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Students' Mathematical Modeling Ability in Answering 2022 PISA-released items in Scientific Context

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Abstract

Mathematical modeling is one of the essential 21st-century skills that students must possess to connect mathematical concepts with real-world problems. Despite its recognized importance, the performance of Indonesian students in modeling tasks remains low, as reflected in the 2022 PISA results. This study aims to analyze students' mathematical modeling ability in solving scientific-context problems derived from the 2022 PISA-released items. The research used a descriptive qualitative method involving 25 students of seventh grade from SMP IT Raudhatul Ulum. Data were collected through students' written responses to four PISA problems and analyzed using a rubric based on modeling indicators by Blum and Leiss. The findings show that most students 56% are in the low category, struggling with modeling and interpretation, 36% are in the medium category with partial skills, and only 8% are in the high category, able to complete all stages of modeling. Students struggle to translate real-world problems into mathematical models and interpret results contextually. These findings highlight the need for contextual learning strategies to strengthen students' modeling competencies in scientific settings.

Keywords: mathematical modeling ability, PISA 2022, scientific context

1. Introduction

Nowadays, mathematical modeling is one of the key abilities students must possess. Mathematical modeling ability transforms real-world problems into mathematical problems using a series of mathematical symbols, operations, and relationships (Febriani et al., 2024). In line with the statement of Maulani et al. (2022), mathematical modeling ability not only reflects high-level mathematical thinking skills but also involves systematically transforming contextual situations

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into mathematical forms. Based on this description, it can be concluded that mathematical modeling ability is an essential competency that students must possess because it allows them to represent, process, and solve real-world problems mathematically through knowledge, symbols, and relationships between mathematical concepts.

The urgency of developing mathematical modeling skills is stated in the Regulation of Kementerian Pendidikan dan Kebudayaan Number 24 of 2016, where one of the objectives of learning mathematics emphasizes mathematical modeling skills such as making mathematical models, solving mathematical models, and interpreting the solutions obtained (Rosmawati, 2020). This ability is increasingly relevant and widely used in society in the 21st century because of its great benefits in real-life applications and mathematics learning (Wulandari et al., 2016). This aligns with Widana (2021) statement that mathematical modeling skills are essential for students to participate actively in 21st-century global society. Based on these foundations, it is clear that modeling skills are crucial skills that students must possess.

One of the international studies that explicitly measures students' mathematical modeling abilities is the Programme for International Student Assessment (PISA) conducted by the OECD (Novitasari, 2019). PISA aims to measure the extent to which students can apply the knowledge and skills acquired in school to face problems in everyday life (Junika et al., 2020). This assessment assesses students' procedural abilities and ability to formulate, employ, and interpret mathematics in various contexts, including personal, social, work, and scientific contexts (Putra & Vebrian, 2020). Thus, problem-solving is one of the cores of the PISA assessment and is a benchmark for the quality of education in various countries.

However, the reality shows that the mathematical modeling ability of Indonesian students is still relatively low (Kurniawati & Rosyidi, 2019; Mubarokah et al., 2020). This is revealed in the results of the PISA study. Since first participating in PISA in 2000, Indonesia's ranking has never significantly increased (Junika et al., 2020). In fact, in the latest PISA results in 2022, Indonesia is ranked 12th from the bottom (Rizky et al., 2024), with a score decreasing from 379 in 2018 to 366 points (Alfaruqi & Nurwahidah, 2025). Bilad et al. (2024) noted that of the four contexts measured by PISA, namely personal, occupational, societal, and scientific, the scientific context is a challenge for students in Indonesia. The scientific context in PISA emphasizes students' ability to use mathematics to understand and solve problems related to scientific activities (Maharani & Abadi, 2020). The low problem-solving ability of Indonesian students on scientific context questions shows that there is still a gap between mathematics learning in the classroom and its implementation in complex and contextual scientific problems. Similar difficulties were also found at the research site, SMP IT Raudhatul Ulum. Based on interviews with mathematics teachers at the school, many students still struggle to understand contextual problems, construct appropriate mathematical models, and interpret the results. This indicates that the gap between classroom mathematics learning and its application in complex scientific contexts also occurs at the school level, not only nationally.

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The low achievement of students is not only related to the knowledge aspect but also closely related to the mathematical modeling ability of students (Wulandari et al., 2025). Therefore, an analysis of student's ability to solve PISA questions in a scientific context is essential because it can provide an overview of the extent to which students carry out the modeling stages. Based on these conditions, this study examines students' problem-solving abilities in answering PISA 2022 questions in a scientific context. The results of this study are expected to be the basis for designing more contextual learning strategies and supporting the strengthening of students' modeling abilities in Indonesia.

2. Methods

This study uses a descriptive method with a qualitative approach that aims to describe students' mathematical modeling abilities in solving PISA scientific context problems. The following are indicators and descriptors of mathematical modeling abilities based on Blum & Leiss (2007) and those adapted from (Rosmawati, 2020).

Table 1.
Indicators and Descriptors of Mathematical Modeling Ability

No	Indicator	Descriptor
1	Understand the problem and form a model based on reality	a. Making assumptions from a problem
2	Making mathematical models using real models	a. Making the right mathematical model b. Manipulating mathematical models
3	Answering math questions using the mathematical models formed	a. Using appropriate problem-solving strategies b. Answering mathematical questions using the mathematical model formed
4	Interpreting results	a. Conclude the mathematical results obtained in a real-world context
5	Validating the solution	a. Re-examine the situation obtained

The subjects of this study were 25 seventh-grade students at SMP IT Raudhatul Ulum. Data collection techniques included photo documentation during the implementation stage and students' responses to four items from the 2022 PISA scientific context. These data were utilized to analyze how students solved problems based on mathematical modeling indicators. The following are the 2022 PISA problems that will be tested on students.

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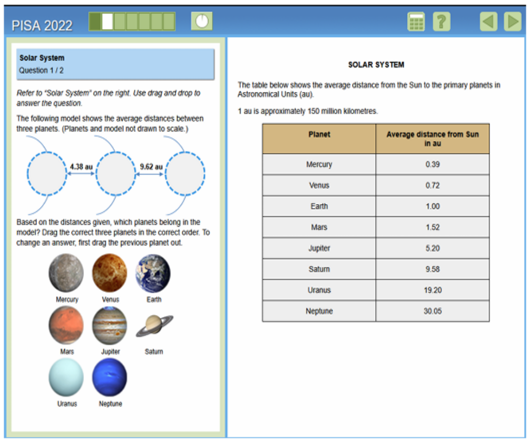
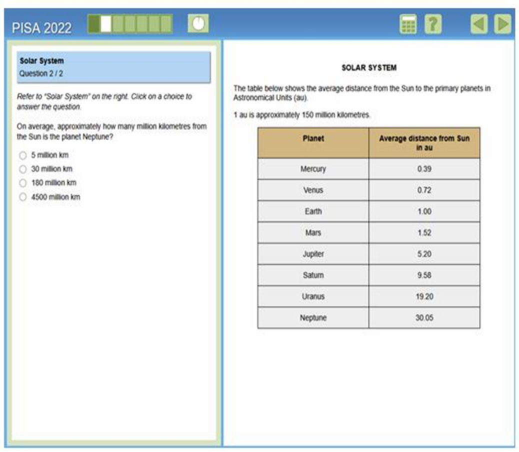
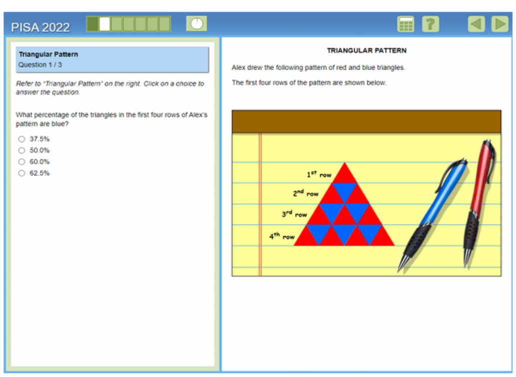
Table 2.
PISA 2022 Problems Scientific Context

<table>
<tr><th>Number</th><th>Problem</th><th>Content</th><th>Context</th><th>Level</th></tr>
<tr><td>1</td><td>
</td><td>Quantity</td><td>Scientific</td><td>3</td></tr>
<tr><td>2</td><td>
</td><td>Quantity</td><td>Scientific</td><td>2</td></tr>
<tr><td>3</td><td>
</td><td>Quantity</td><td>Scientific</td><td>1a</td></tr>
</table>

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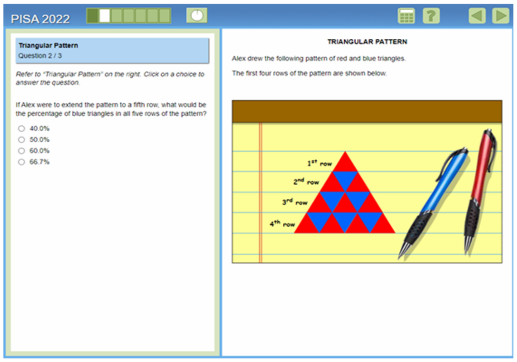
Number	Problem	Content	Context	Level
4		Quantity	Scientific	2

The research procedure is carried out in three stages: preparation, implementation, and analysis. First, the preparation stage is completed by compiling research instruments such as the 2022 PISA Problems in the scientific context of four problems and an assessment rubric based on mathematical modeling skills. The next stage is implementation, which is conducting research in one meeting. The meeting is used to test PISA problems for students. The next stage is the analysis stage, which is carried out by giving scores to the results of students' answers. Then, students' mathematical modeling abilities are categorized into three categories, namely low, moderate, and high, as in the following table.

Table 3.
Scoring Rubric for Mathematical Modeling Ability

Indicator	Score	Descriptor
Understanding the problem and forming a model based on reality	3	Writes what is known–asked and assumptions with correct and complete data
	2	Writes what is known–asked and assumptions with correct but incomplete data
	1	Writes what is known–asked and assumptions incorrectly
	0	Does not write what is known, asked, or assumptions
Making a model using real models	4	Writes model and manipulation correctly and completely
	3	Writes model and manipulation correctly but incompletely
	2	Writes model and manipulation incorrectly but completely

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	1	Writes model and manipulation incorrectly and incompletely
	0	Does not write the model or manipulation
Answering math questions using the mathematical models formed	4	Writes strategy using the formed model with correct and complete result
	3	Writes strategy using the formed model with correct but incomplete result
	2	Writes strategy using the formed model with incorrect but complete result
	1	Writes strategy using the formed model with incorrect and incomplete result
	0	Does not write the solution
Interpreting mathematical results obtained in the real world	3	Writes correct and complete conclusion
	2	Writes correct but incomplete conclusion
	1	Writes incorrect and incomplete conclusion
	0	Does not write a conclusion
Validating the solution	3	Writes validation correctly and completely
	2	Writes validation correctly but incompletely
	1	Writes validation incorrectly and incompletely
	0	No validation written

Table 4.
Student Value Categories

Interval	Category
71-100	High
36-70	Moderate
0-35	Low

3. Result and Discussion

Students' Answers in Answering Problem Number 1

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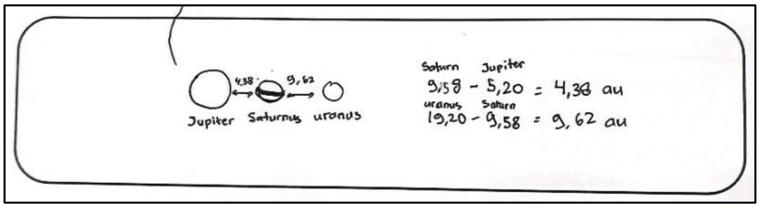
A sample of students' answers in solving problem number 1 with a scientific context related to the solar system can be seen in Figure 1 below.

Figure 1.
Student Answers to Problem Number 1



Based on the analysis of students' responses to Problem 1, several indicators of mathematical modeling ability can be identified. At the first stage (Indicator 1: Understanding the problem and form a model bases on reality), students demonstrated the ability to interpret the problem context by recognizing the differences in distance between planets (measured in AU) and relating them to the positions of Jupiter, Saturn, and Uranus in the solar system. This reflects their capacity to make assumptions and connect contextual information with mathematical representation.

At the second stage (Indicator 2: Making mathematical models using real models), students constructed a mathematical model by using numerical data from the table and calculating the distance between the planets, such as Saturn – Jupiter = 4.38 AU and Uranus – Saturn = 9.62 AU. This indicates that students were able to process and manipulate mathematical models according to the information provided.

At the third stage (Indicator 3: Answering math questions using the mathematical models formed), students applied appropriate problem-solving strategies by comparing calculated distances and then determining the correct order of the planets, namely Jupiter, Saturn, and Uranus, based on the constructed model.

However, no evidence was found for the fourth stage (Indicator 4: Interpreting mathematical results obtained in the real world) and the fifth stage (Indicator 5: Validating the solution). Students tended to stop at the computational results without extending their answers to interpretation in the scientific context or re-examining the accuracy and validity of their conclusions. This indicates that while some aspects of the modeling process were achieved (Indicators 1 – 3), the higher-order stages requiring reflection and validation were not evident.

Students' Answers in Answering Problem Number 2

A sample of students' answers in solving problem number 2 with a scientific context related to the solar system can be seen in Figure 2 below.

Figure 2.

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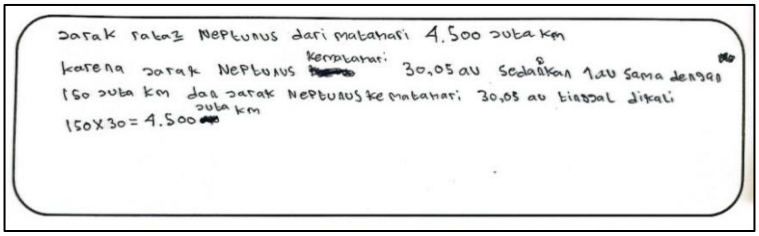
Student Answers to Problem Number 2



Based on the analysis of students' responses to problem number 2, several indicators of mathematical modeling ability can be identified. At the first stage (Indicator 1: Understand the problem and form a model based on reality), students demonstrated an understanding of the context by recognizing that the distance from Neptune to the Sun could be expressed in astronomical units (AU) and then converted into kilometers using the information that 1 AU = 150 million km. This indicates their ability to make appropriate assumptions from the problem and connect contextual information with mathematical representation.

At the second stage (Indicator 2: Making mathematical models using real models), students constructed a model by establishing the relation between the distance of Neptune from the Sun in AU and kilometers, then processing the model through calculation (150 × 30.05 = 4,500). This demonstrates their ability to construct and manipulate a mathematical model appropriately using numerical data.

At the third stage (Indicator 3: Answering math questions using the mathematical models formed), students applied the correct problem-solving strategy, namely unit conversion based on a fixed rasio and used the model to determine the distance of Neptune from the Sun in kilometers. This shows that the students were able to answer the mathematical question using the model formed.

Furthermore, evidence of the fourth stage (Indicator 4: Interpreting mathematical results in the real-world context) can also be found. The students explicitly expressed the result in the form of a contextual statement: "The distance from Neptune to the Sun is 4.500 million km." This reflects their ability to interpret results beyond mere computation.

However, there was no evidence of the fifth stage (Indicator 5: Validating the solution). The students did not attempt to re-examine their results or compare them with external sources to ensure accuracy. Therefore, although Indicators 1 – 4 were successfully demonstrated, the modeling process remained incomplete at the validation stage

Student Answers to Problem Number Three

Figure 3 below shows a sample of students' answers to problem number 3 in a scientific context related to triangular patterns.

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Figure 3.
Student Answers to Problem Number 3

Based on the analysis of students' responses to problem number 3 regarding the blue and red triangle patterns, it can be seen that the indicators of mathematical modeling ability are not comprehensively achieved, and the overall performance reflects a low level of modeling competence. Unlike the responses in problems 1 and 2, the indicators in probem number 3 appear inconsistently, as students tend to remain at the stage of observation without progressing into full model construction and validation.

In the first step (Indicator 1: Understand the problem and form a model based on reality), students try to interpret the problem by observing the number of blue triangles in each row (0, 1, 2, and 3). This indicates an attempt to recognize the visual pattern. However, the assumption is incomplete because it is not connected to the total number of triangles in the figure, and thus does not form a sufficient basis for a mathematical model.

In the second step (Indicator 2: Making mathematical models using real models), the students do not develop an explicit mathematical model. They only state the number of blue triangles but do not represent the relationship between the blue and total triangles (which should be 1 + 3 + 5 + 7 = 16). Therefore, indicator 2 is not achieved.

In the third step (Indicator 3: Answering math questions using the mathematical models formed), students also fail to use the correct approach. Although they identify the total number of blue triangles (6), they do not explain the calculation of the percentage. Instead of computing (6/16 × 100 = 37.5%), the student directly writes 37.5%. This shows that both indicators 3a and 3b are not met.

In the fourth step (Indicator 4: Interpreting mathematical results in the real-world context), students do not connect their answers to any meaningful context, namely that the percentage of blue triangles in the triangular pattern that Alex drew is 37.5%. Similarly, in the fifth step (Indicator 5: Validating the solution), the student does not engage in reflection or re-examination to determine whether the obtained solution is reasonable based on the available data.

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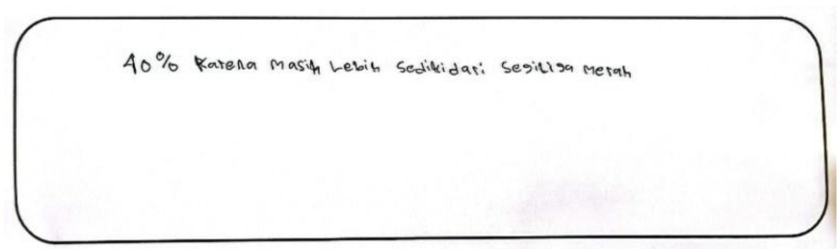
Thus, of the five indicators of mathematical modeling ability, only a partial attempt at Indicator 1 (understanding the problem) is evident, while Indicators 2, 3, 4, and 5 remain unmet. This analysis highlights that students' responses to problem number 3 reflect a low level of modeling ability, as they do not move beyond observation toward model construction, calculation, interpretation, or validation.

Student Answers to Problem Number Four

Figure 4 below shows a sample of students' answers to problem number 4 in a scientific context related to triangular patterns.

Figure 4.

Student Answers to Problem Number 4



Based on the analysis of students' responses to problem number 4 regarding the triangular pattern up to the fifth row, it can be concluded that the students demonstrated low mathematical modeling ability. The response provided, namely "40% because it is still less than the red triangle", reflects a mere guess without any mathematical calculations.

In the first step (Indicator 1: Understand the problem and form a model based on reality), students failed to make correct assumptions from the given situation because they did not recognize the growth pattern of the blue triangles and the total number of triangles in each row. Consequently, the second step (Indicator 2: Making mathematical models using real models) was also not achieved, as there was no attempt to construct a model or manipulate numerical data, such as calculating the ratio of blue triangles to the total triangles.

In the third step (Indicator 3: Answering math questions using the mathematical models formed), the students did not use systematic problem-solving strategies or operate based on a mathematical model. Instead, the response was purely speculative and lacked any data processing. The fourth step (Indicator 4: Interpreting mathematical results in the real-world context) was also not fulfilled, as the students did not relate their answers to the contextual meaning, namely that the percentage of blue triangles in the fifth-row pattern is actually 40%.

Finally, in the fifth step (Indicator 5: Validating the solution), the students did not reflect on or re-examine the plausibility of their answers based on the given data. Overall, the absence of a

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complete modeling process from understanding the problem, constructing a model, applying mathematical procedures, interpreting results, and validating the solution indicates that students' mathematical modeling ability in this problem remains at a low level.

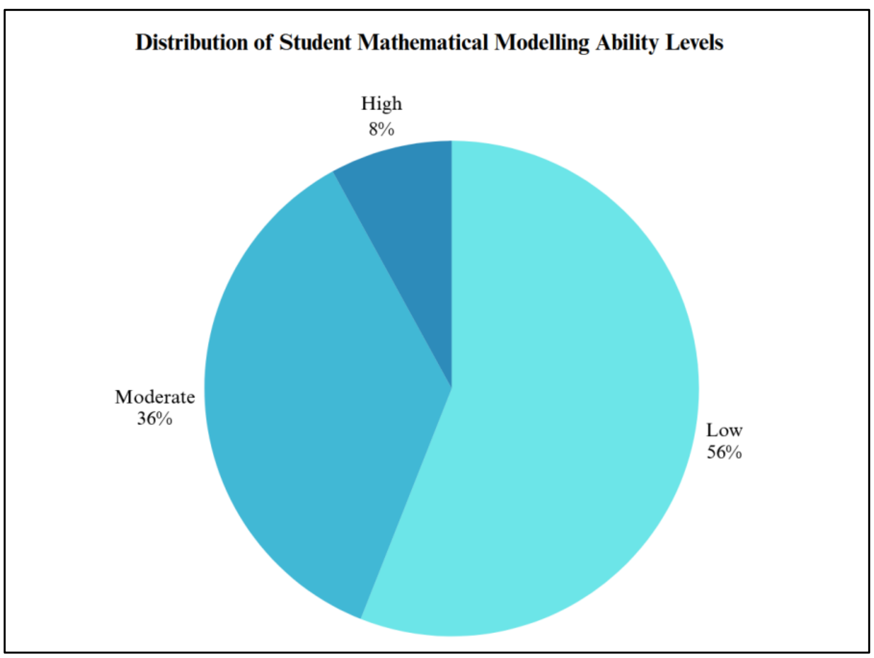
After testing the 2022 PISA problems, the scientific context provides scoring according to the score table that has been made. There are 4 PISA problems, and the maximum score is 68. After calculating the score, the data from the students' answers will be grouped according to the category of mathematical modeling ability presented in the following table.

Table 5.
Mathematical Modeling Categories

Category	Interval	Frequency
High	71-100	2
Moderate	36-70	9
Low	0-35	14

The visual presentation of the distribution of student mathematical modeling ability level can be seen ini Figure 5. Bellow.

Figure 5.
Distribution of Student Mathematical Modeling Ability Level



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Based on the data above, most students, namely 14 out of 25 students or 56% of students, are in the low category. This shows that more than half of students experience significant difficulties in applying the concept of mathematical modeling to solve PISA problems in a scientific context. This difficulty can be caused by a lack of understanding of basic concepts, limited analytical skills, or a lack of experience connecting real contexts with mathematical models. This is supported by Hauda et al. (2023) who state that mathematical modeling is still considered difficult because students still find it challenging to understand problems, cannot change real problems into mathematical models, and are unable to solve mathematical models, so the low mathematical modeling ability of students is closely related to the lack of reinforcement of basic concepts and the lack of contextual problem practice that requires the application of modeling (Khusna & Ulfah, 2021).

Furthermore, as many as nine or 36% of students are in the moderate category. In this case, it shows the mathematical modeling ability of students, where students can understand and apply it in solving problems comprehensively. However, there are still weaknesses in data interpretation and in choosing the right model. In line with Yolandari et al. (2025) statement that, students at the moderate level often have difficulty choosing the most appropriate mathematical model in the context of the problem, even though they already understand the basic concept.

Then two or 8% of students are included in the high category. This shows that a good mastery of mathematical modeling can effectively integrate mathematical concepts and scientific contexts in solving PISA problems. Students in this category show the strong potential and adequate ability to solve complex problems. This is in line with the statement by Febriani et al. (2024) that students with high ability typically have better cognitive abilities and more intensive learning experiences in mathematical modeling.

From a cognitive perspective, most middle school students are still at the early stage of formal operations (Piaget). At this developmental level, students begin to develop abstract reasoning but still encounter difficulties in connecting mathematical representations with complex real-world contexts (Lestari et al., 2023). This explains why the majority of students fall into the low and moderate categories, especially regarding the indicators of interpreting results and validating solutions. On the other hand, students in the high category generally exhibit greater cognitive maturity and broader learning experiences, which enable them to perform the modeling process more comprehensively. This analysis highlights that students' mathematical modeling ability is influenced not only by conceptual mastery but also by their developmental stage of thinking.

Overall, these results illustrate that students' mathematical modeling skills in scientific contexts still need to be improved, especially to reduce the proportion of students in the low category. Improvement can be made through more contextual learning, using relevant models, and strengthening data analysis and interpretation skills. Thus, it is hoped that students can be better

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prepared to face challenges in solving mathematical problems in the future, especially in complex scientific contexts such as those tested in PISA. This aligns with Raqiqa et al. (2024) the importance of problem-based learning approaches and mathematical modeling to significantly improve students' abilities.

4. Conclusion

The findings of this study reveal that students' mathematical modeling abilities are still predominantly at a low level, with 56% of students categorized as low, 36% as moderate, and only 8% as high. This distribution reflects a fundamental challenge in the learning process, as many students are unable to fully engage with the stages of modeling, particularly in interpreting and validating solutions. Their tendency to halt at the calculation stage without connecting results to real-world contexts indicates that modeling is perceived merely as a procedural task rather than a reflective problem-solving process. The contributing factors such as limited conceptual mastery, insufficient analytical reasoning, and lack of experience with contextual problems, show that current learning practices may not yet provide adequate opportunities for students to develop mathematical modeling skills. Therefore, the low performance is not only a matter of students' individual abilities but also a reflection of how instructional approaches shape their engagement with mathematical modeling. These findings underline the importance of designing learning strategies that integrate contextual approaches, encourage reflective interpretation, and provide systematic exposure to problem-based modeling tasks. By doing so, students can gradually build the capacity to connect abstract mathematical processes with meaningful real-world applications, thereby enhancing their readiness to tackle complex problems such as those presented in PISA's scientific contexts.

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