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UNCOVERING STRATEGIES AND DECISION-MAKING APPROACHES OF GRADE XI STUDENTS ON PISA PROBLEMS

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ABSTRACT
Mathematical decision-making skills are required when students face questions that require sorting information and determining the appropriate solution steps, such as PISA problems. This study aims to describe how 11th grade students make mathematical decisions in solving PISA problems by reviewing decision patterns at each stage of problem solving. The approach used is qualitative with a case study design, involving subjects selected purposively. Data were collected through problem-solving tests and task-based interviews, then validated through triangulation of written answers, interview results, and researcher notes. The results showed that intuitive subjects tended to make quick decisions based on visual perception and spontaneous beliefs without mathematical verification. Empirical subjects used visual observation of shapes and previous experience with limited calculations. Heuristic subjects relied on general rules that were considered appropriate for the structure of the problem, although oversimplification often occurred. Rational subjects took structured steps through complete calculations and comparison of alternatives before making a decision. These findings indicate that variations in thinking strategies affect the accuracy of mathematical decisions made by students. Further studies on mathematical decision-making can be directed at variations in problem contexts, the use of more subjects, or analyses that integrate other factors such as learning styles and representation abilities, so that understanding of the decision-making process can be developed more comprehensively.
Keywords: decision making, PISA test, gender.

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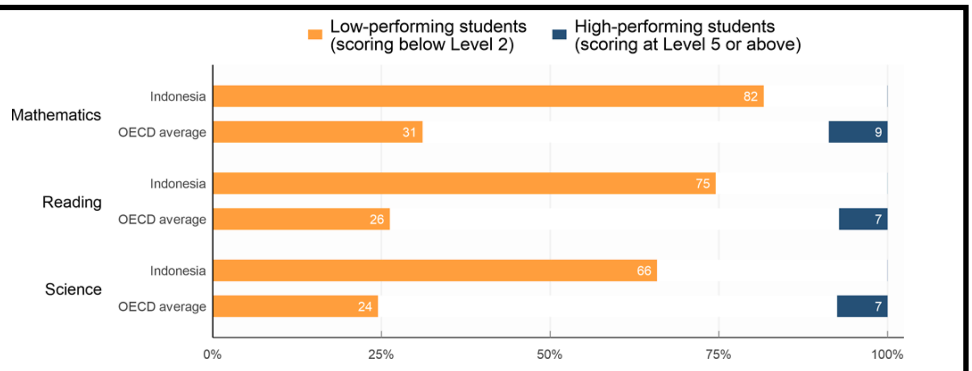
INTRODUCTION

Students' ability to solve mathematics problems depends not only on their mastery of concepts, but also on how they choose the right steps during the problem-solving process (Andrade et al., 2020). Students often face problems, both in everyday life and in the classroom, that require quick and accurate decisions so that they can determine the best solution or next step (Yuliana, 2015). The skill of choosing effective steps is crucial for resolving problems properly. Problems are usually contextual in real life. Therefore, they require thorough assessment of information, conditions, and resolution objectives. Wang & Ruhe (2007) emphasize that decision-making skills are a key part of effective thinking. Individuals with this skill tend to be able to consider alternatives rationally, choose the most appropriate strategy, and produce more accurate solutions.

These questions require high cognitive levels, such as questions that require visual reasoning, interpretation of representations, and analysis of several possible solutions (Drastisianti & Alighiri, 2021), students are required to select relevant information, evaluate alternative strategies, and decide on the most appropriate steps. A study by Fatma & Suwarno (2023) shows that most students face obstacles not only because of their weak understanding of concepts, but also because of inaccurate mathematical decisions, such as choosing steps impulsively, focusing too much on surface information, or using practical strategies that are not in line with the characteristics of the question. This phenomenon confirms that the fundamental issue that needs to be examined is not only related to mastery of the material, but also how students make decisions when faced with tasks of a high cognitive level.

Contextual questions that commonly appear in high-level cognitive assessments, including PISA, require students' decision-making skills. These types of questions not only require conceptual understanding, but also the ability to organize information from real-life situations that are often complex (Dewantara, 2018). The PISA test has several domains, one of which is space and shape. This domain is often used in mathematics learning studies because the tasks require students to read diagrams, understand spatial relationships, and make appropriate use of visual representations. The results of research by Kolar & Hodnik (2021) show that success in solving contextual problems is influenced by mathematical literacy, reasoning, and understanding of the context of the problem. Decision-making skills act as a link between conceptual understanding and strategy application, so that success depends not only on procedural abilities, but also on the accuracy of the decisions made at each stage of problem solving. The following is an international evaluation based on the Programme for International Student Assessment (PISA) test for Indonesian students. A summary of Indonesia's PISA results is shown in Figure 1.



Sumber: OECD. PISA 2022 Database. Tables I.B1.3.1. I.B1.3.2 and I.B1.3.3.

Figure 1. Indonesia's 2022 PISA test results

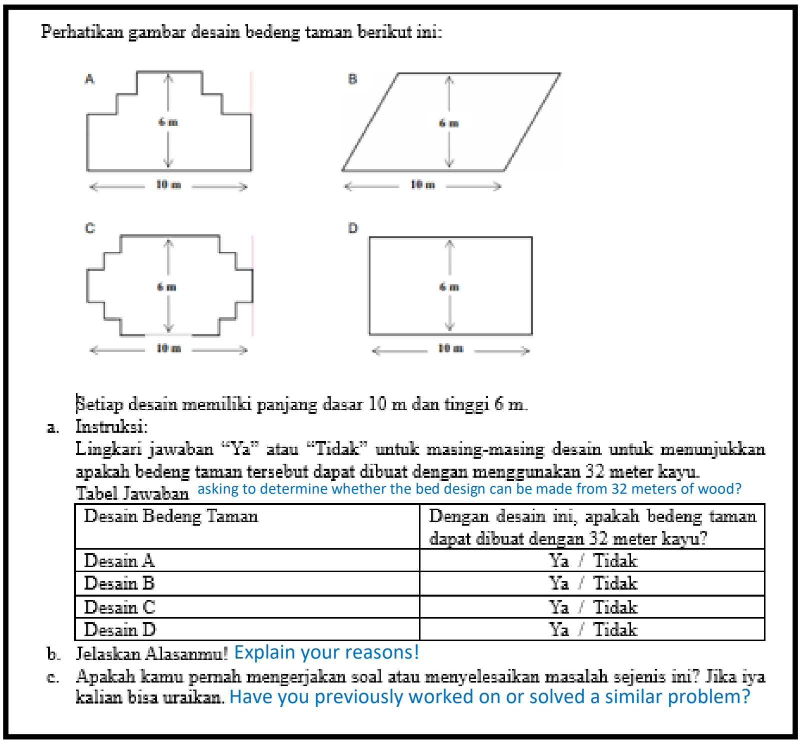
A report by the Organisation for Economic Co-operation and Development (OECD) shows that the proportion of Indonesian students who are able to achieve a high level of proficiency is still very low. As many as 82% of Indonesian students are still below Level 2, which is categorized as low performers, while the proportion in OECD countries is around 31%. On the other hand, almost no Indonesian students are able to reach Level 5 or Level 6, which are categorized as high performers, even though the OECD average is 9%. The OECD (2022) findings also show that only 18% of Indonesian students can reach Level 2 and above in mathematics assessments, far behind the OECD average of 69%, and not a single Indonesian student has attained Level 5 or 6. These results also reveal difficulties when students are faced with complex problems that require alternative evaluations and logical justification of decisions. This data confirms that poor performance is not solely due to a weak understanding of content, but also partly due to a mathematical decision-making process that has not developed optimally.

Individuals have different tendencies when making decisions. Wang & Ruhe (2007) categorize the decision-making process into four types: intuitive, empirical, heuristic, and rational. Inappropriate selection methods can result in a decrease in the accuracy of problem solving (Lamond & Thompson, 2000). Intuitive and empirical approaches are related to cognitive psychology, each relying on instinct and previous experience, although the mechanisms are not yet fully understood. Heuristics can produce efficient decisions, but the simplification of the rules used has the potential to cause errors (Gigerenzer & Gaissmaier, 2011). Meanwhile, the rational approach involves systematic information processing to compare alternatives objectively. Therefore, it is important to analyze decision-making through these four categories to understand students' thinking patterns in determining strategies for solving mathematical problems.

Previous studies have discussed decision-making skills in mathematics learning, both in relation to problem solving and the development of students' conceptual understanding. A study by Siebert et al. (2021) emphasizes the role of decision-making in mathematical problem solving, while Salimi et al. (2024) shows its contribution to conceptual understanding in real-world contexts. Other studies by Fitri et al. (2024) and Maratusholiha (2019) highlight this from a qualitative perspective and cognitive style. On the other hand, studies that explicitly link students' decision-making processes with high-level cognitive contextual questions, such as those used in the PISA survey, are still relatively limited. Furthermore, previous studies have not thoroughly explored students' thought processes in making decisions at each stage of problem solving. Therefore, this study aims to understand how 11th grade students make mathematical decisions when solving PISA mathematics problems by examining the decision-making tendencies that occur at each stage of problem solving. Through these findings, this study is expected to provide an understanding of how the mathematical decision-making process takes place based on its categories, as well as serve as a reference for educators in developing learning that encourages better mathematical decision-making skills.

METHOD

This study uses a qualitative approach with a case study design to explore how students make mathematical decisions in solving PISA problems. The research subjects are 11th grade students who were purposively selected based on their ability to explain their thought processes and their willingness to participate in-depth interviews. Each category consisted of one female subject and one male subject. Data were collected through two main instruments, which were decision-making tests and task-based interviews. The questions used were adapted from the original PISA problems with contextual adjustments.


Perhatikan gambar desain bedeng taman berikut ini:

A 6 m 10 m
B 6 m 10 m
C 6 m 10 m
D 6 m 10 m

Setiap desain memiliki panjang dasar 10 m dan tinggi 6 m.

a. Instruksi:
Lingkari jawaban "Ya" atau "Tidak" untuk masing-masing desain untuk menunjukkan apakah bedeng taman tersebut dapat dibuat dengan menggunakan 32 meter kayu.
Tabel Jawaban asking to determine whether the bed design can be made from 32 meters of wood?

Desain Bedeng Taman	Dengan desain ini, apakah bedeng taman dapat dibuat dengan 32 meter kayu?
Desain A	Ya / Tidak
Desain B	Ya / Tidak
Desain C	Ya / Tidak
Desain D	Ya / Tidak

b. Jelaskan Alasanmu! Explain your reasons!

c. Apakah kamu pernah mengerjakan soal atau menyelesaikan masalah sejenis ini? Jika iya kalian bisa uraikan. Have you previously worked on or solved a similar problem?

Figure 2. PISA Problems

Following the test, interviews were conducted in two stages, first to confirm the decision-making categories and second to explore the students' decision-making processes from the beginning to the completion of the task. Data analysis was carried out through data reduction, presentation, and conclusion drawing, involving coding, categorization, and examination of patterns between subjects. Data validity was strengthened through triangulation between test and interview answers, as well as peer discussions. The entire process was carried out with attention to research ethics, ensuring the confidentiality of identities and the full consent of participants. For ease of understanding the naming of subjects, initials consist of two capital letters. The first letter is the first letter of each category (Intuitive (I), Empirical (E), Heuristic (H), and Rational (R)). The second letter is the initial letter for gender: Male (M) and Female (F).

RESULT AND DISCUSSION

The research was conducted at a senior high school in Malang. The selected class consisted of 33 students. The subjects were divided into four decision-making categories, except for the absence of female subjects in the heuristic category. The selected subjects were then analyzed and interviewed to obtain more detailed information from the decision-making test results. The analysis process was conducted by referring to decision-making indicators (each process was assigned a code labeled 'PK' followed by a number, with the numbering not implying a fixed sequence) adapted from Wang & Ruhe (2007), as shown in Table 1.

Table 1. Decision-Making Process

Code	Process	Description
PK1	To comprehend the decision-making problem and to identify the decision goal in terms of Object (O) and its attributes (A).	• Recognize the problem (what needs to be decided). • Define the goal (what you want to achieve from the decision). • Define the objects and their attributes (what the options are, and what factors will be used to evaluate them).
PK2	To search for alternative solutions ($\mathcal{A}$) and criteria (C) for the right decision-making strategy.	• Exploring information they already know (e.g., remembering formulas, problem-solving strategies, or previous experiences). • Proposing alternative ways to solve the problem (verbally, in writing, or through action). • Mentioning or writing down criteria that they consider important in choosing a strategy/alternative.
PK3	To quantify alternatives ($\mathcal{A}$) and criteria (C), if the search should be go on.	• Comparing several alternatives that have been found. • Assessing whether existing solutions meet certain criteria (e.g., right/wrong, effective/ineffective, easy/difficult). • Deciding to seek additional information because existing alternatives/criteria are still insufficient/inappropriate.
PK4	To build a set of Decisions (d) based on the alternatives ($\mathcal{A}$) and criteria (C) as obtained in previous searches.	• Organizing options into several reasonable decisions based on existing criteria. • Writing down/explaining the reasons why an alternative can be chosen. • Making a list of decisions (not just raw alternatives).
PK5	To select the preferred decision(s) on the basis of satisfaction of decision makers.	• Make a final decision from several available options. • Explain the reasons for the choice, reflecting satisfaction/suitability with criteria that are important to the individual. • Stop the evaluation process, meaning that the individual feels sufficiently confident with the choice made.

PK6	To represent the decision(s) in a new sub- OAR model.	• Explain the final decision in a well structured way (e.g. write down the options, supporting attributes, and the reasoning behind them). • Create a representation (it can be a description, diagram, table, or model) that shows how the decision was made. • Connect the decision to the initial goal set in PK1.
PK7	To memorize the sub-OAR model in Long Term Memory.	• Able to repeat or explain the decision and reasoning after some time has passed. • Use similar decisions/strategies in different problems (indicating that knowledge has been stored). • Reflect on the experience by mentioning that they will use that method again in the future.

Intuitive

The following are the answers to the IM (male) subject written test when solving PISA problems.

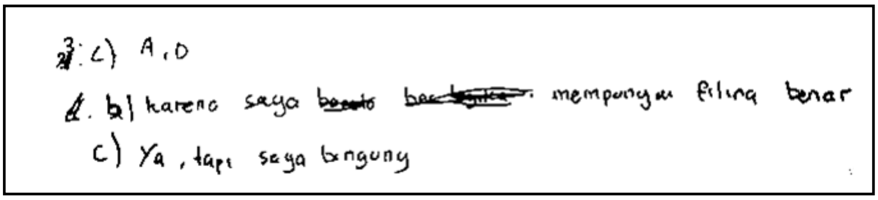


Figure 3. Subject IM answers

Based on the answers written in Figure 3, it can be seen that students immediately chose alternative answers (A, D) without providing logical reasons or clear calculation processes beforehand. This indicates that the decision was made based on personal belief or intuition. The statement *"because I have a feeling that it is correct"* confirms that the decision relied on subjective judgment rather than mathematical reasoning. This pattern is in line with the characteristics of intuitive decision makers who rely on quick impressions but do not always understand the logical basis for their decisions (Kahneman, 2011). Also, the statement "*yes, but I'm confused*" answers the question that students feel they have done similar problems before but are confused when working on the given problem. They then decide to use their personal feelings or instincts to make a decision. This reflects a common characteristic of intuitive decision makers who often think quickly and trust their initial impressions but do not fully understand the logical basis for their decisions (Todd & Gigerenzer, 2012).

Based on the interview results, subject IM showed an intuitive decision-making process, where decisions were made based on a feeling of correctness and visual perception of shape, rather than systematic mathematical calculations. This can be seen from the statements "*I just look at the shape*" and "*my feeling tells me that's right.*" In Wang & Ruhe (2007) theory, the subject only carried out part of the seven steps of decision making (PK1–PK7). The subject skipped PK1 to PK3, which are the stages of understanding the problem, determining the strategy, and developing alternatives. Subjects jump directly to PK4 (formulating a decision) and PK5 (making a decision) without quantitative analysis. The decisions made are also not accompanied by in-depth evaluation or rational reflection, as reflected in the statement "*yes, but I'm also confused*," which only shows emotional awareness, not conceptual reflection (partial in PK6).

The following are the answers to the IF subject written test when solving PISA problems.

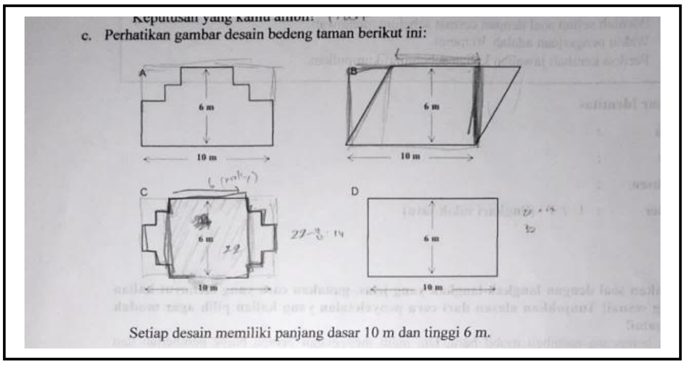


Figure 4. Subject IF answers

Based on the results of the IF work, in design A, the student drew lines outside the staircase image, making the design rectangular. In design B, the student shaded and drew diagonal lines on the sloping part, indicating that he was trying to break down the sloping trapezoid into a simpler shape that could be understood, which was a rectangle. In design C, the student shaded the center and sides thickly, indicating that he was contrasting the main rectangle with the extensions on both sides. Signs such as small numbers and additional strokes indicate an attempt to estimate the area. Meanwhile, design D only has thickened lines without additional sketches, indicating that the student saw it as the simplest and easiest shape to understand. The student then calculated the perimeter of the shape, which was $20 + 12 = 32$. The student tried to make all the designs that looked difficult into flat shapes that were easy to understand. The IF subject was shown to have completed the PISA Space and Shape questions by relying on visual observation and understanding of the geometric structure of each design.

Looking at the PK1–PK7 flow, the subject had actually gone through PK1 because they understood that the problem was about having enough wood to make the design. In PK2, the subject recognized the available shape alternatives and paid attention to the structure of each design. But in PK3, which is the stage of setting decision criteria, the subject didn't seem to have explicitly established the basis for their assessment. The subject did not systematically calculate the perimeter or compare the lengths of the sides. As a result, when entering PK4 (evaluating alternatives), the subject relied more on visual impressions, for example, by matching shapes or estimating that a design was "enough" without any evidence of calculation. In PK5, the selection stage, the subject immediately determined the alternative answer based on the estimated shape that was considered closest to the wood limit. The transcript sections "*yes... I think it's enough*" and "*just match it*" show that the decision was made when the shape seemed reasonable according to his perception. In PK6, when asked to explain their reasoning, subjects were unable to provide mathematical explanations and only repeated the same basis for their estimates. Meanwhile, in PK7, the reflection stage, the statement "*but I'm confused*" shows that they did not fully understand the basis for their decision and had difficulty reassessing whether their choice was correct.

The findings on intuitive subjects are also consistent with the results of Ramírez-Contreras et al. (2023), which explain that students often use spatial intuition in mathematical decision-making, especially when dealing with complex geometric shapes. Meanwhile, Suwarto et al. (2023) emphasize that students' intuition in mathematics learning usually emerges when they feel more confident in their 'sense of correctness' than in rational calculations that they have not yet mastered. Thus, it can be concluded that IM and IF subjects carry out intuitive decision-making processes, namely judging based on the appearance of shapes and personal beliefs without calculation. Such decisions are quick and efficient, but do not go through a formal reasoning process, so they do not fully meet the indicators of mathematical decision-making processes according to the Wang and Ruhe model.

Empirical

The following are the answers to the EM subject written test when solving PISA problems.

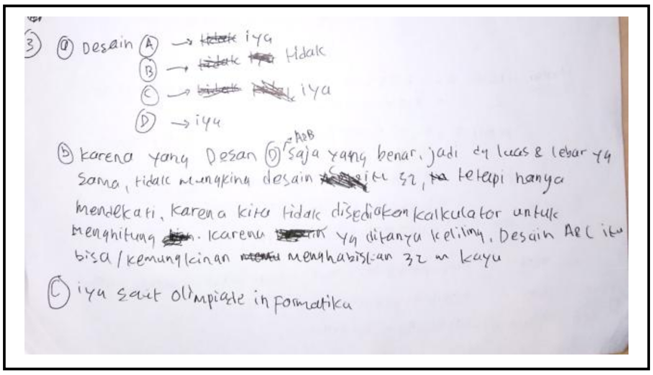


Figure 5. Subject EM answers

Based on the answer sheets, male subjects with an empirical type chose designs A, C, and D as shapes that could be made with 32 meters of wood. In the reasoning section, EL subjects wrote that only these designs were considered feasible because they had lengths and widths that fit within the material limits, while other designs were impossible to make. The subjects also mentioned that no calculator was provided to calculate the perimeter, so the decision was made based on logical estimates and observations of the shapes. This statement shows that the subjects did not guess intuitively, but rather used empirical reasoning by relying on visible evidence and their experience of having encountered similar problems in informatics competitions to come up with the answer.

Based on the interview results, subject EM assessed designs A, C, and D as feasible because visually they had realistic length and height proportions for construction from 32 meters of wood. The explanation, "*because it's similar to a rectangle, so the perimeter length is likely to be almost the same*," shows that the subject used visual experience and understanding of size and perimeter to estimate the result. As opposed to intuitive types who rely on feelings, the EM subject based their decision on visible evidence and logical reasons that could be explained. The subject also considered the limitations of the working conditions, "*because no* *calculator was provided for calculations,"* which shows their awareness of the context of the situation (situated reasoning).

In the written assignment, the subject marked 'Yes' for designs A, C, and D, and 'No' for design B. The reason given was that the three selected designs "*probably did not exceed 32 meters*" and the decision was made based on logical estimation due to the no calculator. In the interview, the subject explained that he assessed shapes A, C, and D as feasible possibilities because they were similar to rectangles, so he thought their perimeters were almost the same. The subject also stated that he did not calculate numerically, but observed the shapes and drew on his previous experience in dealing with similar problems. From all the explanations, there was no evidence that the subject calculated the perimeter, established a formula, or wrote down explicit mathematical steps.

Based on this evidence, the subject's decision-making process can be traced back to stage PK1. The subject understood the purpose of the question, as seen from the statement that he needed to know which ones did not exceed 32 meters. This understanding shows that EM recognized the main problem and constraints, so that PK1 emerged clearly. In PK2, the subject reviewed the entire design by observing its visual form. The subject EM uses their experience with rectangular shapes as a reference to estimate the perimeter. This shows that alternatives have been explored, although not in a formal mathematical way. However, there is no evidence that the subject explicitly sets criteria as intended in PK3. The subject did not state measurable criteria, such as the perimeter must be 32 meters, or compare alternatives based on numbers. What emerged were implicit criteria in the form of shape similarity and estimates not exceeding the material, but these criteria were not expressed as part of a structured strategy. Therefore, PK3 only appeared partially and did not emerge completely.

The PK4 stage is evident when the subject discriminated between designs that were likely sufficient and those that were longer, thus compiling an initial set of decisions consisting of designs A, C, and D. This grouping was based on observations of form, not calculations. Although simple, this process involves organizing alternatives as defined by PK4. In PK5, the subject makes a final decision by clearly marking which ones are 'Yes' and 'No.' This decision is made after comparing the existing shapes, not randomly, so that a final decision is indeed reached.

In PK6, the subject is able to explain the reasons for their decision. EM mentions that rectangular shapes "*usually do not exceed*" a certain size, and the EM subject uses shape logic to decide. This explanation shows that PK6 emerges, even though its substance is still based on visual experience, not mathematical representations such as models, calculations, or tables. Meanwhile, in PK7, there was no evidence that the subject stored the strategy in long-term memory or would use it again in another context. The subject only stated that he would calculate if there was a calculator or more time, but did not mention that this estimation strategy was one he would use again. Thus, PK7 did not appear in the data.

Overall, based on the evidence that emerged, the subject EM showed a decision-making pattern dominated by visual observation and previous experience, rather than formal mathematical procedures. The stages that were clearly visible were PK1, PK2, PK4, PK5, and PK6, while PK3 only appeared partially and PK7 was not visible. These findings indicate that the subject's decision-making process is empirical, but not entirely systematic because some steps do not appear in the data. The strategy used is consistent with the characteristics of empirical decision-makers who rely on real experience and formal logic in evaluating alternatives.

The following is the written test answer of subject EP when solving the PISA problems.

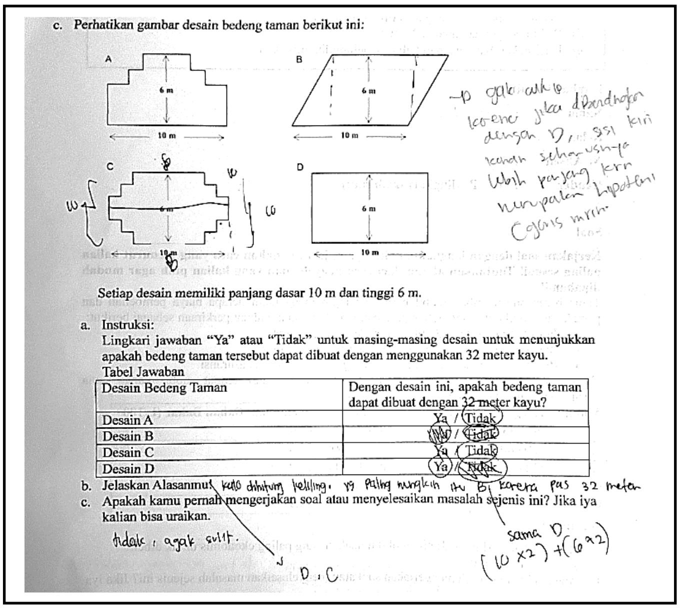


Figure 6. Subject EF answers

Based on the results of the work on the answer sheet, the subject identified the length and height of each design, then wrote down the perimeter formula to check its suitability with the 32 meters of wood. The decision made was 'Yes' for designs C and D and 'No' for A and B. Statements such as "*if you calculate the perimeter, this one is most likely because it fits 32 meters*" show that the subject associates the logic of calculation with the real context of wood usage.

Based on the results of interviews and analysis of student work, the EF subject demonstrated an initial understanding of the task (PK1). Evidence of PK1 can be seen from the statement that the first thing to do is to know the circumference first in order to know whether there is enough wood, as well as from the action of writing down the circumference formula for design D. This statement shows that EP explicitly understands the purpose of the decision, which is to check whether the circumference of each design fits within the 3-meter limit. In the next process (PK2), subject EF reviewed all design alternatives (A, B, C, and D). Evidence of PK2 can be seen from her statement that the subject "*calculated one by one*" and that designs with clear measurements, such as design D, were used as the starting point for comparison. The inclusion of all alternatives in their consideration shows that they explored the available options thoroughly. In addition, the subject used previously known information, namely the formula for the perimeter of a rectangle and the understanding that the hypotenuse must be calculated using Pythagoras, as reflected in their explanation of design B.

In PK3, which is the stage of determining assessment criteria, there is clear evidence that the EF subject uses explicit numerical criteria. She emphasized that the perimeter of each design must not exceed 32 meters and that a design with a result of exactly 32 meters could be created. She established these criteria based on the question instructions, not on visual estimates. Thus, PK3 can be said to have emerged strongly because the EF subject linked quantitative criteria (perimeter $= 32$ m) with the limitations of the wood material in the context of the problem. The PK4 stage appears when the EF subject begins to differentiate alternatives based on calculation results. On the worksheet, she calculates the perimeter of design D using the formula $2(10 + 6)$ and tries to estimate the perimeter of other designs. The process of evaluating and comparing the results of each alternative forms the basis for compiling a set of decisions, namely that designs C and D are feasible to make, while A and B are not. Evidence of PK4 emerges from the subject's own corrections to their answers. She initially chose B and D, but after considering the slanted side of design B, which they thought "*should be longer if calculated using Pythagoras,*" they changed their decision. This behavior shows that she reevaluated based on the criteria they had set.

The final decision (PK5) was made when the EF subject declared two designs (C and D) as the most feasible designs because their circumferences fit within the 32-meter limit. This decision was final, unchanged at the end of the interview, and supported by previous calculations. The statement "*yes, because it has been calculated and the results are accurate*" reinforced that the decision had been made after a process of comparison. In PK6, the EF subject was able to explain the reasons for his choice again. She stated that a shape with a perimeter of exactly 32 meters could logically be made with the available materials and emphasized that designs with sloping sides tended to exceed this limit. This explanation shows that she can represent their decision verbally and connect the object (design), attribute (side length), and relation (perimeter to material limit). The representation she provided was not in the form of a diagram or formal model, but it fulfilled the characteristics of PK6 because she could explain how the decision was made.

Meanwhile, there is no evidence in the interview data or worksheets that PK7 appeared. Subject EF did not state that the strategy would be used again in other contexts, and there was no indication that the decision pattern had been stored as long-term knowledge. She only mentioned that the question would be confusing without calculation, but did not show any reflection on the consistency of the strategy she would use in the future. Thus, PK7 did not appear. Overall, based on the available evidence, Subject EF underwent a more complete decision-making process than the other empirical subjects. PK1, PK2, PK3, PK4, PK5, and PK6 appeared clearly and were supported by calculations, re-evaluations, and verbal justifications. The only stage that is not apparent is PK7. This pattern reflects the character of empirical decision makers who combine experience, formal logic, and calculation procedures to determine the most reasonable choice in the context of the 32-meter perimeter constraint.

Findings on the empirical subject show that they solved the problem not through complete mathematical calculations, but through visual observation of shapes, consideration of previous experiences, and practical reasoning about the sufficient length of wood. The way students assessed designs A, C, and D as shapes that "*most likely did not exceed 32 meters*" is in line with the findings of Ramírez-Contreras et al. (2023), which explain that some students make mathematical decisions by relying on the direct evidence they see and their experience in dealing with similar situations. In this study, students tended to reinforce their choices through visual observation and patterns of experience, rather than through formal calculations.

Heuristic

The following is the written test answer of subject HM when solving the PISA problems.

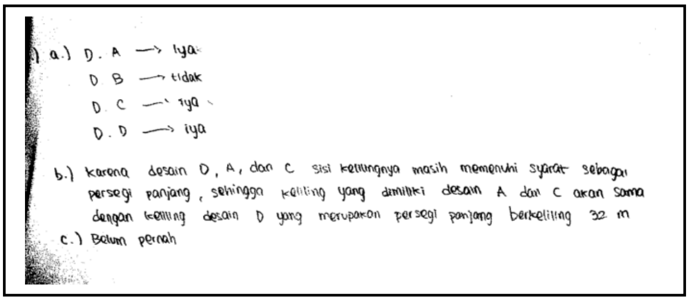


Figure 7. Subject HM answers

Based on the students' answers, HM wrote that "*designs D, A, and C still meet the requirements for a rectangle in terms of perimeter. Therefore, the perimeter of designs A and C will be the same as design D, which is a rectangle with a perimeter of 32 m*." Male subjects used an approach based on a well-known general rule, which is that all rectangles are considered to have the same perimeter. Subject HM did not perform actual calculations to check the length of each design's sides, but instead drew conclusions based on similarities in shape. This process reflects a heuristic representation strategy, which involves following existing patterns or general rules and then applying them to situations that are considered similar (Savolainen, 2017). However, its application is not entirely accurate because shapes A and C are not identical to perfect rectangles. Thus, the decisions made by the subjects contain elements of over-generalization, but still demonstrate logical and efficient thinking processes in accordance with the characteristics of heuristic decision makers according to Wang & Ruhe (2007).

Based on the results of interviews and analysis of written responses, the subject does not fully belong to the category of heuristic decision makers. He does not show the main characteristics of heuristic decision makers, who tend to still consider alternatives. However, in the decision-making process, the subject uses one of the heuristic thinking strategies, the representation strategy, which is to follow existing patterns or general rules and then apply them to situations that are considered similar. In this case, the subject considered designs A, C, and D to have the same perimeter because they all resembled rectangles. He applies patterns that he has learned previously without making further calculations. Thus, although the subject cannot be categorized as a complete heuristic decision maker, he demonstrates the use of heuristic representation strategies in his mathematical decision making, which serves as a bridge between conceptual experience and practical application in the context of the problem.

In this study, female subjects with heuristic categories were difficult to identify. The findings on heuristic subjects are in line with the view that heuristics in mathematical problem-solving work as efficient shortcuts but have the potential to produce overgeneralization. Nasir & Singh (2023) show that many students rely on heuristic knowledge in the form of general rules that are transferred to new situations without always checking the context in detail. These rules help speed up decision-making, but at the same time can lead to errors when the structural details of the problem are ignored. In the context of geometry tasks and realistic problems, Hänze & Leiss (2022) also found that students tend to use simple heuristic schemes when dealing with similar-looking shapes, for example, by assuming that shapes that are only slightly modified will have more or less the same size characteristics. The findings of Dewi et al. (2024) on mathematical decision-making types also reinforce this. Students with heuristic tendencies often rely on the overall similarity of shapes and the belief that 'commonly used rules' are sufficient, without always double-checking the details of the calculations. Within this framework, HL's behavior provides a concrete example of how representation heuristics help students make decisions quickly, but at the same time open up the possibility of oversimplification when mathematically significant differences in form are ignored.

Rational

The following is the written test answer of subject RM when solving the PISA problems.

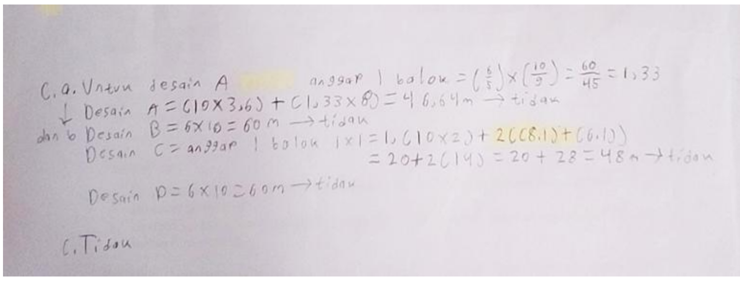


Figure 8. Subject RM answers

Based on the student's work, he began by making an assumption (assuming 1 block = 13.33) to simplify the calculation, then used this data to calculate the area of each design mathematically. This shows that the subject demonstrated a rational and logical thought process. The subject also wrote down each step of the calculation in detail, starting from the calculations for designs A, B, C, to D, and made a final decision based on the numerical results. However, the answer was incorrect because the requirement was the perimeter, while the subject used the concept of area.

Subject RM began by making a basic assumption (assuming 1 block = 13.33) to standardize the units, then performed calculations on each design alternative (A, B, C, and D) separately. Each result was compared with the 32-meter material limit to determine its feasibility. This step shows that the subject not only understood the context of the problem, but also considered each alternative before making a decision. Based on the results of the subject's work and explanations, it appears that the decision-making process was cognitively ideal, as the subject demonstrated systematic, logical, and numerically-based thinking.

Based on the results of the work and interviews, subject RM understood that the task required the selection of a design that fit within the 32-meter wood limit (PK1), but the main error was apparent from the start when he calculated the area instead of the perimeter, so his mathematical orientation was incorrect. Subject RM continued to review all alternatives (PK2), as seen from the calculations he made for designs A, B, C, and D, but there was no evidence of the correct criteria being set, such as "the perimeter must be 32 meters," so PK3 did not appear. The process of evaluating each design based on the area calculation results showed PK4, although the evaluation was not relevant to the purpose of the question. He then made a final decision (PK5) based on the area values. When asked to explain his reasoning again, Subject RM emphasized that he calculated each one individually to find out which ones exceeded 32 meters, then realized that he was wrong because he should have calculated the perimeter, not the area, so PK6 appeared but contained justifications that were not relevant to the context. There is no evidence of PK7 because the subject showed no indication that the strategy or understanding was stored for reuse. Overall, Subject RM went through some of the decision-making stages, but the entire process was built on a misunderstanding of the quantity to be calculated, so the structure of the decision-making did not lead to the correct answer.

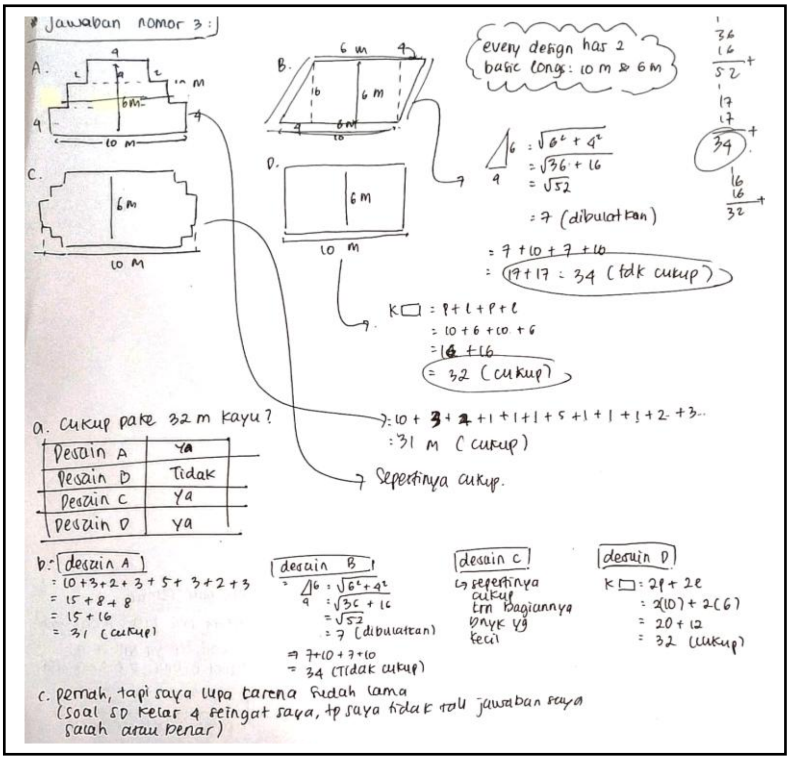


Figure 9. Subject RF answers

Based on the results of the work and interviews as presented in Figure 9, evidence of PK1 is clear when the RF subject states that the first step he thought of was to check the perimeter, because all designs have the same length and height, so the only difference is in the shape. This understanding is in line with his explanation, "*what needs to be checked is the perimeter, so we know which one can be made with 32 meters of wood*," which shows that she understands the objectives and limitations of the problem accurately. In PK2, Subject RF reviewed all designs, stating that she started with the simplest design, which was design D, so that she could use it as a reference to understand the perimeter patterns in other designs. The statement "*I started with the simplest one... so it could be a benchmark for other designs*" shows that she organized the alternatives based on the level of complexity of the shape. Evidence PK3 emerged from her explicit criteria, that each design must have a perimeter not exceeding 32 meters, and decisions were made based on the suitability of the calculation results with this limit.

In PK4, Subject RP evaluated each design by performing actual calculations, including using the Pythagorean theorem for the slanted side in design B. She explained this process by saying that she calculated each one individually to determine which designs were greater than

32 and which remained within the limit. After completing the calculations, Subject RF made a final decision (PK5) by marking designs as 'sufficient' and 'insufficient' based on the numerical results, which she compared directly with the value of 32 meters. In PK6, she was able to restate the reasons for her decision in a structured manner, for example, that some designs exceeded the limit because it were more complex in shape even though they looked similar, and that design D was the reference because its calculation was the simplest and most accurately described the length limit of the wood. There was no evidence of PK7 because Subject RP did not state that he would use this strategy in other situations, nor did she show any long-term storage of decision patterns. Overall, the data shows that Subject RF carried out most of the decision-making steps (PK1–PK6) clearly, consistent with the character of a rational decision maker who relies on mathematical calculations and logical justifications at each step.

The results of the rational subjects' research are in line with the findings of Siebert et al. (2021), which explain that individuals who are able to organize information systematically tend to make more accurate decisions because they explicitly evaluate alternatives. The rational subjects in this study exhibited this pattern when they calculated the perimeter of each design one by one, applied the Pythagorean theorem to the slanted sides, and then compared the final results with the requirement of 32 meters of wood. This step shows a strong tendency toward deliberate reasoning, an evaluative process that is considered key in mathematical decision-making.

Furthermore, research by Salimi et al. (2024) supports this finding by showing that students who are accustomed to verifying their steps and providing mathematical justifications perform better on higher-level cognitive questions. Rational subjects showed this pattern when they wanted to double-check the strategy they used after realizing they had used the concept of area, then corrected it to perimeter. This spontaneous reflection shows that subjects have self-regulation skills, an indicator related to the effectiveness of mathematical decisions.

However, these findings also intersect with the Gigerenzer & Gaissmaier (2011) critique that rational thinking that is overly focused on mathematical algorithms can cause individuals to become trapped in over-exactness, which is the tendency to prioritize calculations without considering whether they are appropriate for the context. This phenomenon appeared when the rational subjects in this study calculated the area first before realizing that what was needed was the perimeter. This conceptual error shows that rational thinking does not always guarantee accurate interpretation of context, and this is in line with Gigerenzer's finding that systematic thinking can still produce errors if understanding of the task's objective is not completely stable from the outset.

CONCLUSION

This study shows that Grade XI students exhibit different tendencies in mathematical decision-making when solving PISA problems, aligning with the categories proposed by Wang & Ruhe (2007). Intuitive students tend to choose answers quickly based on visual perception and spontaneous judgment, whereas empirical students rely on concrete experience and observations of shape without detailed calculation, yet still provide logical reasons. Heuristic students apply general patterns or rules they perceive as similar to the problem situation, although such simplifications are not always accurate. Meanwhile, rational students demonstrate a more systematic thought process through mathematical calculations, comparison of alternatives, and data-based justification, even though conceptual errors may still occur. Overall, these findings indicate that variations in how students process information, evaluate alternatives, and construct justifications significantly influence the decisions they make, highlighting that mathematical decision-making is a complex cognitive process not solely determined by conceptual mastery but also by the thinking strategies students employ when facing high-cognitive-demand tasks.

Based on these findings, mathematics teachers and schools are advised to provide more contextual and higher-level cognitive exercises so that students become used to examining information, evaluating alternatives, and providing reasons for their decisions, as well as encouraging students to reflect on their problem-solving strategies. Further research on mathematical decision-making could focus on varying the context of problems, using more subjects, or integrating other factors such as learning styles and representational abilities, so that understanding of the decision-making process can be developed more comprehensively.

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