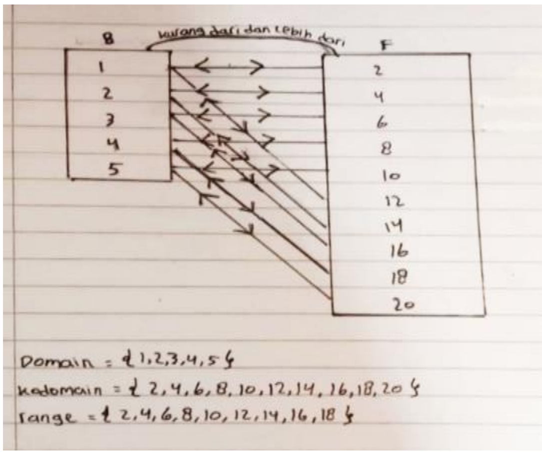

Figure 1. Student Answers

Based on one of the student responses that came closest to the correct answer, the student was able to solve the problem and translate it into mathematical symbols. Although the student could represent the relation using an arrow diagram, they made errors in identifying the specific type of relation and the range; ideally, the student should have identified a single type of relation, such as "less than" or "greater than," to accurately determine the range. Furthermore, the student failed to present the relation systematically, for instance, by listing the sets involved, identifying possible relations between them, creating an arrow diagram, and determining the domain, codomain, and range. This response indicates that the student did not fully grasp the nature of the problem. The student failed to note relevant information provided in the problem statement, such as the knowns, the unknowns, and the full details of the problem.

Field findings from SMPN 1 Depok indicate that 283 out of 311 eighth-grade students scored below the Minimum Mastery Criteria (KKM) on the second-semester midterm assessment. Instruction was delivered using an expository model characterized by a teacher-centered approach. During lessons on sets and relations, some students did not pay close attention and appeared unenthusiastic about the class. Additionally, some students failed to complete homework assignments on relations, citing forgetfulness. These issues indicate a lack of student readiness for learning and a lack of teacher attention to students who did not complete their homework.

When the teacher asked a question regarding the set of square numbers less than 6, students were only able to list the members of the set, meaning they could only express the set using the enumeration method (listing members). Furthermore, the students were unable to describe a set and still struggled with reasoning, such as when the teacher wrote out a set using the enumeration method namely $A = \{4^2, 5^2, 6^2, 7^2, 8^2\}$, students were unable to determine the form of the set.

The practice problems assigned by the teacher were drawn from the textbooks used by students in school. Students are unaccustomed to working on contextual problems; consequently, they are unable to formulate situations mathematically, apply mathematical concepts, facts, procedures, and reasoning, or interpret, apply, and evaluate mathematical results when faced with questions regarding relations and sets linked to real-life issues.

According to Mutia et al. (2021), students' familiarity with routine problems presented by educators rather than solving non-routine problems like those found in PISA is a factor contributing to low mathematical literacy among students. This aligns with research by Masfufah & Afriansyah (2021), which identified students' lack of understanding regarding PISA-based problems as a cause of their low mathematical literacy.

Mathematics is often perceived as an abstract discipline consisting solely of formulas and numbers. This paradigm would shift if mathematics instruction focused on solving real-life problems. In classroom learning activities, teachers often prioritize the final result over the learning process itself. Ideally, the learning process should guide students to discover and apply concepts; however, many students struggle when subject-matter problems are adapted to reflect real-life mathematical situations. This presents a challenge for mathematics teachers in designing instruction and formulating problems that align with real-life issues.

As previously explained, a crucial component of mathematical literacy is the process of mathematization. This process encompasses formulating, employing, interpreting, and evaluating mathematics across various contexts. In practice, the choice of method or representation depends heavily on the specific situation or context of the problem being solved. Students are expected to apply their knowledge in diverse contexts, yet many struggle to do so. A student capable of applying knowledge to one task might not know how to apply it to another. Students need to gain experience solving problems across a range of situations and contexts to learn to use their skills effectively (Ojose, 2011).

This process can be facilitated through teaching methods that provide students with practical experience. Various learning methods and approaches are designed to facilitate such experiences, including the Realistic Mathematics approach (Budiono et al., n.d.), problem-based learning (De Graaff & Kolmos, n.d.), problem-solving, and contextual learning. Through these approaches, students encounter contextual or real-world problems that help enrich their knowledge. At this stage, students use their reading skills to translate real-world situations into mathematical problems, solve them, and interpret the results within the real-world context.

In doing so, they actively develop and apply their mathematical literacy skills. The problems used in instruction should align with the students' own experiences. Suitable problems should possess four characteristics: they must be real, complex, engaging, and robust (Modelling and Applications in Mathematics Education, n.d.). Fundamentally, the problems should reflect real-world contexts and authentic issues. Although finding the right problems can be challenging, the problems presented should not be merely standard word problems; they may contain extraneous information or unknown elements (Wijaya et al., 2015).

Efforts to foster mathematical literacy among students must involve instruction linked to real-world situations, specifically scenarios that are easy for students to understand and visualize, thereby strengthening their mathematical understanding. This is supported by the view of Sumirattana et al. (2017) that "mathematics should be linked to reality, remain close to children's experiences, and be relevant to society." Mathematics instruction is conducted through real-life events that resonate with children's experiences and are socially relevant, enabling students to visualize them. Students acquire mathematical knowledge by independently constructing concepts from real-world events they can envision. Consequently, it is hypothesized that instruction using the Problem-Based Learning (PBL) model, combined with the Indonesian Realistic Mathematics Education (IRME) approach, can enhance students' mathematical literacy. This realistic approach is implemented through mathematization. This aligns with Gravemeijer's (1994) view that the realistic mathematics approach is rooted in Freudenthal's interpretation namely, that mathematics is an activity consisting of the process of mathematization.

Mathematical literacy can be improved through high-quality instruction, which requires teachers to employ appropriate learning models. Research by Ayunis & Dorisno (2022) demonstrates that the IRME approach is effective in enhancing mathematical literacy skills. Furthermore, there is a need for technology-based instructional innovations that connect learning to everyday contexts to address 21st-century challenges; one such innovation is *Math Trail*-based learning using the MathCityMap application. Based on the issues outlined above, the researcher is motivated to conduct a study that combines the PBL model with the IRME approach based Math Trail to improve students' mathematical literacy.

This study differs from previous research by developing a PBL model that integrates the IRME approach based Math Trail activities using the MathCityMap application, with a specific focus on polyhedra (3D shapes with flat faces). Conducting this research at this time is crucial for achieving optimal results regarding students' mathematical literacy, which is assessed annually through the National Assessment. Thus, this study is expected to provide an in-depth analysis of students' mathematical literacy within a Math Trail based PBL model that incorporates the IRME approach.

METHOD

This study employs a mixed-methods approach, specifically a sequential explanatory design. The sequential explanatory method is a mixed-methods approach that involves collecting and analyzing quantitative data in the first stage, followed by collecting and analyzing qualitative data in the second stage, informed by the initial quantitative findings (Creswell, 2014). Quantitative data collection was conducted first, followed by qualitative data collection. The quantitative component aimed to obtain data on students' mathematical literacy levels following the implementation of a Math Trail-based PBL model using the IRME approach. Meanwhile, the qualitative component involved analyzing students' mathematical literacy categorized as high, medium, or low after the implementation of the Math Trail-based PBL model using the IRME approach. This model was implemented with the aid of MathCityMap across six sessions: one session was dedicated to the pretest, and the final session to the mathematical literacy posttest. Learning activities utilizing the Math Trail-based PBL model with the IRME approach spanned four sessions.

RESULTS AND DISCUSSIONS

The quality of instruction encompasses three stages: planning, implementation, and evaluation. The mathematics instruction conducted in this study met all three quality criteria: (1) at the planning stage, the developed instructional materials were deemed valid; (2) regarding implementation, the instructional process was rated positively and elicited a favorable response from students; and (3) at the evaluation stage, the instruction met the criteria for effectiveness. The first quality criterion relates to the preparation stage. Data from this stage included instructional materials, specifically teaching modules; learning objective sequences (ATP); "Math Trail" teaching materials via Mathcitymap; interview guidelines; and questionnaires regarding implementation and student responses. Based on validity criteria, the preparation stage, which incorporated PBL-based instruction using the IRME approach and Math Trail components, was categorized as good.

The next criterion relates to the process stage. Data on the PBL-IRME-Math Trail instruction were analyzed for implementation quality. Observations were conducted by a mathematics teacher from SMPN 1 Depok over four sessions; based on implementation criteria, the instruction was rated as good. The final criterion relates to the evaluation stage. Mathematical literacy test results for the experimental class showed that 29 out of 30 students achieved mastery. The minimum mastery criterion used in this study was a score of 75. SPSS calculations indicated that the PBL-

IRME-Math Trail approach enabled more than 80% of students in the experimental class to achieve mastery. The mean mathematical literacy test scores for the experimental and control classes were 85.87 and 81.23, respectively, with standard deviations of 7.385 and 8.760. The total number of students across both classes was 60. Calculations using SPSS software yielded a significance value of 0.031 under the "Equal Variances Assumed" condition; since this value was lower than the alpha level (sig < 0.05), the null hypothesis (H0) was rejected. It was concluded that there was a difference in the mathematical literacy post-test results between the experimental and control classes. Furthermore, a comparison of average scores indicates that the experimental class achieved better mathematical literacy outcomes than the control class.

Based on the research findings and calculations, the following conclusions were drawn: (1) PBL instruction utilizing the IRME approach and Math Trail activities achieved the criteria for class mastery; (2) the experimental class's average mathematical literacy test score was superior to that of the control class; (3) there was an improvement in students' mathematical literacy; and (4) PBL instruction utilizing the IRME approach and Math Trail activities had a positive effect on mathematical literacy test results. Thus, it can be concluded that PBL instruction utilizing the IRME approach and Math Trail activities proved effective.

Students' mathematical literacy, assessed within the Problem-Based Learning (PBL) framework by integrating the Indonesian Realistic Mathematics Education (IRME) approach and Math Trail activities, was measured using a post-test with a maximum score of 100 and a minimum of 0. The mathematical literacy post-test consisted of four questions administered to 30 students in the experimental class at SMPN 1 Depok, Cirebon Regency. The post-test results for the experimental class showed a highest score of 96 and a lowest score of 60. Calculations using SPSS software (version 17.0) yielded a mean score of 85.87 and a standard deviation (SD) of 7.385. A higher standard deviation indicates a wider data spread (higher heterogeneity), whereas a lower standard deviation indicates a narrower data spread (higher homogeneity) (Manfaat, 2018).

The mathematical literacy of students in the experimental class at SMPN 1 Depok, Cirebon Regency, was categorized into three levels: high ($\mu+\sigma$), medium (μ), and low ($\mu-\sigma$). Here, the symbol μ represents the mean score, while σ represents the standard deviation. The mathematical literacy categories for the experimental class students are presented in the following table.

Table 2. Frequency of Mathematical Literacy Scores

Score	Frequency	Frequency (%)	Category
$X \geq 93$	6	20%	High
$79< X <92$	20	66.67%	Medium
$X \leq 78$	4	13.33%	Low
Total	30	100%	

In general, the level of mathematical literacy following the implementation of the Math Trail based PBL model using the IRME approach was normally distributed; the majority (66.67%) fell into the medium category, while the remainder were classified as high (20%) or low (13.33%).

To facilitate the analysis of field-collected data, the researcher assigned codes to each subject, each question number, and each mathematical literacy indicator related to the "space and shape" content domain. The coding system established by the author is as follows.

Table 3. Informant Code: Mathematics Literacy Category

Ability Category	Name (Initials)	Informant Code
High	KA	LMT
Medium	BP	LMS
Low	RR	LMR

Table 4. Mathematical Literacy Indicators

Aspects measured	Indicators
Formulate	A1 Identify mathematical aspects of a problem.
Able to formulate situations mathematically	A2 Translate the problem into mathematical language or a mathematical

	representation using appropriate symbols, diagrams, or modeling.
Employ Able to apply mathematical concepts, facts, procedures, and reasoning	B1 Design a strategy to find a mathematical solution. B2 Apply the necessary mathematical concepts during the solution-finding process using geometric representations and data analysis.
Interpret Capable of interpreting, applying, and evaluating mathematical results.	C1 Reinterpret the solution results obtained within the context of the real-world problem. C2 Explain the reasons why the results or conclusions align with the context of the given problem.

Regarding the coding system established to facilitate data analysis, the codes consist of the subject identity, the question number, and the indicator code. For example, LMT1A1 refers to a subject with high mathematical literacy who answered question number 1 under indicator A1; in this instance, LMT is the subject code, 1 is the question number code, and A1 is the indicator code, and so forth.

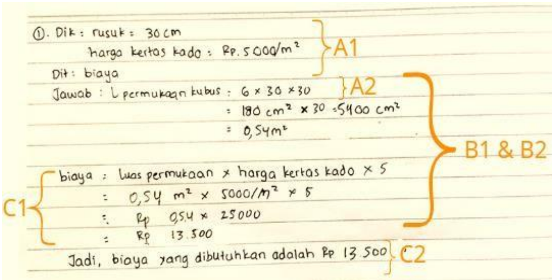

Figure 3. Answer sheet for question number 1 by LMT

Based on an analysis of the written responses and interview transcripts regarding Question 1, it can be concluded that Subject 1 demonstrated mastery of all six mathematical literacy indicators associated with the problem. This is evidenced by Subject 1's ability to: (1) Identify mathematical aspects of the problem (LMT-IA1): The student was able to recognize mathematical concepts and elements relevant to the problem. (2) Translate the problem into mathematical language (LMT-1A2): The student was able to represent the problem using appropriate mathematical models, symbols, images, or diagrams. (3) Formulate a solution strategy (LMT-1B1): The student was able to devise systematic steps to solve the problem. (4) Apply mathematical concepts (LMT-1B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMT-1C1): The student was able to relate the mathematical solution to the real-world context of the problem. (6) Explain the reasoning behind the results (LMT-1C2): The student was able to logically explain why the solution aligned with the problem's context.

The student's successful solution to Question 1 indicates that Subject 1 has achieved a high level of mathematical literacy. This is further reinforced by Subject 1's ability to write down and explain the answers to each question comprehensively and accurately.

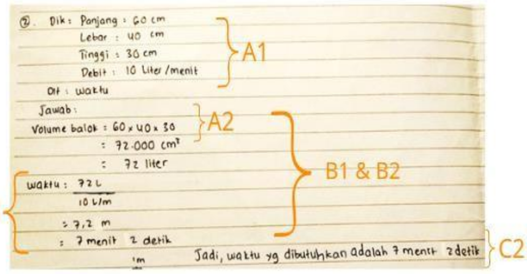

Figure 4. Answer sheet for question number 2 by LMT

Based on an analysis of LMT students' written responses and interview transcripts regarding question 2, it can be concluded that the subject demonstrated mastery of all six mathematical literacy indicators associated with the problem. This is evidenced by their ability to: (1) Identify mathematical aspects of the problem (LMT-2A1): Students were able to recognize mathematical concepts and elements relevant to the problem. (2) Translate the problem into mathematical language (LMT-2A2): Students were able to represent the problem using appropriate mathematical models, symbols, images, or diagrams. (3) Formulate a solution strategy (LMT-2B1): Students were able to devise systematic steps to solve the problem. (4) Apply mathematical concepts (LMT-2B2): Students were able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMT-2C1): Students were able to relate the mathematical solution to the real-world context of the problem. (6) Explain the reasoning behind the results (LMT-2C2): Students were able to logically explain why their solution aligned with the context of the problem.

The students' proficiency in successfully solving question number 2 indicates that Subject 1 has achieved a high level of mathematical literacy. This is evidenced by Subject 1's ability to write down and explain the answers to each question completely and accurately.

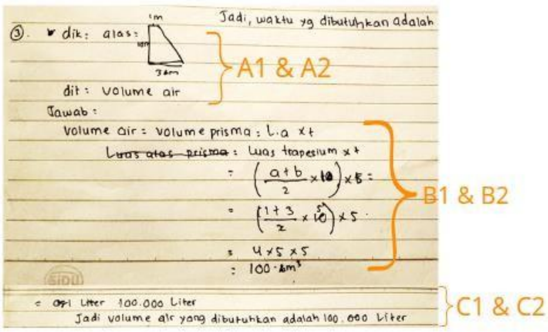

Figure 5. Answer sheet for question number 3 by LMT

Based on an analysis of written responses and interview transcripts regarding the LMT task (Question 3), it can be concluded that Subject 1 demonstrated mastery of several mathematical literacy indicators. This is evidenced by the student's ability to: (1) Identify mathematical aspects of the problem (LMT-3A1): The student was able to recognize the mathematical concepts and elements relevant to the problem. However, the student did not fully state the information provided or the specific question being asked. (2) Translate the problem into mathematical language (LMT-3A2): The student was able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams. The student could convert the given information into a drawing of the prism's base and record the information and concepts used to solve the problem. (3) Devise a solution strategy (LMT-3B1): The student was able to formulate systematic steps to solve the problem. (4) Apply mathematical concepts (LMT-3B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution (LMT-3C1): The student was able to relate the mathematical solution to the actual context of the problem. (6) Explain the reasoning behind the result (LMT-3C2): The student was able to logically explain why the solution aligned with the problem's context.

The student's successful completion of Question 3 indicates a high level of mathematical literacy. This is evidenced by the ability to write down and explain complete, accurate answers to each question. Although Subject 1 demonstrated a good understanding of mathematical concepts and solved the problem correctly, the student did not fully and clearly record key information for indicator A1 and still struggled to link the problem to a real-world context. This was evident in Subject 1's inability to explain the connection between the problem and real life regarding indicator C1.

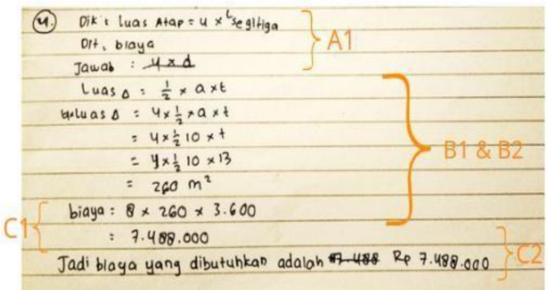

Figure 6. Answer sheet for question number 4 by LMT

Based on an analysis of the LMT student's written responses and interview transcripts regarding question 4, it can be concluded that Subject 1 demonstrated mastery of several mathematical literacy indicators relevant to the problem. This is evidenced by the student's ability to: (1) Identify mathematical aspects of the problem (LMT-4A1): The student was able to recognize mathematical concepts and elements relevant to the problem. Although the student recorded the known information and the question asked, they failed to accurately identify and note crucial information provided in the problem statement for indicator A1; instead, they wrote the roof area formula, which belonged in the solution section (indicator A2), in the section designated for "known" information. (2) Translate the problem into mathematical language (LMT-4A2): The student was able to represent the problem using appropriate mathematical models, symbols, images, or diagrams. They successfully determined the concepts and formulas needed to solve the problem, even though these were not explicitly stated in the solution section. (3) Devise a solution strategy (LMT-4B1): The student was able to formulate systematic steps to solve the problem. (4) Apply mathematical concepts (LMT-4B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMT-4C1): The student was able to relate the mathematical solution results to the real-world context of the problem. (6) Explain the reasoning behind the results (LMT-4C2): The student was able to logically explain why their solution results aligned with the context of the problem.

Figure 7. Answer sheet for question number 1 by LMS

Based on an analysis of the LMS student's written responses and interview transcripts regarding problem number 1, it can be concluded that Subject 2 demonstrated mastery of several mathematical literacy indicators in solving the problem. This is evidenced by Subject 2's ability to: (1) Identify the mathematical aspects of the problem (LMS-IA1): The student was able to recognize the mathematical concepts and elements relevant to the problem by noting the given information and what was being asked. (2) Translate the problem into mathematical language (LMS-1A2): The student was able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams; specifically, the student represented the problem by writing down the formula for the surface area of a cube. (3) Formulate a solution strategy (LMS-1B1): The student was able to devise systematic steps to solve the problem. (4) Apply mathematical concepts (LMS-1B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMS-1C1): The student was able to relate the mathematical result to the actual context of the problem. However, the student was unable to perform the unit conversion from cm² to m². (6) Explain the reasoning behind the result (LMT-1C2): The student was able to logically explain why the solution result aligned with the problem context. However, the student's answer was not entirely accurate.

The student's ability to solve problem 1 successfully indicates that Subject 2 has achieved a moderate level of mathematical literacy. This is evidenced by Subject 2's ability to clearly write down and explain the answers to each question.

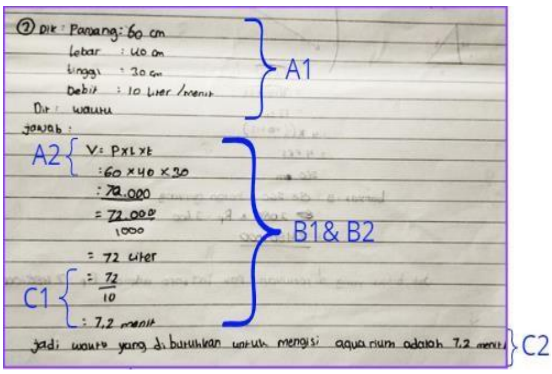

Figure 8. Answer sheet for question number 2 by LMS

Based on an analysis of the LMS student's written responses and interview transcripts regarding problem number 2, it can be concluded that Subject 2 demonstrated mastery of several mathematical literacy indicators in solving the problem. This is evidenced by Subject 2's ability to: (1) Identify mathematical aspects of the problem (LMS-2A1): The student was able to recognize mathematical concepts and elements relevant to the problem by noting the given information and what was being asked. (2) Translate the problem into mathematical language (LMS-2A2): The student was able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams. The student successfully represented the problem by writing down the formula for the volume of a rectangular prism. (3) Formulate a solution strategy (LMS-2B1): The student was able to devise systematic steps to solve the problem. (4) Apply mathematical concepts (LMS-2B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMS-2C1): The student was able to relate the mathematical solution to the real-world context of the problem. (6) Explain the reasoning behind the result (LMS-2C2): The student was able to logically explain why the solution result aligned with the context of the problem.

The student's proficiency in successfully solving problem number 2 indicates that Subject 2 has achieved a moderate level of mathematical literacy. This is evidenced by Subject 2's ability to clearly write down and explain the answers for each part of the problem.

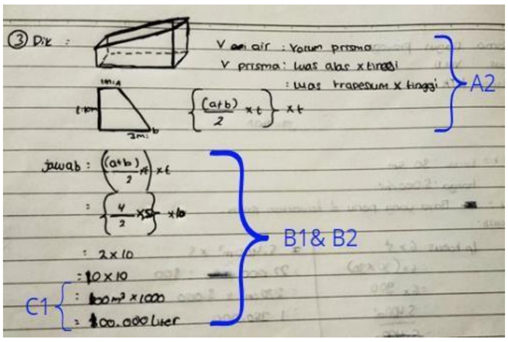

Figure 9. Answer sheet for question number 3 by LMS

Based on an analysis of the LMS student's written responses and interview transcripts regarding question 3, it can be concluded that Subject 2 demonstrated mastery of several mathematical literacy indicators relevant to the problem. This is evidenced by Subject 2's ability to: (1) Identify mathematical aspects of the problem (LMS-3A1): The student encountered difficulties in recognizing mathematical concepts and elements relevant to the problem, as well as in noting down known information and the specific questions asked. (2) Translate the problem into mathematical language (LMS-3A2): The student was able to represent the problem using appropriate mathematical models, symbols, images, or diagrams; specifically, the student successfully represented the problem with an illustration of a prism-shaped swimming pool. (3) Formulate a solution strategy (LMS-3B1): The student was able to devise systematic steps to solve the problem by writing down the prism volume formula to calculate the volume of water in the pool. (4) Apply mathematical concepts (LMS-3B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMS-3C1): The student was able to relate the mathematical solution to the real-world context of the problem. (6) Explain the reasoning behind the result (LMS-3C2): The student was not yet able to logically explain why the solution result aligned with the problem's context. The student did not write a concluding answer.

The student's ability to successfully complete question number 3 indicates that Subject 2 has achieved a moderate level of mathematical literacy. This is evidenced by Subject 2's ability to clearly write and explain the answers to each question.

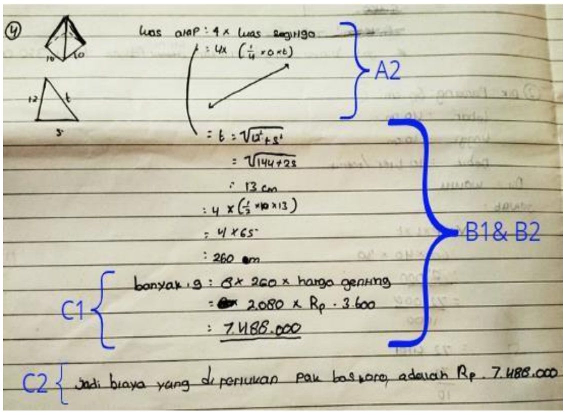

Figure 10. Answer sheet for question number 4 by LMS

Based on an analysis of the LMS student's written responses and interview transcripts regarding question 4, it can be concluded that Subject 2 demonstrated mastery of several mathematical literacy indicators relevant to the problem. This is evidenced by Subject 2's ability to: (1) Identify mathematical aspects of the problem (LMS-4A1): The student struggled to recognize the mathematical concepts and elements relevant to the problem and did not record the given information or the specific question asked. (2) Translate the problem into mathematical language (LMS-4A2): The student was able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams; specifically, the student represented the problem with an illustration of a pyramid-shaped roof. (3) Formulate a solution strategy (LMS-4B1): The student struggled to formulate systematic steps to solve the problem and did not clearly write down the formulas or solution methods. (4) Apply mathematical concepts (LMS-4B2): The student was able to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpret the solution results (LMS-4C1): The student was able to relate the mathematical solution to the real-world context of the problem. (6) Explain the reasoning behind the result (LMS-4C2): The student was able to logically explain why the solution result aligned with the context of the problem.

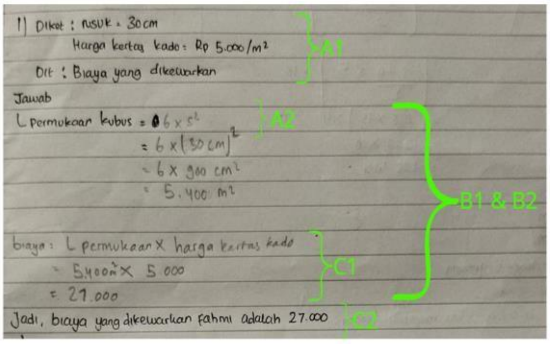

Figure 11. Answer sheet for question number 1 by LMR

Based on the analysis of written responses and interviews regarding problem number 1, Subject 3 (LMR) demonstrated a reasonably good understanding of mathematical literacy across several problem indicators. This is evidenced by LMR's ability to: (1) Identify mathematical aspects within the problem (Indicator A1): LMR was able to recognize the mathematical concepts and elements relevant to the problem. Subject 3 was able to list the given information as well as the information requested by the problem. (2) Translate the problem into mathematical language (Indicator A2): LMR was not yet able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams. Subject 3 wrote down an incorrect formula for the surface area of a cube. (3) Formulate a solution strategy (Indicator B1): LMR was not yet able to formulate systematic steps to solve the problem. However, because Subject 3's initial formula was incorrect, the final solution was incorrect as well.

Although LMR demonstrated competence in indicators A1, B1, B2, and C1 both in writing and orally weaknesses in indicators B2 and C2 across both assessment forms indicate a need for improvement. Specifically, LMR needs to enhance its ability to translate problems into mathematical language and apply mathematical concepts, as well as to solve problems by linking mathematics to real-world contexts and logically explaining why the solution aligns with the problem's context.

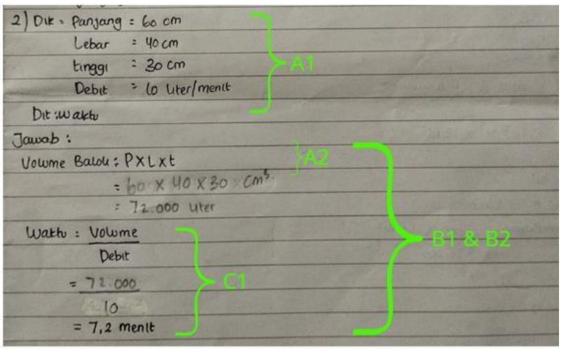

Figure 12. Answer sheet for question number 2 by LMR

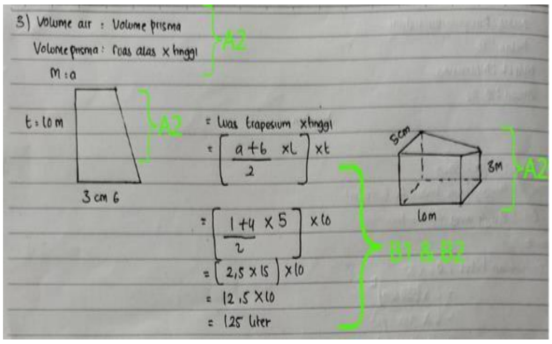

Figure 13. Answer sheet for question number 3 by LMR

Based on an analysis of written responses and an interview with LMR regarding problem number 2, Subject 3 demonstrated a reasonably good understanding of mathematical literacy across several problem indicators. This is evidenced by LMR's ability to: (1) Identify mathematical aspects of the problem (indicator A1): LMR was able to recognize mathematical concepts and elements relevant to the problem. Subject 3 was able to list the given information as well as the information required by the problem. (2) Translate the problem into mathematical language (indicator A2): LMR was able to represent the problem using appropriate mathematical models, symbols, drawings, or diagrams. Subject 3 correctly wrote down the formula for the volume of a rectangular prism. (3) Devise a solution strategy (indicator B1): LMR was able to formulate systematic steps to solve the problem. (4) Apply mathematical concepts (indicator B2): The student was able to use mathematical concepts and theories relevant to the problem during the solution process.

Although LMR demonstrated proficiency in indicators A1, A2, B1, B2, and C1 in writing, Subject 3 was unable to interpret the solution results or logically explain why the result aligned with the problem's context. Overall, while LMR showed a reasonably good grasp of mathematical literacy regarding several indicators, there are still aspects requiring improvement particularly concerning communication skills and the ability to relate mathematics to real-world contexts.

Based on an analysis of LMR's written responses and interview regarding question number 3, LMR has not demonstrated adequate mathematical literacy across several problem indicators.

This is evident from LMR's inability to: (1) Identify mathematical aspects of the problem (indicator A1): LMR failed to recognize the mathematical concepts and elements relevant to the problem. Subject 3 did not record the information provided or the specific question asked. (2) Interpret the solution results (indicator C1): LMR was unable to relate the mathematical solution results to the actual context of the problem. (3) Explain the reasoning behind the results (indicator C2): LMR could not logically explain why the solution results aligned with the problem context.

LMR was unable to identify the mathematical aspects of the problem or apply relevant mathematical concepts and theories during the solution process.

Subject 3 also struggled to demonstrate verbal competence in indicators B2 and C2; this means LMR could not explain the solution process or the reasoning behind the results. Furthermore, LMR did not demonstrate mastery of indicators A1, B1, B2, C1, and C2 in writing, indicating an inability to relate mathematical solution results to the actual problem context in written form.

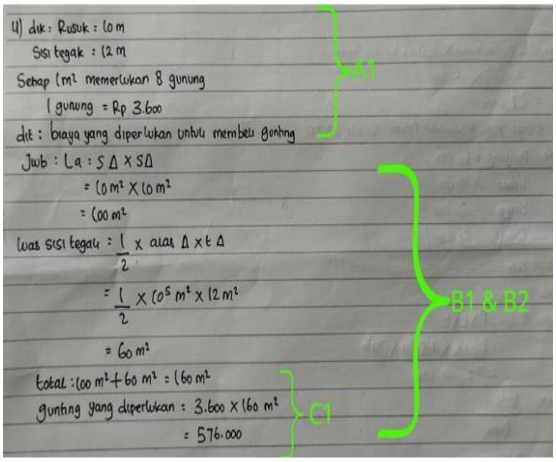

Figure 14. Answer sheet for question number 4 by LMR

Based on an analysis of the written responses and interview results regarding question number 4, LMR has not demonstrated comprehensive mathematical literacy for the problem. This is evident from LMR's inability to meet the six indicators associated with the problem: (1) Identifying mathematical aspects of the problem (indicator A1): LMR was unable to recognize the mathematical concepts and elements relevant to the problem. The subject did not note down the provided information or the specific question asked. (2) Translating the problem into mathematical language (indicator A2): LMR was able to represent the problem using appropriate mathematical models, symbols, images, or diagrams. However, the subject was unable to explain this verbally during the interview. (3) Designing a solution strategy (indicator B1): LMR was unable to formulate systematic steps to solve the problem. (4) Applying mathematical concepts (indicator B2): LMR was unable to utilize mathematical concepts and theories relevant to the problem during the solution process. (5) Interpreting the solution results (indicator C1): LMR was unable to relate the mathematical solution to the real-world context of the problem. (6) Explaining the reasoning behind the results (indicator C2): LMR was unable to provide a logical explanation as to why the solution result aligned with the context of the problem.

CONCLUSION

The Problem-Based Learning (PBL) model utilizing the Indonesian Realistic Mathematics Education (IRME) approach and the Math Trail method has proven effective in fostering mathematical literacy among eighth-grade students at SMP Negeri 1 Depok. Based on an analysis of responses and interviews, students with a high level of mathematical literacy (LMT) met all six indicators of LMT. Students with a moderate level of mathematical literacy (LMS) were able to meet three indicators: identifying mathematical aspects within a problem, translating the problem into mathematical language, and formulating a solution strategy. Students with a low level of mathematical literacy (LMR) were able to correctly meet only one indicator: identifying mathematical aspects within a problem.

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