Jurnal Gantang *11*(1) (2026): 99 - 110

e-ISSN: 2548-5547
p-ISSN: 2503-0671

http://ojs.umrah.ac.id/index.php/gantang/index

Students' obstacles in solving mathematical literacy problems using the onto-semiotic approach

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Submission: December 16th 2025; Accepted: May 24th 2026; Published: May 31st 2026
DOI: https://doi.org/10.31629/jg.v11i1.8066

Abstract

Mathematical literacy is crucial for students, requiring both an understanding of mathematical concepts and the ability to apply them in solving diverse problems. However, students frequently encounter difficulties with mathematical literacy tasks, particularly those involving proportions, which may constitute learning obstacles. This study aims to identify and analyze students' learning obstacles in the context of mathematical literacy on the topic of proportions using an onto-semiotic approach. Qualitative research with a phenomenological approach was employed in this study, involving 27 eighth-grade students at a State Junior High School in Ngoro. Data collection techniques include tests, interviews, and documentation studies. Data analysis consisted of three stages: reduction, presentation, and conclusion. This study reveals three types of learning obstacles among students: (1) epistemological obstacles, which arise from students' limited understanding of concepts related to proportion; (2) ontogenic obstacles, which occur due to a leap in students' cognitive transition; and (3) didactical obstacles, which are caused by procedural teaching methods. Based on the onto-semiotic approach, the students had difficulty understanding mathematical language, defining mathematical ideas, applying the property of proportion, and performing appropriate procedures. This study provides insights that may assist teachers in designing more effective instructional strategies.

Keywords: learning obstacles; mathematical literacy; proportion; onto-semiotic approach

How to cite: Amanda, A. T., Hidayanto, E., & Hafiizh, M. (2026). Students' obstacles in solving mathematical literacy problems using the onto-semiotic approach. *Jurnal Gantang, 11*(1), 99 – 110. https://doi.org/10.31629/jg.v11i1.8066

I. Introduction

Along with developments in education, mathematics learning in the 21st century no longer focuses solely on students' mastery of specific mathematical topics. Instead, it emphasizes applying students' understanding to solve a range of contextual problems (Drew, 2012; Holenstein, Bruckmaier, & Grob, 2021; Hwang & Ham, 2021; Kilpatrick, 2001; Wong, 2003). This can be achieved if students possess adequate mathematical literacy skills. Mathematical literacy encompasses the ability to apply mathematical concepts, procedures, facts, and tools to understand and explain phenomena in real-world contexts (OECD, 2019; Stacey & Turner, 2015; Sumarni, Jupri, & Juandi, 2025). It also helps students recognize the role that mathematics plays in the world and make sound judgments and decisions (OECD, 2019; Serin, 2023). Therefore, mathematical literacy has become one of the standards for mathematics mastery at both national and international scales.

Based on the PISA test results, the average level of mathematical literacy among Indonesian students remains relatively low. In 2015, 2018, and 2022, Indonesian students' mathematics scores on the PISA test were 386, 379, and 366, respectively, while the global average scores were 490, 487, and 472 (Kemendikbud, 2019; Masfufah & Afriansyah, 2021). In addition, the preliminary study results showed that the average AKM score of students was 66.38, with the lowest score found in algebra content at 58.70. Algebra content includes material on equations and inequalities, relations and functions, and ratios and proportions (Kementerian Pendidikan dan Kebudayaan, 2020).

Proportion is a crucial topic for middle school students to understand. Sevinc & Lizano (2024) state that two basic concepts, among many others, are ratio and proportion. In addition, many daily activities are closely related to the concept of proportion (Ben-Chaim, Keret, & Ilany, 2012; Domondon et al., 2024). A thorough understanding of this concept is commonly viewed as a crucial link between concrete numerical reasoning in arithmetic and the abstract thinking required in algebra and advanced mathematics (Avcu & Avcu, 2010; Martinovic, 2024). However, if students' understanding of this topic is not well facilitated, it can affect their understanding of more advanced mathematics topics.

Several studies indicate that students have difficulty solving problems involving proportions and make errors. Ambarwati & Ekawati (2022) found that students had difficulty representing mathematical situations using mathematical models and were also unable to interpret mathematical results in real-life contexts. Fauziah & Cahya (2021) identified that students had difficulty translating words or phrases into mathematical notation, applying mathematical operations, and distinguishing between several concepts related to proportions. In addition, Wardani, Prabawanto, & Jupri (2024) found that students had difficulty understanding the given problems and the basic concepts of proportions needed to solve them.

Several difficulties students encounter when solving mathematical literacy problems indicate that they face obstacles in their learning. Learning obstacles are external or internal disturbances that hinder students' ability to learn (Warli, Fatimah, Wicaksono, & Kaha, 2025). Learning obstacles based on their nature are classified into three categories: (1) ontogenic obstacles (students' cognitive mental unpreparedness); (2) epistemological obstacles (limited knowledge when dealing with certain contexts); and (3) didactical obstacles (inappropriate methods or approaches used by teachers in instruction) (Brousseau, 2002; Suryadi, 2019).

Learning obstacles provide a theoretical lens to identify the origins of students' difficulties in solving mathematical literacy problems. However, identifying the nature of the obstacle itself is often insufficient to explain how these difficulties manifest in students' mathematical activity (Erbay, 2024; Febriyanti, Mustadi, & Jerussalem, 2021). To address this limitation, the onto-semiotic approach serves as a tool for understanding the complex nature of mathematical concepts by analyzing the use of mathematical objects that emerge in the problem-solving process (Godino, Font, Wilhelmi, & Lurduy, 2011; Kamariah, 2022). In this approach, mathematical objects consist of six primary entities: (1) languages (terms, notation, expressions, and graph); (2) situation (problems, exercise, extra or intra mathematical applications, etc.); (3) definition (description of a mathematical idea); (4) properties which are generally expressed as statements; (5) procedure (operation, algorithm, and technique); and (6) argument used to validate and explain property and procedure (Font, Godino, & Gallardo, 2013; Godino, Batanero, & Font, 2007; Godino, Batanero, & Roa, 2005).

Although previous studies have discussed various learning obstacles in mathematics, such as difficulties in solving problems (Nurhayati, Priatna, Herman, & Dasari, 2023) and challenges in instructional planning (Prabowo, Suryadi, Dasari, Juandi, & Junaedi, 2022), there is still a lack of research that specifically focuses on students' learning obstacles in the context of mathematical literacy using the onto-semiotic approach. Through this approach, students' difficulties can be interpreted in terms of their nature and the specific mathematical objects they struggle with. This gap highlights the need for further study and motivates the present study to identify students' learning obstacles in solving mathematical literacy problems using the onto-semiotic approach. This study provides more detailed insights to help teachers identify which aspects of mathematical objects require attention, which may assist them in designing more effective instructional strategies and avoiding the identified obstacles.

II. Research Method

This study adopts a qualitative phenomenological approach that focuses on understanding how individuals construct meaning from their lived experiences (Byrne, 2025; Creswell & Poth, 2018). In the context of mathematics learning, students' learning obstacles cannot be fully understood solely from their answers; they require exploration of how students experience and interpret difficulties during the problem-solving process. Therefore, this approach was chosen to identify and analyze students' learning obstacles in solving mathematical literacy problems on the topic of proportion using the onto-semiotic approach.

The participants consisted of 27 eighth-grade students at a State Junior High School in Ngoro who had studied the topic of proportion. Purposive sampling was used to select the research subjects, namely four students considered capable of providing rich, detailed insights into students' learning obstacles related to mathematical objects within the onto-semiotic approach.

The data collection techniques in this study included a written test, an interview, and documentation. The instruments in this study consisted of a researcher, a mathematical literacy problem on proportions, interview guidelines, and learning documents, including mathematics textbooks and students' notes.

The tests were conducted to identify students' obstacles in solving mathematical literacy problems. The interviews were conducted using in-depth questions to obtain more detailed information and clarify students' responses. Meanwhile, learning documents are used to explore teachers' instruction and to examine students' work. Before being used in research, the test instruments and interview guidelines were validated by experts in mathematics education.

The data analysis technique in this study followed the framework proposed by Miles & Huberman (1994), which consisted of data reduction, data presentation, and conclusion verification to obtain information about the learning obstacles students experienced when solving mathematical literacy problems using an onto-semiotic approach.

III. Results and Discussion

Identification of learning obstacles in this study was obtained from test results, interviews, and learning documentation. The test results are grouped by the types of difficulties students encounter when solving problems, using the onto-semiotic approach, which focuses on five entities: language, situation, definition, property, and procedure. The diagnostic test results for 27 students working on problems are shown in Table 1 below.

Table 1. Diagnostic results of the students' test grouping

Case	Difficulties		Total
	Problem 1a	**Problem 1b**	
I	Procedure	-	12
II	Procedure	Language	5
III	Procedure	Definition	2

JURNAL GANTANG. May 2026; *11*(1): 99 - 110
p-ISSN. 2503-0671
e-ISSN. 2548-5547

IV	Property, procedure	Definition	1
V	Definition, procedure	-	1
VI	Language	Language	6

As presented in Table 1, students from cases IV and V (S1 and S2) were selected to obtain details about learning obstacles for problem 1a; students from case II (S3) were selected to obtain details about learning obstacles for problem number 1b; and students from case VI (S4) were selected to obtain details about learning obstacles that prevented them from answering the problems.

Based on students' answers to the mathematical literacy test, interview results, and learning documents, three types of learning obstacles were identified in solving mathematical literacy problems on the topic of proportions: epistemological, ontogenic, and didactical.

Epistemological Obstacles

Epistemological obstacles arise from students' limited knowledge when dealing with specific contexts. In other words, students understand a concept but cannot use it in other problems (Azmi, Purwanto, Anwar, & Muksar, 2025). This obstacle was found when students attempted to solve problem 1a. It can be seen from S1's answer in Figure 1.

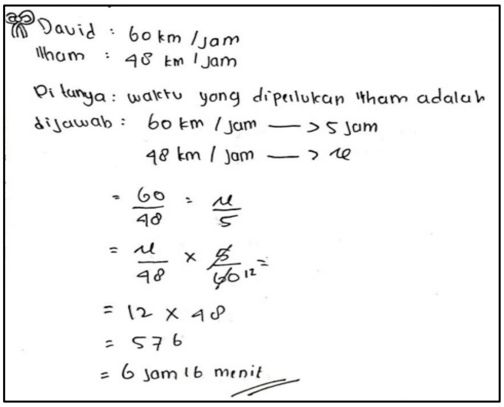

Figure 1. The answer of S1 on point a

The following excerpt presents the translated transcript of the interview between the researcher (R) and S1:

R : Why does S1 use the concept of inverse proportion?

S1 : I tried to calculate them one by one, and if I used direct proportion, the results could not be calculated. Actually, I don't really understand how to differentiate between direct and inverse proportion.

R : What do you mean by "it can't be calculated?"

S1 : The result is 5/48 multiplied by x/60. It's complicated, Ma'am.

R : Now explain your ways to solve this problem!

S1 : First, 60 divided by 48 equals x over 5, reversed because it is inverse proportion. Then we get x/48×5/60. I simplify the numbers, so 12×48, since we're finding x, gives 576 minutes, which is 5 hours plus 76 minutes, so that becomes 6 hours 16 minutes.

R : How can 60/48 = x/5 become x/48 × 5/60?

S1 : Cross-multiply 60 with 5 and x with 48. The crossed numbers are divided, and then the two pairs of numbers are multiplied.

Based on S1's answer in Figure 1 and the interview transcript, S1 had difficulty in distinguishing between the definitions of direct and inverse proportion. She assumed that if the problem was solved using the direct proportion formula, $60/48 = 5/x$, it would yield a complicated value. This occurred due to an error in applying the means-extremes property, leading to an incorrect problem-solving procedure. This finding suggests an epistemological obstacle, as students' knowledge of the concept of proportion could not be transferred to a different problem. Therefore, according to constructivist theory, students may not be fully able to flexibly construct knowledge to deal with new situations (Hechter, Stols, & Combrinck, 2022; Loyens, Rikers, & Schmidt, 2008). The influence of the term "cross-multiplication" used by students for memorizing the property of proportion is discussed further in the didactical obstacles section.

In addition, epistemological obstacles can also be found in the S2's answer in Figure 2.

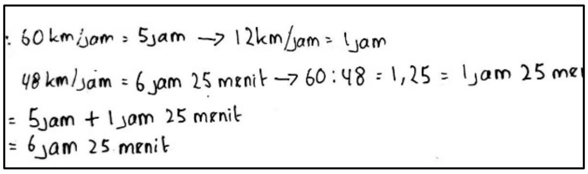

Figure 2. The answer of S2 on point a

The following excerpt presents the translated transcript of the interview between the researcher (R) and S2:

R : Explain how you solved this problem!

S2 : To calculate the time Ilham took, divide 60 by 48, which equals 1.25 hours, or 1 hour 25 minutes. Then add this time to David's time: 5 hours plus 1 hour and 25 minutes equals 6 hours and 25 minutes.

R : Why does 60 divided by 48 result in 1.25 hours, which is then added to Ilham's time?

S2 : Because the question asks for Ilham's time, and since Ilham is slower, his time is longer, so it is added. Actually, I'm still confused and just did it randomly because I forgot the formula.

Based on Figure 2 and the interview results, S2 had difficulty defining the multiplicative relationship between speed and time in an inverse-proportion context. S2 simplified the relationship as a direct proportion by reducing 60 km/h = 5 hours to 12 km/h = 1 hour. Additionally, S2 still relies on additive relationships between the two quantities being compared, leading to incorrect problem-solving procedures. This finding suggests an epistemological obstacle, as the student relied on a familiar proportional procedure without recognizing the inverse relationship between the quantities. Akkaya & Dilekli (2025) and Barumbun & Kharisma (2022) have shown that students' reliance on procedural strategies may lead to epistemological obstacles, limiting their ability to transfer knowledge across different problem contexts. In addition, S2 made an error when converting units of time, assuming that 1.25 hours equals 1 hour and 25 minutes. Similar errors were also found among other students when converting units of time, even when their final numerical answer appeared correct.

Furthermore, an epistemological obstacle was found when students attempted to solve problem 1b, which involved the direct proportion presented in a graph. It can be seen from S3's answer in Figure 3.

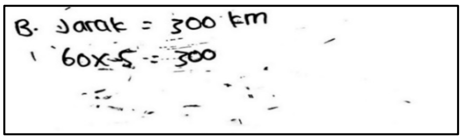

Figure 3. The answer to S3 on point b

The following excerpt presents the translated transcript of the interview between the researcher (R) and S3:

R : From the graph shown in the problem, are you able to understand it?

S3 : Hmm.. I don't really understand. What I know is that this graph shows the relationship between the fuel used by car X and the distance traveled.

R : Okay. How do you read it?

S3 : Umm.. (S3 fell silent and thought). I'm confused. I don't know how. I've never had a question like this before.

Based on Figure 3 and the interview results, S3 was unable to read the linear graph that represented the directly proportional relationship. This shows that the student had limitations in understanding the mathematical language they had never encountered before. Consequently, S3 did not continue her work because she did not know which concepts or procedures to apply to solve the problem. This finding suggests an epistemological obstacle, as the student's understanding of proportional relationships appears to be limited to familiar procedural contexts. This is in line with the findings of Aswin, Jupri, & Prabawanto (2025) and Cai & Rott (2024), which indicate that students often struggle to solve problems when tasks differ from those they typically encounter. Thus, when faced with a new type of problem, students tend to require additional explanation and clarification to determine appropriate steps and strategies (Kandaga, 2022).

Ontogenic Obstacle

Ontogenetic obstacles are closely related to the cognitive limitations of individuals at a given developmental stage (Brousseau, 2002). These obstacles occur when there is a gap in students' conceptual development, preventing them from constructing their own understanding. In this study, an ontogenetic obstacle is evident in S4's answer shown in Figure 4.

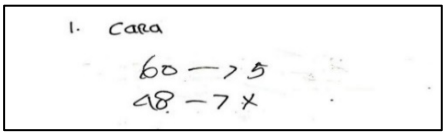

Figure 4. The answer to S4

The following excerpt presents the translated transcript of the interview between the researcher (R) and S4:

R : Why did you not continue your work?
S4 : Because at that time I was really confused.
R : But you've learned about proportions before, right?
S4 : Yes, I have, but I forgot.
R : Were you able to understand the material?
S4 : Honestly, not really. It was explained and written on the board, but it just didn't sink in. Many formulas were hard to understand, and I couldn't concentrate well.

Based on Figure 4, S4 only wrote down the given information and did not continue the answer. After being asked in more depth, it became clear that S4 struggled to understand the concept of proportion, which had been presented abstractly during instruction. She perceived proportion as a collection of abstract formulas that were difficult to understand, which reduced her interest in the material. As a result, she was unable to identify the language, definitions, properties, and procedures needed to solve the problem. This indicates that students' cognitive abilities had not yet reached the level required for abstract thinking, resulting in an ontogenetic obstacle. It aligns with Kaur, Mcloughlin, & Grimes (2022) and Fyfe, Mcneil, & Borjas (2015) that developmental transitions can create learning obstacles for middle school students when they engage with more complex mathematical relationships.

According to Piaget's theory of cognitive development, students aged 12-13 are in the early stage of formal operations (Oogarah-Pratap, Bholoa, & Ramma, 2025). However, this age range is still in the students' cognitive transition from concrete to abstract thinking. When teaching materials are presented directly in abstract form, it creates a cognitive leap that hinders knowledge construction. Furthermore, Suryadi (2019) classifies ontogenic obstacles into three types: psychological, related to students' low interest and motivation in the material; instrumental, demonstrated by students' inadequate grasp of the key concepts underlying the material; and conceptual, related to a mismatch between the conceptual level of instruction and students' learning experiences.

Didactical Obstacle

Didactical obstacles in this study were identified in several fundamental concepts taught by the teacher. Based on the written work and interviews with students S1 and S4, instruction focused on directly explaining definitions, procedures, and properties without facilitating students' independent construction of understanding. This is supported by students' notes, which indicate that the material was presented in an abstract formula. One example of these notes is shown in Figure 5.

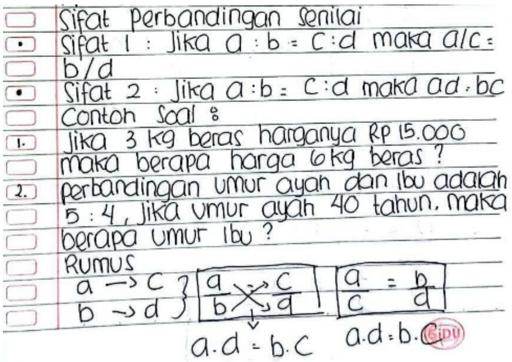

Figure 5. Student's note

The use of abstract formulas can hinder students' ability to develop conceptual understanding. Prasetyawan, Kusumah, & Prabawanto (2025) emphasize that students should be encouraged to construct their own understanding so that the concepts learned become meaningful and more enduring. Therefore, it is important to adopt a holistic instructional approach that considers students' cognitive development and prior knowledge, such as the *CRA (Concrete-Representational-Abstract) approach* (Huan, Meng, & Suseelan, 2022; Pauji, Suryadi, Setambah, & Hendriyanto, 2023).

In addition, the teacher's instructional approach suggests limited opportunities for students to engage with non-routine problem-solving tasks, as reflected in S3's work. This is further supported by the student's notes, which show that the teacher emphasizes worked examples and assigns practice tasks that closely resemble those examples. This is in line with Warli et al. (2025), who state that when instruction emphasizes procedural knowledge without a strong conceptual foundation, students may succeed in familiar tasks but struggle with non-routine problems. Providing more practice tasks, real-world contexts, and hands-on learning experiences can enhance students' conceptual understanding (Schwichow, Zimmerman, Croker, & Hendrik, 2016).

Moreover, procedural instruction may lead to misconceptions during concept formation, as reflected in S1's work. The teacher used the term "cross-multiplication" as a mnemonic to recall the means-extremes property of proportions. Previous studies have reported that mnemonic strategies can improve students' performance in recalling mathematical procedures or facts (Miller & Obara, 2017; Wulandary & Kawai, 2024). However, this strategy can give students a narrow view of mathematics as a collection of formulas that must be memorized rather than concepts to be understood (Graybeal & Strickland, 2018; Kalder, 2012). Mnemonic strategies can be effective when the underlying concepts are first constructed, and the teacher explicitly demonstrates each step in forming the mnemonic.

IV. Conclusion

Based on the results and discussion presented above, students' learning obstacles in solving mathematical literacy problems on the topic of proportions include epistemological, ontogenic, and didactical obstacles. Epistemological obstacles arise from students' limited understanding of proportional concepts. Ontogenetic obstacles arise from students' cognitive unpreparedness, as many are still transitioning from concrete to abstract thinking. Didactic obstacles arise from instructional methods that emphasize direct, procedural teaching, thereby hindering students' development of conceptual understanding of proportions. Based on the onto-semiotic approach, the students had difficulty understanding mathematical language, defining mathematical ideas, using the properties of proportion, and performing the appropriate procedures.

The results of this study provide insights into the learning obstacles students face in understanding the topic of proportions. The onto-semiotic approach can help teachers identify aspects that need to be explored in instruction, thereby enabling the design of effective didactical strategies to address these obstacles. Ultimately, this may help improve students' performance on mathematical literacy assessments, such as AKM and PISA.

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JURNAL GANTANG. May 2026; *11*(1): 99 - 110
p-ISSN. 2503-0671
e-ISSN. 2548-5547