ISSN 2502-5872 (Print)
ISSN 2622-3627 (Elektronik)

Volume 11 Number 3, August 2026, 757-770

STUDENTS' MATHEMATICAL LITERACY PROBLEM-SOLVING SKILLS BASED ON KRULIK AND RUDNICK'S THEORY

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ABSTRACT

This study sought to describe high school students' mathematical literacy problem-solving skills based on the stages of Krulik and Rudnick. A qualitative descriptive approach was adopted. Data were obtained from a mathematical literacy task and semi-structured interviews. The participants comprised tenth-grade students from a senior high school in Malang Regency, who were classified into high, medium, and low categories. One subject from each category was purposively selected for an in-depth investigation. The data were analyzed following the interactive model proposed by Miles, Huberman, and Saldana, consisting of data condensation, data display, and conclusion drawing. The findings revealed that the subject in the high category fulfilled all indicators across every stage of Krulik and Rudnick's framework. The subject in the medium category fulfilled most indicators but demonstrated limitations at the Select a Strategy stage by failing to identify all possible solutions and at the Reflect and Extend stage by not fulfilling all indicators. In contrast, the subject in the low category fulfilled only the indicators at the Read and Think stage and several indicators at the Explore and Plan stage, while failing to fulfill the indicators at the subsequent stages.

Keywords: Problem Solving, Mathematical Literacy Question, Krulik and Rudnick.

How to Cite: Anugrahani, D., & Hidayah, I. N. (2026). Students' Mathematical Literacy Problem-Solving Skills Based on Krulik and Rudnick's Theory. *Mathline: Jurnal Matematika dan Pendidikan Matematika, 11*(3), 757-770. http://doi.org/10.31943/mathline.v11i3.1186

PRELIMINARY

Problem-solving skills are among the essential competencies in 21st-century education (Khalid, Saad, Hamid, Abdullah, Ibrahim & Shahrill, 2020; Szabo, Körtesi, Guncaga, Szabo & Neag, 2020). When solving mathematical problems, students are expected to go beyond obtaining the correct answer by understanding the problem and developing an appropriate solution plan. However, many students still tend to rely on formulas and procedures without engaging in the complete problem-solving process (Pramuditya, Noto & Azzumar, 2022; Ruliani, Nizaruddin & Murtianto, 2018).

Krulik and Rudnick (1993) defined problem solving as a process in which individuals use their previously acquired knowledge, skills, and understanding to address unfamiliar situations through a series of interconnected problem-solving stages. Such

ability develops through students' engagement in problem-solving activities (Son, Darhim & Fatimah, 2020). However, previous studies have indicated that students may encounter difficulties when progressing through the complete problem-solving process, which can lead to incomplete solutions or responses that fail to address the problem appropriately (Vidad & Quimbo, 2021; Hadi & Suhendra, 2025). Therefore, a more in-depth investigation of students' problem-solving skills is needed.

In this study, students' problem-solving skills were examined through mathematical literacy tasks, as these tasks require students to formulate, employ, and interpret mathematics in a variety of contexts (OECD, 2019). These characteristics enable students to demonstrate their problem-solving skills more comprehensively. However, mathematical literacy remains a challenge for Indonesian students. PISA results have shown a decline in Indonesia's mathematical literacy performance from 2018 to 2022 (Setiawan, Wardono, Wijayanti, Mulyono & Bishtawi, 2024; Shofa & Hidayah, 2024). Consistent with these findings, Fadilah, Subanti and Usodo (2023) reported that students demonstrated problem-solving skills only at the initial stages when solving high-level PISA tasks. Similarly, Muhaimin, Sholikhakh, Yulianti, Ardani, Hendriyanto and Sahara (2024) found that students still experienced difficulties in interpreting problems, formulating mathematical models, and communicating their solutions.

This study adopted Krulik and Rudnick's problem-solving stages, namely *Read and Think, Explore and Plan, Select a Strategy, Find an Answer,* and *Reflect and Extend,* as the analytical framework because these stages provide a comprehensive framework for examining students' problem-solving skills at each stage of problem solving (Krulik & Rudnick, 1993). Previous studies have examined students' problem-solving abilities based on Krulik and Rudnick's framework in different contexts. Salwa, Hidayah & Aribuabo (2025) investigated students' problem-solving abilities using contextual circle problems, whereas Setiani, Lukman & Agustiani (2024) focused on junior high school students' difficulties in solving linear equation problems. However, evidence regarding tenth-grade senior high school students' mathematical literacy problem-solving skills assessed through authentic mathematical literacy tasks and analyzed comprehensively across all five stages of Krulik and Rudnick's framework remains limited.

To address this gap, this study contributes to the existing literature by examining tenth-grade senior high school students' mathematical literacy problem-solving skills through authentic mathematical literacy tasks and providing an in-depth qualitative analysis across all five stages of Krulik and Rudnick's framework. Accordingly, this study aims to describe tenth-grade senior high school students' mathematical literacy problem-solving skills based on Krulik and Rudnick's problem-solving stages.

METHODS

This study employed a qualitative descriptive design to describe students' mathematical literacy problem-solving skills based on Krulik and Rudnick's problem-solving stages. The participants were 21 tenth-grade students from one senior high school in Malang Regency. All participants completed one mathematical literacy task and were classified into high, medium, and low categories based on the mean and standard deviation criteria proposed by Arikunto (2018). One student from each category was then selected through purposive sampling based on three criteria: written responses that reflected the characteristics of the category, the ability to communicate their reasoning during the interview, and willingness to participate. Data were collected through a mathematical literacy task followed by semi-structured interviews with the selected subjects.

The research instruments consisted of a mathematical literacy task and a semi-structured interview guide. Before data collection, the instruments were reviewed by the research supervisors and formally validated by an expert in mathematics education. The instruments were revised based on the validator's feedback, while the mathematical literacy task was subsequently reviewed by the mathematics teacher at the research site to ensure its suitability for the research context. The data were analyzed using the interactive model of Miles, Huberman and Saldana (2014), which consists of data reduction, data display, and conclusion drawing. The analysis was guided by the problem-solving indicators proposed by Krulik and Rudnick. The stages and problem-solving indicators proposed by Krulik and Rudnick used in this study are presented in Table 1.

Table 1. Krulik and Rudnick's Problem Solving Stages and Indicators

No.	Problem Solving Stages	Problem Solving Indicators
1.	*Read and think*	Identify the facts
		Identify the question
		Visualize the situation
		Describe the setting
2.	*Explore and plan*	Organize the information
		Is there sufficient information?
		Is there too much information?
		Draw a diagram or construct a model
		Make a chart, table, graph, or drawing
3.	*Select a strategy*	Pattern recognition
		Working backwards
		Guess and test
		Reduction/expansion
		Organized listing/exhaustive listing
4.	*Find an answer*	Use computational skills
		Use algebraic skills
		Use geometric skills
5.	*Reflect and extend*	Check your answer

No.	Problem Solving Stages	Problem Solving Indicators
		Find alternate solutions
		What if ...?
		Extend to a generalization
		Discuss the solution
		Create interesting variations on the original problem

RESULT AND DISCUSSION

Based on the participants' responses to the mathematical literacy task, the mean score reached 7,48 with a standard deviation of 3,96. Based on Arikunto's (2018), classification criteria, the participants were grouped into three categories: high, medium, and low, as presented in Table 2.

Table 2. Classification of Participants Based on Mathematical Literacy Task Scores

Category	Score Criteria	Number of Students
High	$X \geq 11{,}44$	3
Medium	$3{,}52 < X < 11{,}44$	14
Low	$X \leq 3{,}52$	4

Based on this classification, one research subject was selected from each category and cited as S1, S2, and S3.

Problem-solving skills of the high category subject (S1)

S1 fulfilled all problem-solving indicators across all stages of Krulik and Rudnick's problem-solving framework. At the *Read and Think* stages, S1 demonstrated the ability to identify the facts and the question by writing the known and required information on the written response and restating the information when interviewed. Figure 1 presents the subject's visualization of the problem situation.

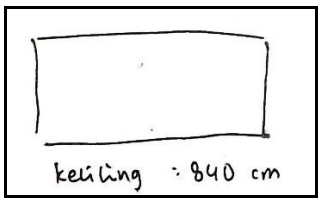

Figure 1. S1's Answer at The *Read and Think* Stage

In addition, S1 restated the problem situation in their own words during the interview, as illustrated in the following excerpt.

P : Describe the situation presented in this problem in your own words!
S1 : There is a study group consisting of male and female students with several conditions regarding their numbers. We were asked to determine the possible group sizes that satisfy these conditions and then identify which group would fit the table available in the library.

At the *Explore and Plan* stage, S1 demonstrated the ability to organize the information by identifying the constraints in the problem and constructing a mathematical model representing the relationship between the numbers of male and female students, as presented in Figure 2.

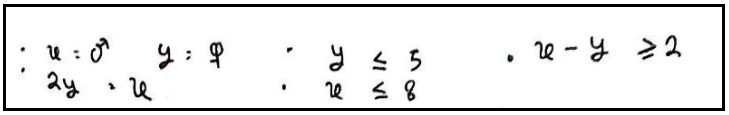

Figure 2. S1's Answer at The *Explore and Plan* Stages

Furthermore, the interview findings indicated that S1 considered the information provided in the problem sufficient for solving it and identified information that was not used. S1 also organized the information by constructing a table, as presented in Figure 3.

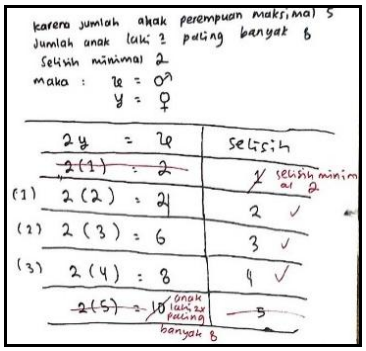

Figure 3. S1's Answer at The *Explore and Plan, Select a Strategy*, and *Find an Answer Stages*

At the *Select a Strategy* stage, S1 demonstrated pattern recognition, as illustrated by the following interview excerpt.

P : Did you notice any patterns in the information provided in the problem?
S1 : The number of female students is always half the number of male students. When the numbers are added together, the total is always a multiple of three.

Furthermore, S1 demonstrated the guess-and-test strategy by trying various possible values and verifying whether they satisfied all the given conditions. The ability is illustrated in Figure 3 and further supported by the following interview excerpt.

P : How did you try a possible solution and check whether it satisfied the given conditions?
S1 : I started with the number of female students because the maximum was five. Then, I checked each possible value one by one to determine whether it satisfied all the given conditions before identifying the group that matched the table's capacity.

Based on the written answer, S1 simplified the problem by constructing a mathematical model and organizing all possible values into a table, allowing all pairs that satisfied the given conditions to be identified. This ability is illustrated in Figure 3. After

testing all possible values, S1 summarized the valid pairs in a summary table. The final results are presented in Figure 4.

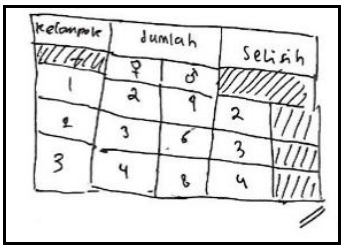

Figure 4. S1's Answer at The *Select a Strategy* Stage

Based on Figure 4, S1 eliminated the possibilities that did not satisfy the given conditions, resulting in all valid pairs being identified. At the *Find an Answer* stage, S1 demonstrated computational skills by determining the pairs that satisfied all the given conditions. This ability is also illustrated in Figure 3. The same figure further shows S1's use of algebraic skills when expressing the relationship between the numbers of male and female students using a mathematical model. In addition, S1 applied computational skills to verify that the total number of group members matched the table's capacity. S1's final answer is presented in Figure 5.

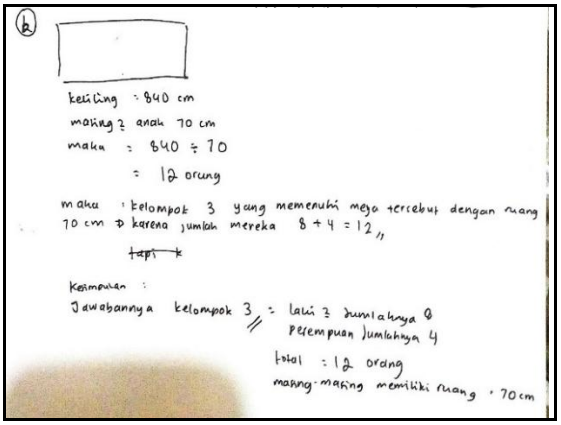

Figure 5. S1's Answer at The *Find an Answer* Stage

Based on Figure 5, S1 calculated 840: 70 to determine the maximum number of students that could be accommodated at the table. This demonstrates S1's use of geometric skills by relating the table's perimeter to the space required for each student. At the *Reflect and Extend* stage, S1 checked both the final answer and the solution process. S1 also considered an alternative solution strategy, as illustrated in the following interview excerpt.

P : Were there any other ways you could have used to solve this problem?
S1 : Yes. I didn't have to use a table. I could have solved it by applying substitution based on the relationship between the numbers of female and male students. However, I used a table because it made the solution process easier.

Student 1's response to the "what if" question is presented in the following interview excerpt.

P : What if the requirement of a minimum difference of two students was removed? How many additional possibilities would there be?
S1 : If the requirement of a minimum difference of two students was removed, there would be four possible pairs. Previously, there were three possible pairs: two female students and four male students, three female students and six male students, and four female students and eight male students. Without the minimum difference requirement, one female student and two male students would also satisfy the given conditions, resulting in one additional possible pair.

S1's ability to extend the solution to a more general situation is demonstrated by applying the same solution strategy to a similar problem. The following interview excerpt illustrates this ability.

P : Can the solution strategy you used be applied to similar problems involving different numbers of students or different table sizes? Please explain!
S1 : Yes, as long as the same pattern can be identified. We just need to know the maximum number of students, the maximum numbers of female and male students, and the required difference between them. Then, the same solution strategy can be applied.

In addition, S1 explained the solution process in a logical sequence, as illustrated in the following interview excerpt.

P : Are you confident in the answer you obtained? Please explain the steps you took to arrive at your answer!
S1 : Yes, I am confident in my solution. First, I identified the information provided in the problem. Then, I constructed a mathematical model and organized all possible values in a table. After that, I checked each possible pair against the given conditions before matching the total number of students with the table's capacity. Based on these steps, I concluded that the appropriate group consisted of four female students and eight male students.

Finally, S1 created a new variation of the original problem by modifying the given conditions while preserving its underlying mathematical structure. The following interview excerpt illustrates this ability.

P : Create a new variation of the original problem by changing one of the given conditions. Then, briefly explain how you would solve it!
S1 : For example, I would change the problem so that the maximum number of female students is six, the maximum number of male students is nine, and the minimum difference is three students, while the number of female students remains half the number of male students. The solution strategy would remain the same. Based on these conditions, there would be two pairs: three female students and six male students, and four female students and eight male students.

These findings indicate that S1's mathematical literacy problem-solving ability fulfilled all the indicators across every stage of Krulik and Rudnick's framework. This finding is consistent with those reported by Sesa & Tanujaya (2022) and Salwa, Hidayah and Aribuabo (2025), who found that students in the high category fulfilled all the problem-solving indicators at each stage of Krulik and Rudnick's framework. Students in this category are able not only to identify relevant information and develop an appropriate solution plan but also to select and implement suitable strategies to obtain correct solutions. Furthermore, they are able to check their solutions and extend the original problem by modifying the given conditions.

Problem solving skills of the medium category subject (S2)

S2 fulfilled most of the problem-solving indicators across Krulik and Rudnick's framework. However, S2 demonstrated limitations, particularly at the *Select a Strategy* and *Reflect and Extend* stages. At the *Read and Think* stage, S2 was able to identify the given information and the question posed in the problem. A visualization of the problem situation is presented in Figure 6.

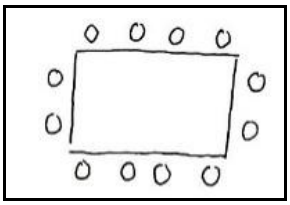

Figure 6. S2's Answer at The *Read and Think* Stage

S2 restated the problem situation in the interview, as illustrated in the following interview excerpt.

P : Describe the situation in this problem in your own words!
S2 : There is a study group with certain requirements regarding the numbers of female and male students. Then, we need to determine which group matches the table's capacity.

At the *Explore and Plan* stage, S2 organized the given information, as shown in the written answer presented in Figure 7.

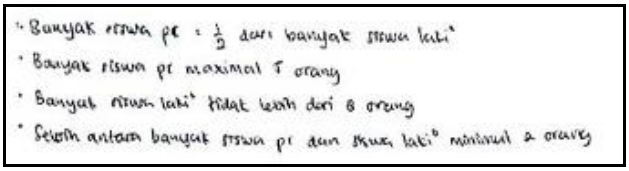

Figure 7. S2's Answer at The *Explore and Plan* Stage 1

Figure 7 shows that S2 was able to organize the given information using bullet points. The interview findings indicate that S2 considered the information provided in the problem sufficient to solve it and identified that students' names were not used in the solution. However, S2 did not construct a mathematical model using symbols or equations. Instead, S2 organized the information by constructing a table, as presented in Figure 8.

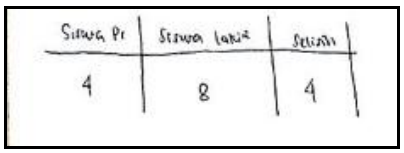

Figure 8. S2's at The *Explore and Plan* Stage 2

Using the table, S2 was able to organize the possible pairs, although not all possible pairs were included. At the *Select a Strategy* stage, S2 did not demonstrate pattern recognition. Instead, S2 applied the working backwards strategy, as illustrated in the following interview excerpt.

P : *Did you first determine the total number of students who could be accommodated at the table and then identify the corresponding numbers of female and male students?*

S2 : *Yes. I first determined the maximum number of students that the table could accommodate by calculating 840: 70 = 12. Then, I looked for a pair in which the number of female students was half the number of male students, namely four female students and eight male students. After that, I checked whether the pair satisfied the given conditions.*

After determining that the table could accommodate 12 students, S2 immediately selected a single pair consisting of four female students and eight male students without considering other possible pairs. The working backwards strategy used by S2 was appropriate for determining a feasible combination based on the table capacity. However, its application remained limited because S2 did not systematically examine other possible combinations that satisfied the given conditions. As a result, S2 was able to obtain a valid solution but did not identify all possible solutions. This indicates that the limitations lie not in the strategy itself, but in the lack of systematic exploration when applying it. This finding is supported by the following interview excerpt.

P : *Did you try to find any other possible pairs besides the one you identified?*

S2 : *No. I did not consider any other possible pairs because I thought there was only one group. Therefore, I was not aware that there were other valid pairs.*

At the *Find an Answer* stage, S2 demonstrated computational skills by determining the number of students that could be accommodated at the table through dividing the

table's perimeter by the space required for each student. S2's written answer is presented in Figure 9.

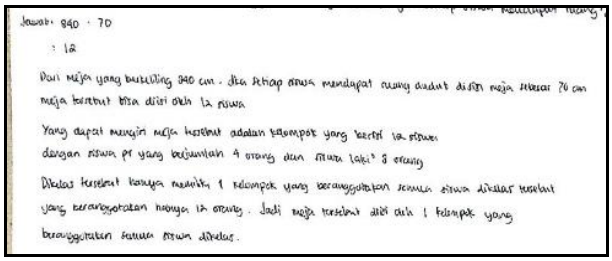

Figure 9. S2's Answer at The *Find an Answer* Stage

In addition, S2 identified a valid pair consisting of four female students and eight male students before verifying that it satisfied all the given conditions. This demonstrates S2's ability to evaluate whether the solution was consistent with the given conditions. The application of geometric skills was evident in the use of the table's perimeter to determine its student capacity. However, S2 did not demonstrate algebraic skills by constructing a mathematical model using symbols or equations to represent the relationship between the variables.

At the *Reflect and Extend* stage, S2 checked the obtained solution, as illustrated in the following interview excerpt. Furthermore, although S2 recognized that an alternative solution strategy might exist, S2 was unable to explain what the strategy would be. This finding is supported by the following interview excerpt.

P : Are there any other solution strategies that you could use to solve this problem?
S2 : Yes, but I do not know what the other strategy would be.

Regarding the "what if" indicators, S2 did not respond to the question, indicating that no attempt was made to explore how changes in the given conditions would affect the solution. Nevertheless, S2 was able to extend the solution strategy to a similar situation. This ability is illustrated in the following interview excerpt.

P : Can the solution strategy you used be applied to similar problems involving different numbers of students or different table sizes? Please explain!
S2 : Yes. Even if the table size is different, the same strategy can still be applied. First, the table's perimeter is divided by the space required for each student to determine the number of students that can be accommodated. Then, the appropriate numbers of female and male students are determined in the same way as before.

In addition, S2 explained the solution process in a logical sequence, although the explanation reflected uncertainty regarding the completeness of the solution. This is illustrated in the following interview excerpt.

P : Are you confident in the answer you obtained? Please explain the steps you took to arrive at your answer!
S2 : I am confident, but not completely. I believe my answer is correct, but I am not sure whether there are other valid pairs. First, I determined the number of students that the table could accommodate by dividing 840 by 70, which gave 12 students. Then, I identified a pair in which the number of female students was half the number of male students, namely four female students and eight male students. Finally, I checked whether the pair satisfied all the given conditions: the number of female students did not exceed five, the number of male students did not exceed eight, and the difference between them was four, which satisfied the minimum difference requirement.

Finally, S2 was unable to create a new variation of the original problem, indicating that not all indicators at the *Reflect and Extend* stage were fulfilled. This finding is consistent with the study by Fadilah, Subanti and Usodo (2023), which reported that students experienced difficulties at the *Select a Strategy* stage. Although students were able to understand the problem, organize the given information, and perform the required computations accurately, they were limited in developing solution strategies that considered all possible pairs. Consequently, this limitation also affected their performance at the *Reflect and Extend* stage, where they were unable to fulfill all of the indicators.

Problem-solving skills of the low category subject (S3)

S3 fulfilled only the indicators at the *Read and Think* stage and some of the indicators at the *Explore and Plan* stage. At the subsequent stages, S3 did not demonstrate the problem-solving abilities reflected in Krulik and Rudnick's framework. At the *Read and Think* stage, S3 was able to identify the given information and the question posed in the problem. A visualization of the problem situation is presented in Figure 10.

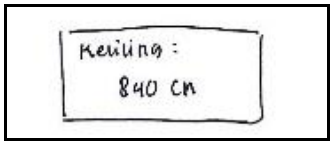

Figure 10. S3's Answer at The *Read and Think* Stage

In addition, S3 restated the problem situation in the interview, as illustrated in the following interview excerpt.

P : Describe the situation in this problem in your own words!
S3 : The problem asks us to determine the possible numbers of female and male students that satisfy the given conditions and then identify the group that matches the table's capacity.

At the *Explore and Plan* stage, S3 demonstrated difficulty in organizing the given information. Nevertheless, S3 recognized that the information provided in the problem was sufficient and identified that the students' names were not used in the solution. S3 constructed a table based on estimation; however, it did not correspond to the given

conditions and therefore did not support the development of an appropriate solution. This is illustrated in Figure 11.

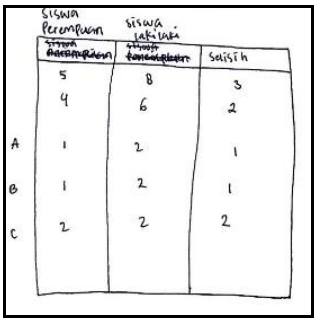

Figure 11. S3's Answer at The *Explore and Plan* and *Select a Strategy* Stages

Although S3 attempted to list the possible combinations of students, the entries in the table did not correspond to the given condition and therefore did not support the development of an appropriate solution. At the *Select a Strategy* stage, S3 was unable to recognize the pattern underlying the relationship between the given quantities. This limitation became evident during the interview when S3 was unable to interpret the relationship between the numbers of female and male students, as shown in the following interview excerpt.

P : Did you notice any specific patterns in the information provided in the problem?
S3 : No
P : Do you understand what the statement means when it says that the number of female students is half the number of male students?
S3 : I don't understand
P : Could you explain what you found confusing?
S3 : I did not fully understand this part. The problem states that the number of female students is half the number of male students. However, because the number of male students is not given, I was confused about how to determine the number of female students.

S3 attempted a guess-and-test strategy by listing several possible combinations in a table, as presented in Figure 11. However, S3 did not verify whether these combinations satisfied the given conditions. In addition, S3 did not produce an organized listing, as the table was constructed based solely on estimation without systematically considering all of the given conditions. At the *Find an Answer* stage, S3 demonstrated basic computational skills; however, these computations were not applied in accordance with the conditions of the problem. Instead, S3 directly used the maximum values without considering the relationships between the variables. Furthermore, S3 did not demonstrate algebraic skills by expressing the relationships between the variables mathematically. Geometric skills were also not demonstrated because S3 did not attempt the part of the problem involving the table's perimeter.

At the *Reflect and Extend* stage, S3 did not review the obtained solution and did not demonstrate an alternative solution strategy. Regarding the "what if" indicator, S3 was unable to explain how changes in the given conditions would affect the solution. Furthermore, S3 did not demonstrate the ability to extend the solution strategy to a similar situation or provide a clear explanation of the solution. S3 also did not demonstrate confidence in the obtained solution. Finally, S3 was unable to create a new variation of the original problem, indicating that none of the indicators at the *Reflect and Extend* stage were fulfilled.

These findings are consistent with those reported by Gayo, Lestari, Oktavianingtyas, Trapsilasiwi and Murtikusuma (2025) and Lika, Making and Lede (2023), who found that students in the low category fulfilled only the indicators at the initial *Read and Think* stage. At the subsequent stages, from *Explore and Plan* through *Reflect and Extend,* students demonstrated difficulties in organizing information, selecting appropriate solution strategies, applying computational skills appropriately, and reviewing their solutions. These findings indicate that the problem-solving abilities of students in the low category remain limited to the initial stage of problem solving.

CONCLUSION

The findings of this study indicate that students' mathematical literacy problem-solving abilities differed across the three subject categories based on Krulik and Rudnick's framework. The high category subject fulfilled all indicators at every stage, from *Read and Think* to *Reflect and Extend.* The medium category subject fulfilled most of the indicators but remained limited in developing solution strategies at the *Select a Strategy* stage, resulting in the failure to identify all possible solutions and to fulfill all indicators at the *Reflect and Extend* stage. In contrast, the low category subject fulfilled only the indicators at the *Read and Think* stage and some of the indicators at the *Explore and Plan* stage but did not fulfill the indicators at the subsequent stages.

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