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Analysis of Students' Errors in Solving Surface Area Problems of Spherical Solids Based on Newman's Error Analysis Theory

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Abstract

The topic of curved surface solids, especially the surface area of a sphere, is essential for solving contextual mathematical problems. However, limited research has examined students' difficulties in this area, particularly using Newman's Error Analysis (NEA). This qualitative study aims to identify and analyze students' errors in solving surface area problems of spheres through NEA. Five 9th-grade students from a public junior high school in Cirebon were selected via purposive sampling. Data were collected through tests and interviews, then analyzed descriptively based on Newman's stages. Triangulation and member checking ensured data validity. Results show that the most frequent errors occurred in the final answer stage, where students failed to reach the correct solution. Errors in process skills were also significant—students could choose the correct formula but struggled with calculations. These findings suggest a need for improved instructional strategies that emphasize conceptual understanding and process fluency. Interactive teaching, visual aids, and targeted practice can help students better comprehend spherical geometry. The study underscores the importance of addressing specific learning obstacles to enhance students' mathematical problem-solving skills.

Keywords: Error Analysis; Newman's Error; Surface Area; Spheres.

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1. Introduction

The topic of curved surface solids is significantly connected to contextual problems, making it essential for students to thoroughly understand this concept. Typically, understanding curved surface solids tends to focus more on real spatial forms, while in the classroom, students often only receive theory without practical applications. However, students need concrete objects to help them grasp the concepts of curved surface solids (Mu'asaroh & Noor, 2021). Understanding of this topic not only provides students with additional knowledge but also equips them with skills useful in various fields, including building design, globe creation, and digital applications (Marasabessy et al., 2021; Muna et al., 2024; Sipahutar & Reflina, 2023). By studying and understanding the topic of curved surface solids, students can develop skills in measuring as well as drawing or representing concepts of solids, especially those involving curved surfaces (Samodra, 2022). To gain a deep understanding of curved surface solids like spheres in mathematics, students must have strong mathematical knowledge, good visualization skills, and an understanding of how these concepts are relevant and applied in a contextual (Muna et al., 2024).

However, in reality, many students struggle to understand solids, particularly curved surface solids. Several factors contribute to this difficulty, including students' challenges in remembering the formulas needed to solve problems, some students' lack of proficiency in arithmetic operations, which causes them difficulties in solving problems, and a lack of understanding in analyzing the given problems (Agustini & Fitriani, 2021; Sitorus et al., 2023; Solin et al., 2023). Issues faced by students in solving problems related to the elements, surface area, and volume of curved surface solids are often caused by the absence of visual aids, media, or teaching tools in learning. To address this, innovative teaching media are needed to improve students' understanding of the topic (Dahlan & Kurniasari, 2022; Muna et al., 2024).

Analyzing obstacles or errors is necessary before designing a learning process. By analyzing errors, teachers can evaluate and improve future learning processes. This allows them to select the appropriate approaches, strategies, media, and instructional models, as well as suitable instructional media, to reduce student errors and enhance the effectiveness of mathematics learning (Asikin et al., 2021). With information regarding student errors in solving problems, teachers can design learning activities to address student difficulties, find preventive solutions to minimize errors, and improve problem-solving skills, ultimately leading to improved student mathematics achievement (Aziza & Eratika, 2022; Gumanti & Kartini, 2022).

In analyzing students' errors in solving mathematics problems, teachers can use Newman's Error Analysis (NEA), which is a method for exploring and studying how students solve problems, so that the research findings can be used as useful assessment tools to improve the quality of learning. Newman's Error Analysis was applied to analyse typical misunderstandings and errors (Kania et.al, 2024). The indicators of errors according to Newman's Error Analysis are: (1) reading errors, which involve mistakes in reading the question, such as recognizing words and symbols; (2) comprehension errors, which involve mistakes in understanding the meaning of the question, including linguistic understanding; (3) transformation errors, which involve mistakes in determining the correct mathematical operation or procedure, translating linguistic understanding into mathematical interpretation; (4) process skill errors, which involve mistakes in performing calculations or mathematical procedures accurately; and (5) encoding errors, which involve mistakes in representing the answer correctly after mathematical processing (Prakitipong & Nakamura, 2006).

By using Newman's Error Analysis, students' errors can be identified more easily and systematically. Students can receive more targeted feedback, allowing them to improve their understanding of mathematical concepts (Rahmawati & Dhian Permata, 2018). Teachers can develop more accurate lesson plans and refine less effective teaching methods, thus helping to optimize students' understanding of the material being taught (Yuzalia & Nufus, 2021). As a result, it will be clearer to determine whether students face difficulties in aspects such as understanding, thought transformation, computational skills, applying process skills, and in constructing or applying responses to problems (Seng, 2020).

Applying Newman's theory to analyze students' errors is a well-recognized practice. For instance, a study conducted by Mangi et al. (2022) revealed that students made errors in solving problems involving algebraic fractions. Additionally, research by Fatimah and Baiti (2022) showed that a common mistake made by students when solving linear equations and inequalities was in the final answer stage, where many failed to find the correct result and to draw accurate conclusions. Similar findings were identified in the study by Handayani and Anggraini (2024), where the most frequent mistake made by female students occurred in the final answer stage. Furthermore, Leuly et al. (2024) explained that students often made errors in selecting the appropriate formula and arithmetic operation needed to solve word problems. By using Newman's Error Analysis, the researcher can identify students' weaknesses in geometric reasoning and problem-solving (Kania et al., 2024). Additionally, the presence of learning media makes the learning process more enjoyable. Fun learning is very necessary for every learning process. It helps students get a meaningful learning process and gives satisfaction because it is the main factor determining (Mustafa et al., 2023).

Considering the above description, the researcher aims to delve deeper into the errors students make in solving problems related to the surface area of spheres, using Newman's Error Analysis theory. Previous studies have generally used NEA to analyze errors in mathematical problems such as arithmetic, algebra, and basic geometry; however, there is still a gap in research specifically examining errors in sphere-related problems. This is important because spheres have unique characteristics that distinguish them from other solids, particularly due to the complexity involved in understanding surface area calculations that involve π (pi) and the radius (Septiyana et al., 2024). It is hoped that this research will assist teachers in identifying and addressing students' errors more accurately, as well as improving students' understanding of the concept of spheres through more efficient and structured teaching methods.

2. Methods

This study employs a qualitative approach with a descriptive design, where the researcher acts as the primary tool for direct interaction with students, to identify and analyze the errors they make in solving problems (Remme et al., 2023). The study aims to identify and analyze students' errors in solving surface area problems of spheres using Newman's Error Analysis theory. The subjects of the study are 5 students from grade IX at a public junior high school in Cirebon Regency, selected using purposive sampling techniques. The students selected as research subjects are those who exhibit errors corresponding to the indicators listed in Table 1 below.

Table 1 - Error indicators based on Newman's error analysis theory (Savitri & Yuliani, 2020)

No	Newman's Error Procedure	Indicator
1	Reading Errors	• Students experience difficulty in recognizing symbols and words in the questions, which can lead to misinterpretation of the question. • Students are unable to read or interpret mathematical symbols correctly, which results in errors during the problem-solving process. • Students' inability to read the structure or format of sentences in the questions leads to mistakes in understanding instructions or questions.
2	Comprehension Errors	• Students are unable to understand and record information correctly and accurately in writing. • Students cannot explain important parts of the question correctly. • Students can explain important parts of the question, but their explanations are incomplete. • Students' inability to write down all the information or questions from the problem completely. • Students write down information or questions from the problem, but it is not entirely accurate.
3	Transformation Errors	• Students cannot translate or represent information using the appropriate variables. • Students are unable to convert the information given in the problem into mathematical statements.
4	Process Skill Errors	• Students experience difficulty in determining the correct mathematical formula to solve the problem. • Students make errors in addition, subtraction, multiplication, or division even when using the correct formula. • Students do not follow the order of operations rules, leading to incorrect final answers. • Students stop working on the problem before completing all the steps, which results in an incorrect final answer.
5	Encoding Errors	• Students forget or incorrectly add units (e.g., cm, m^2) to the final result, even though the numerical value is correct. • Students do not simplify the final answer, such as not reducing fractions or decimals, making the answer incomplete.

	• Students write incorrect numbers or symbols in the final answer, even though the calculations are correct. • Students perform all calculations correctly but forget or fail to write down the final answer. • Students do not provide a conclusion relevant to what is asked in the problem, such as writing only a number without explaining the context of the answer. • Students provide a final answer that does not address the question because they misunderstood what was asked.

The research procedure includes several steps: (1) administering a written test on the surface area of spheres with 5 essay questions to identify students' errors. This test is designed with five types of questions labelled Type A, B, C, D, and E, each varying in format but still related to the same learning topic. Each student randomly selects one question type to answer. This model is designed to provide variation in the format of the question while encouraging student independence and critical thinking; (2) analyzing the data by identifying and categorizing errors based on Newman's theory stages; (3) presenting the data in the form of descriptive text that details the types of errors and specific examples for each category; and (4) drawing conclusions about the most common errors and the potential causes of those errors.

The data analysis technique involves data reduction, categorization of types of errors based on the stages of Newman's Error Analysis, and presentation of the data in descriptive narrative form. To ensure data validity, the researcher uses data triangulation by comparing written test results with in-depth interviews conducted with students to clarify the errors made and understand the reasons behind those errors. Additionally, validation is carried out through member checking to ensure that data interpretations align with students' understanding (Saadah et al., 2022).

3. Results and Discussion

3.1. Results

Based on the written test results from each research subject, the following is the analysis of the errors found among students when solving surface area problems of spheres.

Table 2 - Errors of Subjects Based on the Stages of Newman's Error Analysis Theory

Type of Question	Stages of Error				
	1	2	3	4	5
B	✓	–	✓	✓	✓
C	✓	–	–	✓	✓
A	–	–	–	✓	✓
E	–	–	–	✓	✓
B	✓	✓	–	–	✓

3.1.1. Reading Errors

Based on the analysis of the surface area problems solved by the research subjects and the results of interviews, reading errors were identified. These reading errors occur when students incorrectly interpret the information provided in the math problems, leading them to give incorrect answers because the information received cannot be used to solve the problem correctly. This error was found in subjects 1, 2, and 5. The following is a detailed description of the reading errors identified in these subjects:

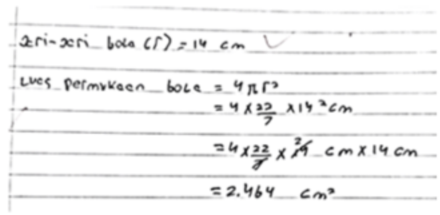
Type B questions	The answer from S1
A sphere has a radius of 14 cm. Determine the surface area of the hemisphere! ($\pi = \frac{22}{7}$)	

Figure 1 Reading Error of Subject 1

In **Figure 1**, the student answered question type B by writing down the given radius of the sphere, which is 14 cm. The student then used the surface area formula for a sphere, which is $4\pi r^2$. The student multiplied the numbers according to the formula, which is $4 \times \frac{22}{7} \times 14\ cm \times 14\ cm$, and obtained the result of $2.464 cm^2$.

In Figure 1, the student made a reading error by not carefully examining the information in the question. Although the problem asked for the surface area of a hemisphere, the student mistakenly calculated the surface area of a full sphere. This indicates that the student misread the question, which resulted in an incorrect answer. The interview with the student confirmed that a reading error led to this misunderstanding.

Researcher: *"When you read the given problem, did you read it carefully?"*
S1: *"Yes, I did."*
Researcher: *"Take a closer look at the problem. What is being asked in the question?"*
S1: *"Hmm … Determine the surface area of a hemisphere".*
Researcher: *"Alright, now look at your answer. Do you think your answer is correct?"*
S1: *"Hehe... I wasn't careful, were I? I ended up calculating the surface area of the whole sphere instead of the hemisphere."*

The interview results with the student reinforce that a reading error occurred. The student admitted that this error was due to a lack of careful reading of the given problem. Although the student initially felt that they had read the problem well, when asked to review their answer, they realized that they had indeed been less attentive in reading the problem.

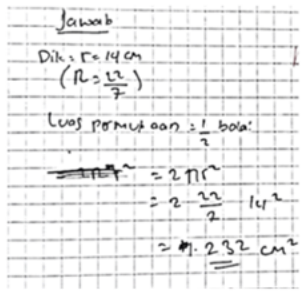
Type C questions	The answer from S2
A sphere has a diameter of 14 cm. Determine the surface area of the hemisphere! ($\pi = \frac{22}{7}$)	

Figure 2: Reading Error of Subject 2

In **Figure 2**, the student answered question type B by writing down the given radius of the sphere, which is 14 cm. The student then used the surface area formula for a hemisphere, which is $2\pi r^2$. The student multiplied the numbers according to the formula, which is $2 \times \frac{22}{7} \times 14^2$, and obtained the result of $1.231 cm^2$.

As seen in **Figure 2**, the student was unable to properly understand and identify the terms or symbols in the question. The reading error led to the student's inability to write the symbols correctly. In the given question, it was stated that the diameter of a sphere is 14 cm, but the student mistakenly thought the given information was the radius, so the student wrote the symbol 'r'. This was confirmed by the interview conducted with the student.

Researcher	:	*"Can you tell me what you know about this problem?"*
S2	:	*"A sphere has a diameter of 14 cm, miss."*
Researcher	:	*"Alright. What is the symbol for the diameter?"*
S2	:	*"It's 'd,' right?"*
Researcher	:	*"Correct. So why did you use the symbol 'r' for the diameter?"*
S2	:	*"Actually, I read the problem quickly, ma'am. So, I thought it was the radius that was given."*

From the interview results, the student was able to state what was given in the problem, but incorrectly wrote the symbol on the answer sheet. The student rushed through reading the problem, which led to an inability to correctly recognize the symbols in the problem. This indicates that the student did not read the problem carefully.

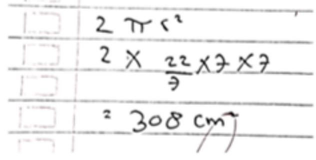
Type B questions	The answer from S5
A sphere has a radius of 14 cm. Determine the surface area of the hemisphere! ($\pi = \frac{22}{7}$)	

Figure 3 Reading Error of Subject 5

In **Figure 3**, the student answered question type B by writing the formula for the surface area of a hemisphere, without including the given information from the question. The student then used the formula for the surface area of a hemisphere, which is $2\pi r^2$.

The student multiplied the numbers according to the formula, which is $2 \times \frac{22}{7} \times 7 \times 7$, and obtained the result of $1.231cm^2$.

Figure 3 shows the reading error made by the student, where the student incorrectly recorded the given radius in the problem. The problem states that the radius given is 14 cm, but the student wrote it as 7 cm. This indicates that the student was unable to accurately interpret the information obtained from reading.

Researcher	:	*"When you read the given problem, did you read it carefully?"*
S5	:	*"I think so, ma'am. Did I make a mistake?"*
Researcher	:	*"Take a closer look at the problem. What is the radius given in the problem?"*
S5	:	*"It's 14 cm, ma'am."*
Researcher	:	*"Alright, then why did you write the radius as 7 cm on your answer sheet?"*
S5	:	*"Oh, right. I was in a hurry, ma'am. I also thought it was the diameter, so I divided 14 cm by 2."*

The results of the interview indicate that Subject 5 incorrectly recorded the given information from the problem due to rushing through the reading.

3.1.2. Comprehension errors

The next error is a comprehension error. These errors are evident from the students' inability to record all the information provided and requested in the problem. According to **Figure 3**, it was found that the students did not thoroughly write down the information provided and asked in the problem. This is illustrated by S5, who immediately wrote the formula and solution for the surface area of a hemisphere. After confirmation through the interview, it was revealed that the student misunderstood the given problem. In the interview, the student mentioned that they thought the given information was the diameter, leading them to determine the radius incorrectly for calculating the surface area of the hemisphere.

3.1.3. Transformation errors

Analysis of the written tests completed by the student revealed errors at the transformation stage. These transformation errors occur when students understand the problem correctly but choose the wrong operation to solve it (Fallo et al., 2021). This transformation error is evident in Figure 1., where the subject used the formula for the surface area of a sphere to solve the problem. This approach does not align with the problem's request to determine the surface area of a hemisphere.

3.1.4. Process skill errors

Process skill errors are related to mistakes made by students during the calculation stage in solving math problems. In this study, it was detected that students could determine the correct formula to solve the problem, but encountered difficulties in performing the calculations accurately. This error is related to the transformation errors that occurred in the previous stage.

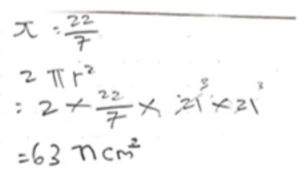
Type E questions	The answer from S4
A lamp is shaped like a sphere with a radius of 21 cm. Determine the surface area of half of the lamp! ($\pi = \frac{22}{7}$)	

Figure 4 Process Skill Error of Subject 4

In **Figure 4**, the student answered a Type E question by writing the formula for the surface area of a hemisphere without including the known values from the problem. The student used the formula $2\pi r^2$, multiplied by $2 \times \frac{22}{7} \times 21 \times 21$, and obtained a result of 6.311 cm².

Based on **Figure 4**, it is evident that the student made an error in the process of solving the surface area of a sphere, where the calculations performed by the student were not accurate. This led to an incorrect solution. The solution presented in **Figure 4.** shows 6,311 cm², whereas the correct result should be 2.772 cm².

Another error is shown in **Figure 1**, where the student incorrectly determined the formula used to solve the problem, resulting in a formula and solution steps that do not match what was asked. **Figure 2** shows that the student incorrectly identified the given information in the problem, leading to errors in the problem-solving process. Meanwhile, **Figure 3** reveals that the student incorrectly recorded a component in the surface area formula for a hemisphere. Specifically, the student wrote the radius as 7 cm instead of the correct 14 cm. This error caused the calculation process in solving the problem to be irrelevant to the correct procedure.

3.1.5. Encoding Errors

Errors in writing the final answer are often related to the previous steps taken by students when solving the problem. Below are the errors found in the final answer writing.

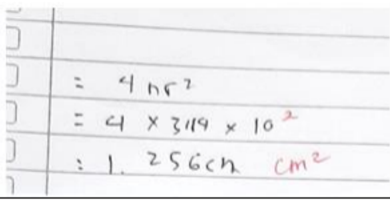
Type A question	The answer from S3
Edo has a ball with a radius of 10 cm. Determine the surface area of Edo's ball. ($\pi = 3{,}14$)	

Figure 5 Encoding Error of Subject 3

In **Figure 5**, the student answered a Type A question by writing the formula for the surface area of a sphere without including the known values from the problem. The student used the formula $4\pi r^2$, multiplied $4 \times 3{,}14 \times 10 \times 10$, and obtained a result of 1.256 cm².

In contrast to other students who were unable to solve the problem correctly, the student in **Figure 5** answered correctly but failed to write the proper unit in the final answer.

Researcher	*:*	*“Take a look at your answer. Is there any mistake in it?”*
S3	*:*	*“It's correct, ma'am.”*
Researcher	*:*	*“Are you sure? Have you included the unit in the final result?”*
S3	*:*	*“Oh yes, I forgot. I didn't include it, ma'am.”*

The results of the interview with Student 3 reveal a lack of precision in completing mathematical problems. As shown in **Figure 1**, the final answer provided by Student 1 is incorrect, with the surface area of the hemisphere being calculated as 2,464 cm^2, whereas the correct value should be 1,232 cm^2. A similar error is evident **in Figure 2**, where Student 2 reported 1,232 cm^2 instead of the correct answer of 308 cm^2. **In Figure 3**, Student 5 incorrectly calculated the surface area of the hemisphere, obtaining 308 cm^2 instead of the accurate 1,232 cm^2. Finally, **Figure 4** shows that Student 4 made an error in the final computation, presenting 6,311 cm^2 as the result, while the correct answer is 2,772 cm^2

3.2. Discussion

The errors in reading the questions identified in this study reflect the students' inability to comprehend the information contained in the questions, such as errors in reading numbers and information related to the surface area of a sphere. These findings are consistent with the research by Mangi et al. (2022), which shows that students often make mistakes in reading the information provided in the questions, resulting in answers that do not align with the intended objectives of the questions. Similar issues were found in the research by Lestari & Afriyansyah (2022), where some students struggled to understand the descriptions in the questions while constructing mathematical models. In the context of linear programming, students faced difficulties in converting variables from contextual problems into mathematical forms, reading units carefully, and failing to identify important information in the questions (Hariyani et al., 2019; Mubarokah & Nusantara, 2020; Rosidah et al., 2022; Simangunsong et al., 2021). Errors at this initial stage often impact subsequent steps, making reading errors a significant factor influencing the problem-solving process.

This study reveals that comprehension errors arise due to students' inability to accurately record information from the problems before beginning to solve them, preventing them from fully noting the given information and the questions asked. These findings are in line with the research by Hidayati & Harisman (2023), which showed that students often make mistakes when writing down and explaining what is known and what is being asked in the problem. Additionally, Nurmayningsih (2023) found that while some students are able to present the given information, they struggle to determine what is being asked when solving ANBK problems through the Merdeka Mengajar Platform (PMM). Furthermore, Mutia (Mutia, 2017) stated that the inability to understand the provided sentences or statements leads to errors in translating symbols.

On the other hand, the analysis reveals the presence of transformation errors, where students often make mistakes in selecting the correct formulas needed to solve problems.

These errors frequently occur in determining the appropriate formulas and calculations required for solving word problems, which then impact the process skills and final answer writing (Leuly et al., 2024). This contrasts with the study by Khofifatur et al. (2024), which reports that in their research, students were able to accurately identify the formulas used to solve mathematical problems.

The identified process skill errors in this study indicate that although students follow the correct steps in solving problems, they make mistakes in multiplication operations, leading to incorrect final results. Similar findings are reported in Sari et al. (2022), which identified process skill errors when students could correctly follow the steps but made errors in calculations. Azzahra & Hidayati (2024) also highlighted that students experienced errors due to a lack of precision in multiplication operations and misunderstandings in algebraic operations. Additionally, other studies found that some students were unable to continue with calculations to reach the final answer, resulting in an incomplete solution to the given problems (Desi Kurnia Wati, Sehatta Saragih, 2024; Hidayanto & Lisrahmat, 2023; Putri & Murtiyasa, 2024).

In this study, encoding errors were also identified, where students made mistakes in determining the final answer, which were related to the previous steps of solving the problem. This finding aligns with the research of Gloria et al. (2024), which identified that the most common error in trigonometric comparison problems was in writing the final answer, with an error rate of 40.17%. Many students failed to find the correct answer to the question. Additionally, some students also forgot to include units in their final answers, often due to rushing to complete the problems given by the teacher (Astrianah & Indrakurniawan, 2024; Kurniawati & Hadi, 2021; Najahah et al., 2022; Tias & Ismail, 2023).

Making inferences reflects students' ability to explain the problems they have solved (Naila et al., 2024). Conclusions play a vital role in the problem-solving process, as they provide specific and accurate answers to the questions or issues at hand. In this context, conclusions should align with the results of a thorough and detailed analysis. Any errors in concluding can distort the problem-solving outcomes, leading to incorrect or ineffective solutions.

Therefore, errors in formulating conclusions must be promptly corrected to ensure the problem-solving process continues effectively. The ability to conclude is not only based on accurate analysis but also on logical and critical thinking skills. In complex problem-solving, an incorrect conclusion can lead to wrong decisions or actions, making proper understanding and correction of these errors crucial.

4. Conclusions

Based on the analysis and discussion, five categories of errors made by students in solving problems related to the surface area of a sphere were identified, according to Newman's Error Analysis theory: (1) reading errors, (2) comprehension errors, (3) transformation errors, (4) process skill errors, and (5) encoding errors. In this study, students made reading errors, which led to their inability to correctly interpret the problem. Furthermore, students failed to comprehensively write down the information provided and the questions asked. In the case of transformation errors, students understood the problem correctly but chose the wrong operation to solve it. Process skill errors were detected when students selected the correct formula but made calculation mistakes. Finally, in terms of encoding, all research subjects made errors. Out of five students, four were unable to solve the problem correctly, while one student solved it correctly but forgot to add the unit to the final answer. Future research should focus on developing effective instructional designs to reduce students' errors in solving mathematical problems. Implementing various teaching methods, such as problem-based learning, collaborative learning, and the use of visual aids, could enhance students' understanding of the material more effectively.

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Conflict of Interest

The authors declare no conflicts of interest. Should any conflicts arise in the future, the authors will take full responsibility.

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