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Exploring Relational Understanding in Statistical Problem Solving Based on Secondary School Students' Learning Styles

Yoga Tegar Santosa[1], Indriastri Nisita[1], Masduki[1*]
[1]Department of Mathematics Education, Universitas Muhammadiyah Surakarta, Indonesia
mas175@ums.ac.id

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ABSTRACT

Relational understanding is one of the crucial aspects of solving mathematical problems, especially on statistical topics. It enables students to apply procedures correctly and understand the underlying concepts, justify their reasoning, and connect mathematical ideas meaningfully. However, most students still lack relational understanding, reflected in their limited ability to interpret, apply, and connect mathematical concepts meaningfully in problem-solving contexts. Although previous studies have examined relational understanding from various psychological perspectives such as adversity quotient, cognitive styles, and self-esteem no studies have specifically and in-depth explored students' relational understanding based on their learning styles. Therefore, this study aims to explore students' relational understanding skills in solving statistical problems based on their learning styles (visual, auditory, reading, and kinesthetic). This study uses a qualitative approach with a case study design. The participants were 31 seventh-grade students from one of the public secondary schools in Karanganyar Regency, Central Java. Data were collected through learning style questionnaires, mathematical problem-solving tests, and in-depth interviews. Data validity was ensured through triangulation, and the data were analyzed through data reduction, presentation, and conclusion drawing. The results showed that student with a visual learning style fulfilled all indicators of relational understanding, including classifying objects, applying and justifying mathematical procedures, and connecting concepts. Reading-style student also met all indicators, though they showed less strength in defining necessary and sufficient conditions. In contrast, while auditory and kinesthetic learners did not meet all relational understanding indicators, their difficulties varied. Auditory student struggled particularly with justifying procedures and connecting concepts, while kinesthetic learners faced challenges in explaining reasoning and classifying objects. These findings can serve as a reference for teachers and educators in designing instructional strategies that are aligned with students' learning styles to enhance their conceptual understanding in mathematics.

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A. INTRODUCTION

Learning mathematics is crucial, especially for students at the middle school level, as it helps them think critically, logically, and creatively in solving problems (Arshad et al., 2017). Among various mathematical topics, statistics is important daily because it enables students to understand, interpret, and make data-based decisions (Pandey, 2018). However, learning statistics presents significant challenges. Students must understand the data context, select appropriate representations, and draw logical conclusions from available information (Prayitno et al., 2022). In addition, many statistical problems are non-routine (Musser et al., 2011), where the solution steps are not immediately obvious (Strenberg & Strenberg, 2012). For this reason, good problem-solving skills are essential to identify appropriate strategies and reach solutions effectively (Khotimah & Masduki, 2016; Pardiansyah et al., 2021). Through such skills, students can solve problems and understand the underlying concepts and processes in greater depth (Choudhar et al., 2022). Therefore, a high level of understanding is needed to relate various concepts and select the right approaches (Masduki et al., 2020; Sutama et al., 2022). Relational understanding is such a high-level understanding, referring to the ability to connect mathematical ideas, apply procedures logically, and understand when and why to use them (Mefiana & Juandi, 2023; Skemp, 2006; Utomo, 2020). Relational understanding allows students to adapt strategies to unfamiliar problems, recall concepts more deeply, and integrate procedures in complex situations (Patkin & Plaksin, 2019). This skill becomes especially vital when problems combine several concepts rather than a single routine procedure (Fitri & Prabawanto, 2021). Relational understanding strengthens students' problem-solving ability and fosters flexible, logical, and creative thinking in finding solutions (Minarni et al., 2016). Therefore, every student needs to develop a relational understanding to apply procedures accurately, reason, connect, and evaluate mathematical concepts meaningfully.

However, in reality, most students in Indonesia still have relatively low relational understanding skills. This is supported by the results of international assessments, such as the Programme for International Student Assessment (PISA) in 2022, which shows that only 18% of Indonesian students can achieve level 2 or higher in mathematical literacy. These levels range from the minimal ability to recognize, interpret, and apply mathematical concepts in simple situations (level 2) to connect various concepts and apply mathematical knowledge flexibly in more complex contexts (level 3 and above). These abilities are in line with the characteristics of relational understanding (Skemp, 2006). In other words, the PISA data shows that as many as 82% of Indonesian students have not reached this level, which indicates that there is still a low ability to understand and relate mathematical concepts meaningfully. Furthermore, Rochsun et al. (2024) said differences in students' learning styles affect their relational understanding skills.

Learning style is the preferred way for individuals to process information and experiences (Cassidy, 2004; Kahle, 1979). Learning style refers to individual differences in the mode of instruction, or learning method considered most effective for them (Pashler et al., 2009). In addition, learning styles also reflect a tendency towards certain mental activities that learners consider more comfortable, such as the tendency to analyze or listen (Rahman & Ahmar, 2017). Learning styles can affect students' learning achievements, including understanding concepts and solving mathematical problems (Masduki et al., 2023). Further, Fleming & Mills (1992) developed a VARK model that classifies learning styles into four main categories: visual, auditory, reading/writing, and kinesthetic. These four categories represent individual preferences in receiving, processing, and conveying information in learning.

Visual learning styles refer to an individual's tendency to perceive information through pictures, graphs, diagrams, or concept maps. Meanwhile, the auditory learning style prefers oral learning through discussions, lectures, or voice recordings. Individuals with a reading/writing learning style find it easier to understand the material through reading and writing activities, for example, by taking notes or reading textbooks. The kinesthetic learning style emphasizes physical engagement and hands-on experience, where learners find it easier to understand the material through practice, simulation, or manipulation of real objects (Fleming & Mills, 1992). These four learning styles show that students have different ways of constructing knowledge, so it is important to conduct further studies on students' relational understanding skills in each learning styles.

Research relevant to this study has been conducted before. Some of them were carried out by (1) Safitri et al. (2018) who described students' relational understanding in solving mathematical problems reviewed from the adversity quotient, (2) Yazidah et al. (2018) and Muchlas (2022) examined students' relational understanding from the cognitive style, (3) Utomo (2020) explored the relational understanding of elementary school students in mathematical problem solving, (4) Sudrajat (2022) examined the influence of relational understanding in the mathematics learning process reviewed from problem-solving skills, (5) Herawati et al. (2024) explore students' relational understanding in relational problem solving and function reviewed from self-esteem, and (6) Rochsun et al. (2024) examine the relationship between relational understanding and student learning style in mathematical problem-solving. From these studies, no studies have been found that specifically and in-depth explore how the characteristics of students' relational understanding in each learning style are not found. Studies by oleh Rochsun et al. (2024) only focused on the statistical relationships between variables without exploring students' relational understanding skills.

Therefore, research is needed that examines more deeply how students' relational understanding is viewed based on their learning style. This study is important to uncover how individual learning preferences influence the characteristics of relational understanding, which can serve as a foundation for designing more effective, adaptive, and personalized mathematics learning strategies. Based on this gap and urgency, this study aims to explore students' relational understanding skills in visual, auditory, reading, and kinesthetic learning styles in solving mathematical problems, especially statistical topics. This exploration focuses on uncovering how relational understanding manifests within each learning style, providing a deeper qualitative insight that has been overlooked in prior research.

B. METHODS

1. Research Design

This research employs a qualitative approach. Qualitative research is a naturalistic inquiry process that seeks an in-depth understanding of social phenomena in their natural context (Sutama et al., 2022). Furthermore, this study uses a case study design. A case study focuses on understanding phenomena within specific boundaries or particular units of analysis, as well as a detailed examination of an individual, a group, an institution, a social movement, or a specific event (Merriam & Tisdell, 2015; Sutama et al., 2022). Specifically, this research explores the relational understanding ability of secondary school students in solving statistical problems based on real-world conditions without manipulation, with a particular focus on each student's learning style.

2. Participants

A total of 31 seventh-grade students from a public secondary school in Karanganyar Regency, Central Java, participated in this study. They volunteered to take part without coercion and expressed their willingness to provide the necessary information for the research. The study was conducted in the even semester of the 2024/2025 academic year, focusing on statistics, particularly the topic of measures of central tendency (mean, median, and mode).

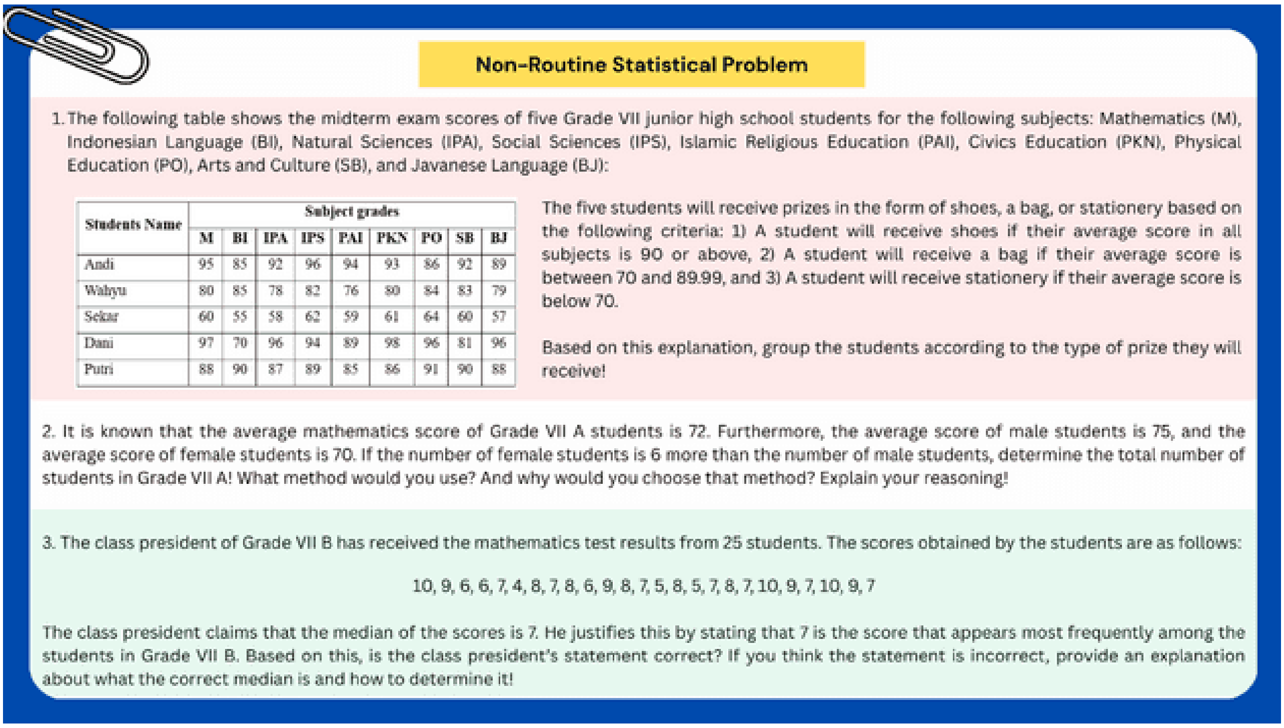
3. Instruments

This study employs two types of instruments: a learning style questionnaire and a mathematical problem-solving test. The learning style questionnaire was developed based on the VARK model (Visual, Auditory, Reading, and Kinesthetic) by Fleming & Mills (1992). The questionnaire consists of 16 multiple-choice questions with four answer options each (source: https://vark-learn.com/the-vark-questionnaire/). Furthermore, this questionnaire is used to identify and classify students' learning styles. Meanwhile, the mathematical problem-solving test was designed based on indicators of relational understanding (Skemp, 2006). These indicators are presented in Table 1. Each indicator is assigned a code to facilitate further data analysis by the researchers.

Table 1. Relational Understanding Indicators

Student's Skill	Indicators	Code
Relational Understanding	1. The ability to classify objects based on whether or not they meet the conditions for concept formation.	CO
	2. The ability to apply concepts through algorithms to solve problems.	AL
	3. The ability to explain the reasons or meaning behind mathematical procedures or formulas.	RM
	4. The ability to connect one concept to another.	CC
	5. The ability to develop the necessary and sufficient conditions of a concept.	NS

The mathematical problem-solving test instrument in this study consists of three essay questions focusing on statistics, specifically the topic of measures of central tendency. These three questions are categorized as non-routine problems since they cannot be solved directly using standard procedures that students have previously mastered. Their solution requires deep thinking and the ability to meaningfully connect various mathematical concepts (Kholid et al., 2024; Toh et al., 2008). Furthermore, Figure 1 presents the mathematical problem-solving test instrument used in this study. Problem number 1 was designed to explore students' relational understanding based on the CO indicator, problem number 2 measures the AL, RM, and CC indicators, while problem number 3 aims to evaluate the NS indicator.



Non-Routine Statistical Problem

1. The following table shows the midterm exam scores of five Grade VII junior high school students for the following subjects: Mathematics (M), Indonesian Language (BI), Natural Sciences (IPA), Social Sciences (IPS), Islamic Religious Education (PAI), Civics Education (PKN), Physical Education (PO), Arts and Culture (SB), and Javanese Language (BJ):

Students Name	Subject grades								
	M	BI	IPA	IPS	PAI	PKN	PO	SB	BJ
Andi	95	85	92	96	94	93	86	92	89
Wahyu	80	85	78	82	76	80	84	83	79
Sekar	60	55	58	62	59	61	64	60	57
Dani	97	70	96	94	89	98	96	81	96
Putri	88	90	87	89	85	86	91	90	88

The five students will receive prizes in the form of shoes, a bag, or stationery based on the following criteria: 1) A student will receive shoes if their average score in all subjects is 90 or above, 2) A student will receive a bag if their average score is between 70 and 89.99, and 3) A student will receive stationery if their average score is below 70.

Based on this explanation, group the students according to the type of prize they will receive!

2. It is known that the average mathematics score of Grade VII A students is 72. Furthermore, the average score of male students is 75, and the average score of female students is 70. If the number of female students is 6 more than the number of male students, determine the total number of students in Grade VII A! What method would you use? And why would you choose that method? Explain your reasoning!

3. The class president of Grade VII B has received the mathematics test results from 25 students. The scores obtained by the students are as follows:

10, 9, 6, 6, 7, 4, 8, 7, 8, 6, 9, 8, 7, 5, 8, 5, 7, 8, 7, 10, 9, 7, 10, 9, 7

The class president claims that the median of the scores is 7. He justifies this by stating that 7 is the score that appears most frequently among the students in Grade VII B. Based on this, is the class president's statement correct? If you think the statement is incorrect, provide an explanation about what the correct median is and how to determine it!

Figure 1. Non-Routine Mathematical Problems

Two experts in mathematics education validated both instruments and analyzed them using the Content Validity Index (CVI) based on Aiken's V coefficient (Aiken, 1980). All essay questions of the mathematical problem-solving test obtained CVI values greater than 0.80, indicating high content validity. Meanwhile, the learning style questionnaire, which consists of 16 multiple-choice items, also showed strong content validity. Fourteen items obtained a CVI score of > 0.80, indicating a high level of validity. In comparison, the remaining two items received scores between 0.60 and 0.79, which are classified as moderate and were revised based on expert feedback (Almanasreh et al., 2019). Furthermore, Cronbach's Alpha was used for both instruments to assess reliability (Taber, 2018). The mathematical problem-solving test obtained a Cronbach's Alpha value of 0.72, and the learning style questionnaire yielded a value of 0.74. Both scores are categorized as reliable (Sujarweni, 2014; Taber, 2018), confirming that the instruments are suitable for use in this research.

4. Data Collection

Data collection was conducted through learning style questionnaires, mathematical problem-solving tests, and in-depth interviews. In the initial stage, researchers distributed learning style questionnaires to all participants to identify each individual's learning style model. Subsequently, all participants completed the mathematical problem-solving test. After the test, researchers evaluated the collected problem-solving results and then selected representative students from each learning style category for in-depth interviews to explore their relational understanding.

5. Validity of Data

Data validity in this study was ensured through method triangulation. Method triangulation is a technique to verify data validity by employing different methods to confirm consistency across findings from various approaches (Creswell & Creswell, 2017). In this study, method triangulation established data credibility by applying multiple methods to the same subjects (students). Mathematical problem-solving results were subsequently cross-verified through in-depth interviews.

6. Data Analysis

Data analysis was conducted using the flow model method. This process encompassed data reduction, data display, and conclusion drawing (Miles et al., 2014). The researchers analyzed students' learning style questionnaire responses to categorize them into four learning style groups. This classification was based on the most frequently selected multiple-choice options for each student. The grouping criteria are presented in Table 2.

Table 2. Learning Style Classification from VARK Questionnaire Responses

Dominant Answer Option	Category
Students selected option "A" more frequently	Kinestethic
Students selected option "B" more frequently	Visual
Students selected option "C" more frequently	Reading
Students selected option "D" more frequently	Auditory

As part of the data reduction process, students' mathematical problem-solving worksheets were assessed using a rubric based on the relational understanding indicators (see Table 3). The student who achieved the highest total score was selected as a representative subject for further analysis within each learning style category. If multiple students earned equal top scores, the researchers examined the depth and clarity of their written responses—notably, how well they demonstrated reasoning and conceptual understanding. The most articulate responses were selected. These selected students then participated in in-depth interviews. Their worksheet and interview responses were analysed and displayed in narrative and tabular formats, forming the basis for concluding relational understanding in statistical problem-solving across learning styles.

The researchers interpreted the students' written responses and interview statements using a deductive approach guided by predefined indicators. Each student's demonstration of the indicators was analysed in depth to determine the level and nature of their relational understanding. Comparative analysis was conducted across the four learning styles to identify patterns, similarities, and differences. To enhance validity, methodological triangulation was applied by comparing the written test results with the interview data, allowing researchers to verify consistency and gain deeper insights into each student's reasoning process, as shown in Table 3.

Table 3. Relational Understanding Skills Assessment Rubric

Indicators	Information	Score
The ability to classify objects based on whether or not they meet the conditions for concept formation	Able to accurately identify and classify objects based on all conditions, and provide logical and comprehensive justification for the classification.	4
	Accurate classification, but the justification is incomplete or unclear.	3
	Partially correct classification; some misunderstanding of the conditions or inaccurate explanation.	2
	Unable to classify objects correctly and fails to provide justification.	1
The ability to apply concepts through algorithms to solve problems	Provides a systematic and complete solution using appropriate algorithms or procedures, and obtains the correct final result.	4
	Provides a reasonably systematic solution with minor errors, yet obtains the correct final result.	3
	The solution is less systematic or uses inappropriate procedures, resulting in an incorrect final answer.	2
	Unable to formulate solution steps or merely guesses the final answer without a procedure.	1
The ability to explain the reasons or meaning behind mathematical procedures or formulas	Provides a thorough and logical explanation for the use of a procedure or formula, demonstrating deep understanding.	4
	Provides a general explanation, although it lacks depth.	3
	Offers a partial or inaccurate explanation.	2
	Unable to provide an appropriate explanation and merely follows the procedure without understanding.	1
The ability to connect one concept to another.	Clearly, relevantly, and logically demonstrates relationships between mathematical concepts in the problem-solving process.	4
	Shows connections between concepts, although not fully developed or explicit.	3
	Mentions two related concepts but does not clearly explain their relationship.	2
	No attempt is made to connect concepts; answers stand alone without conceptual linkage.	1
The ability to develop the necessary and sufficient conditions of a concept	Accurately identifies and explains the necessary and sufficient conditions within a mathematical context.	4
	States both necessary and sufficient conditions, but the explanation lacks clarity or explicitness.	3
	States only one of the conditions (either necessary or sufficient) with limited explanation.	2
	Unable to explain the necessary and sufficient conditions or provides an incorrect explanation.	1

C. RESULT AND DISCUSSION

The learning style questionnaire was administered to 31 seventh-grade students at one of the public secondary schools in Karanganyar Regency. Figure 2 presents the percentage distribution of students across learning style categories. The results show that 22% of students (7 students) were visual learners, 16% (5 students) auditory learners, 10% (3 students) reading learners, and 52% (16 students) kinesthetic learners. These data indicate that the majority of students in this class had a kinesthetic learning style. Subsequently, one student from each learning style category was selected for further exploration of their relational understanding in mathematical problem-solving: S-V (visual), S-A (auditory), S-R (reading), and S-K (kinesthetic).

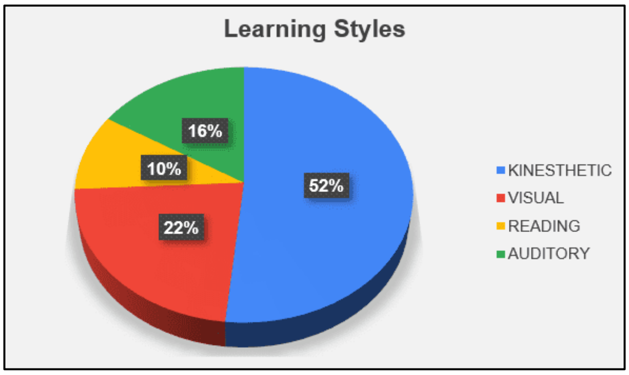


Figure 2. Distribution of Student Learning Styles

1. Indicator 1: Classifying Objects for Concept Formation

This indicator refers to students' ability to classify objects based on whether or not they meet the necessary conditions for concept formation. For students with a visual learning style (S-V), S-V solved the first problem related to classifying five students to receive specific prizes, where the classification was based on each student's average score. Before determining the type of prize each of the five students would receive, S-V first accurately calculated their average scores **(CO)**. Afterwards, S-V recorded the names of the five students along with the prizes they obtained **(CO)**. For clarity, Figure 3 shows S-V's answers to the first problem. Figure 3 reveals that S-V had not written the classification rationale for each student. Subsequently, the researcher conducted an interview with S-V to gain deeper understanding. The interview process was as follows:

P: "In this part, you wrote that Andi got shoes, Wahyu got a bag, Sekar got stationery, and so on. Why did you group them like that?"

S-V: "Umm… because, ma'am, based on the information in the question, students who had an average score above 90 got shoes, those between 70 and 90 got a bag, and those below 70 got stationery." **(CO)**

P: "Okay. So you grouped them based on the students' average scores. How did you calculate the average?"

S-V: "I added up the students' scores from the 9 subjects and then divided by 9, ma'am." **(CO).**

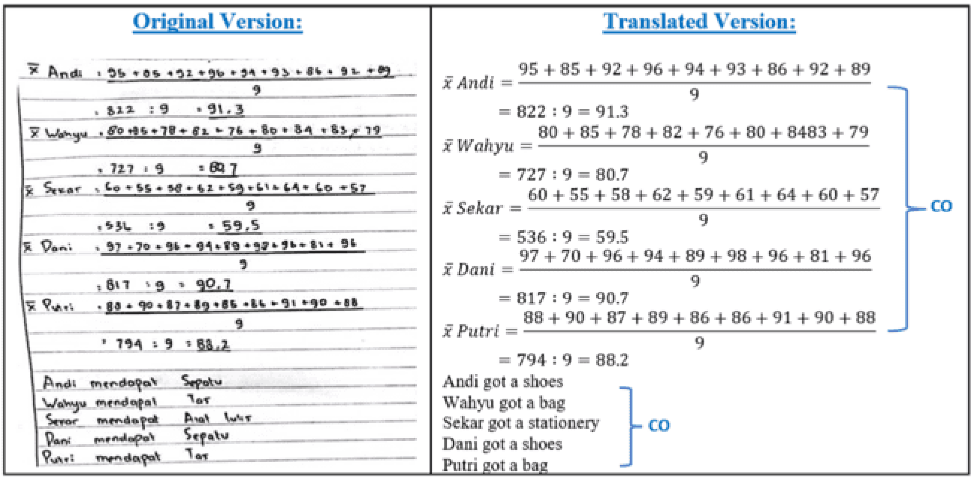


Figure 3. S-V's Answer to the First Problem

Figure 3 and interview results demonstrate that S-V could successfully classify objects (the gifts received by students) using the average concept **(CO)**. S-V displayed solid understanding of the average concept by precisely dividing the total sum of student scores by the number of students to obtain the mean value. Thus, S-V met the relational understanding indicator for object classification based on fulfillment of concept formation requirements **(CO)**. For the auditory learner (S-A), problem-solving for the first task involving gift classification began by calculating the average. Figure 4 presents S-A's solution to the first problem. Notably, S-A's calculated average was correct, and the subsequent classification was also accurate. The researcher then interviewed S-A regarding the reasoning behind this classification.

P: "Here you wrote that Andi got shoes, and so on. Why did you group them like that?"

S-A: "Based on the information in the question. So, students who got an average score of 90 and above received shoes, those who scored between 70 and 90 got bags, and those who scored below 70 got stationery." **(CO)**

P: "How did you calculate the average?"

S-A: "Each student has grades for 9 subjects, right ma'am? So I added up the grades from the 9 subjects and then divided by 9." **(CO)**

Figure 4 and interview results indicate that S-A successfully classified objects (the rewards received by students) using the average concept **(CO)**. S-A demonstrated a strong understanding of the average concept by accurately dividing the total sum of student scores by the number of students to obtain the precise mean value. Therefore, S-A satisfied the relational understanding indicator for object classification based on fulfillment of concept formation requirements **(CO)**.

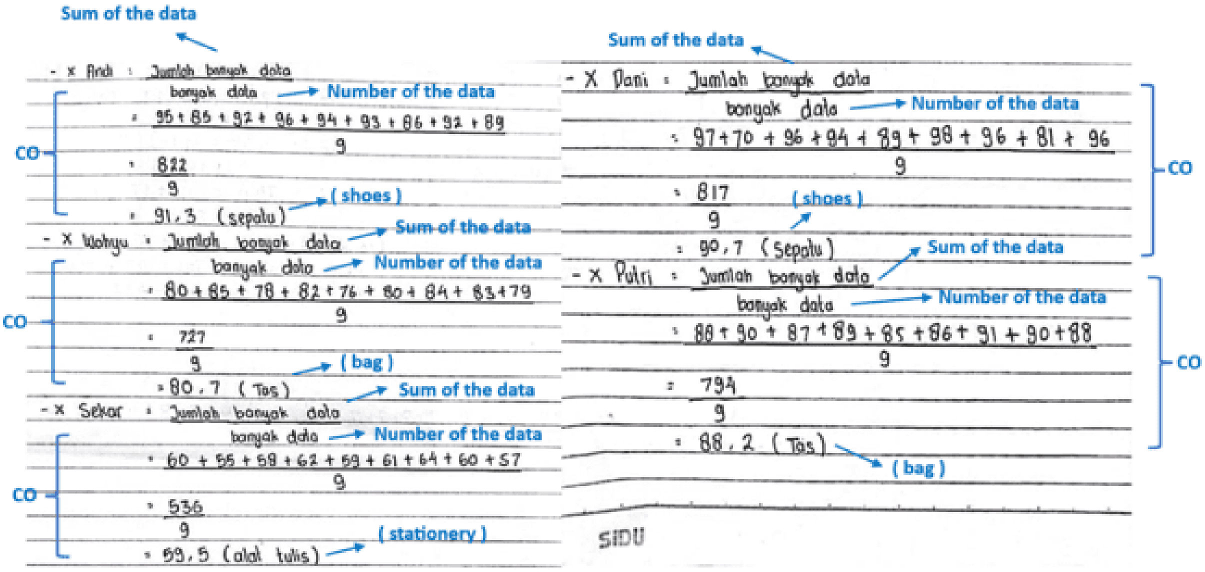


Figure 4. S-A's Answer to the First Problem

For the reading-style learner (S-R), the student approached the first problem regarding the classification of rewards received by each student by first calculating the respective average values (see Figure 5). The researcher then conducted an interview with S-R concerning the solution process for this first problem.

P: "Try to explain how you grouped the gifts received by each student."

S-A: "First, I calculated the average by dividing the total score by the number of scores, ma'am. Then, based on the information in the question, if the average is more than 90, the student gets shoes; less than 70, they get stationery; and between 70 and 90, they get a bag." **(CO)**

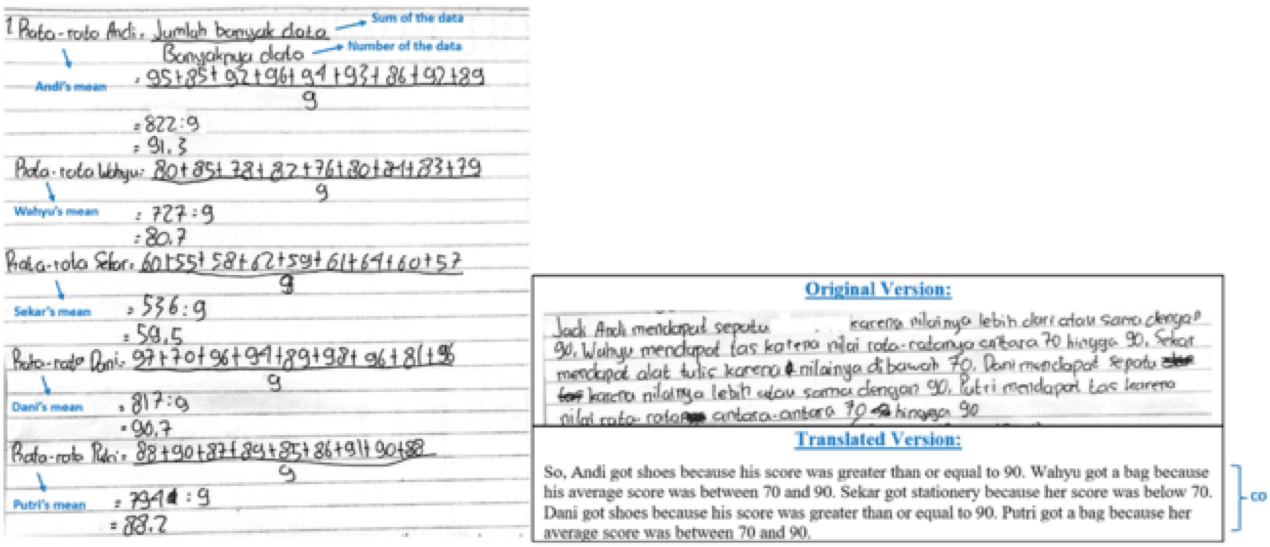


Figure 5. S-R's Answer to the First Problem

Based on the interview and S-R's work results (Figure 5), S-R accurately calculated the average scores of all five students. The rationale S-R used for classifying the rewards received by students also matched the given criteria **(CO)**. S-R explained that Andi received shoes as a reward because his average score exceeded 90, Wahyu received a bag because his average score was between 70 and 90, and so on for all five students, with all classifications being correct

(CO). Thus, S-R satisfied the relational understanding indicator for classifying objects based on fulfillment of concept formation requirements **(CO)**. For the kinesthetic learner (S-K), the student began solving the first problem regarding reward classification by first calculating each student's average score (see Figure 6). While S-K correctly computed the average scores for all five students, they were unsuccessful in properly classifying the rewards according to the given problem requirements. Subsequently, the researcher conducted an interview with S-K to verify their responses.

P: "You wrote that no student received shoes. You also mentioned that this way of grouping was the easiest and the only method you could think of. Is that right? Why?"

S-A: "Well, here's the thing, ma'am. I was confused about the gifts for the students. I only calculated the average, and beyond that, I didn't know what else to do. So I just made a guess like that, ma'am."

The interview and S-K's responses (Figure 6) reveal that S-K did not fully comprehend the information presented in the problem, particularly regarding reward allocation based on average scores. Furthermore, S-K was unable to provide logical justification for the classification and appeared to rely on guessing. Consequently, S-K has not yet achieved relational understanding in object classification based on the specified concept.

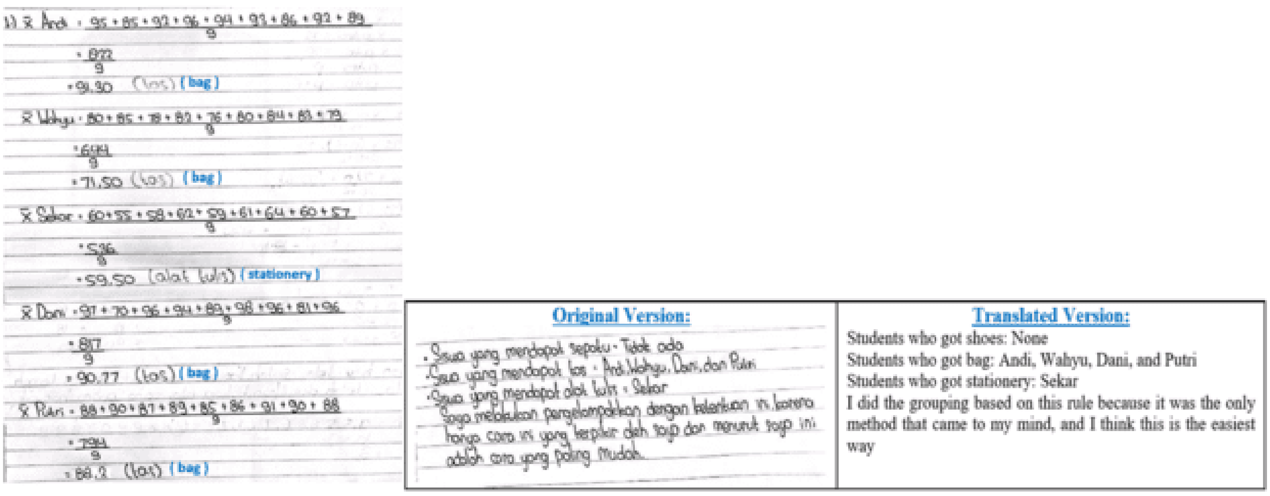


Figure 6. S-K's Answer to the First Problem

2. Indicator 2–4: Applying, Explaining, and Connecting Concepts

These indicators include: the ability to apply concepts through algorithms to solve problems **(AL)**, explain the reasoning behind mathematical procedures or formulas **(RM)**, and connect one concept to another **(CC)**. For the student with a visual learning style (S-V), S-V began the process of solving the second problem by first writing down the given information. Figure 7 shows S-V's response to the second problem related to the combined average.

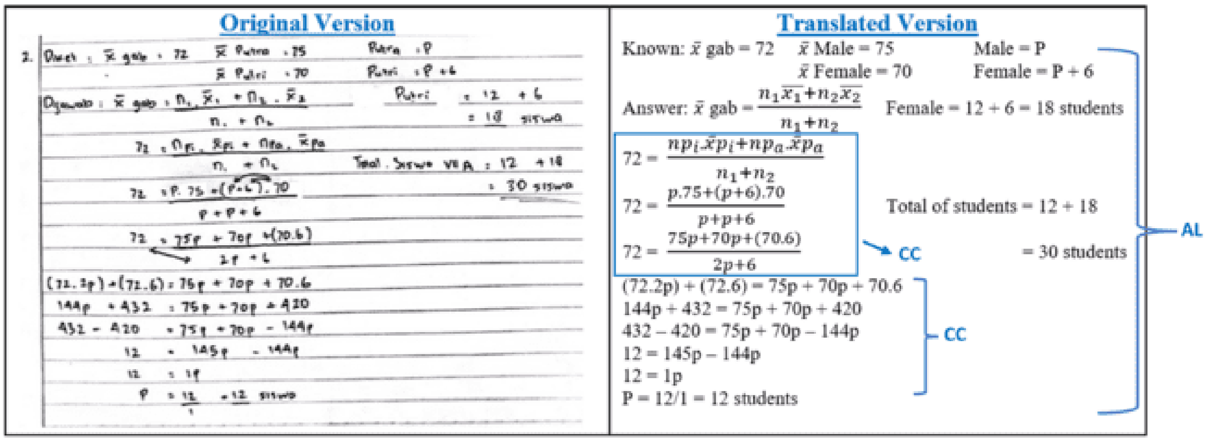


Figure 7. S-V's Answer to the Second Problem

Based on Figure 7, S-V correctly wrote down the given information. They also used variables to represent the average score and the number of male and female students in the problem **(AL)**. Next, S-V began solving the problem by applying the combined average formula **(AL)**. The substitution into the formula was done correctly **(CC)**, as were the subsequent calculation steps. In this process, S-V applied the distributive property in algebra and solved the algebraic equation in the combined average formula using the proper procedure **(AL, CC)**. S-V successfully determined the number of male students, which was 12. Since the number of female students was six more than the males, S-V added 12 and 6, resulting in 18 female students **(AL, CC)**. Thus, the total number of students was 30 **(AL, CC)**. To further examine S-V's problem-solving process, the researcher conducted an interview with S-V. The interview process was as follows.

P : "For question number 2, what was the first step you took to solve it?"

S-V: "Umm. I wrote down the information given in the problem, ma'am. Then I used the combined average formula." **(AL)**

P : "Why did you use that formula?"

S-V: "Well, because this question isn't like question number 1, where we knew all the students' scores. In question 2, we only know the overall average and the average score of each group. So I thought it made more sense to use the combined average, ma'am." **(RM)**

P : "Okay. After writing down the known information and choosing the combined average formula, what was your next step?"

S-V: "Um, I plugged the numbers into the formula, ma'am **(AL)**. Then for the number of female students, it was P + 6, so I substituted it with P + 6 **(AL)**. For the multiplication (P + 6) × 70, I used the distributive property, ma'am **(CC)**. And then I continued like that until I got my final answer here (points to the answer sheet)." **(AL, CC)**

Based on the interview results, S-V was able to clearly explain the reasoning behind using the combined average concept to solve the problem **(RM)**. Thus, based on the problem-solving process shown in Figure 7 and the interview, it is evident that S-V could algorithmically apply the combined average concept in their solution **(AL)**. Additionally, S-V could justify the choice of the combined average formula as a problem-solving strategy **(RM)** and successfully connect their prior knowledge of algebra with the combined average concept **(CC)**. Therefore, S-V met the indicators of relational understanding across the **AL, RM**, and **CC** aspects. Next, for the auditory learning style student (S-A), S-A began solving the second problem by writing down the given information from the question using variables. Afterward, S-A applied the combined average formula to solve it. Figure 8 shows S-A's answer to the second problem.

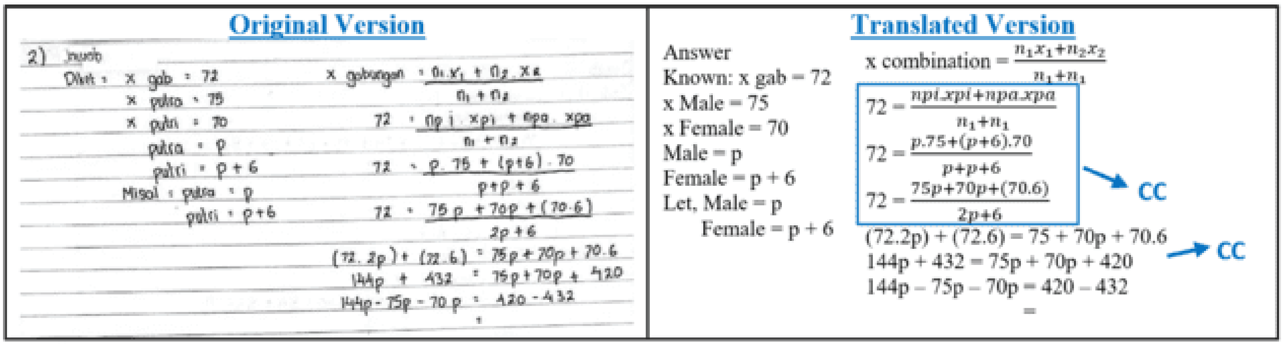


Figure 8. S-A's Answer to the Second Problem

It is evident that S-A correctly substituted the known components into the formula (CC). S-A was also able to solve the algebraic equation derived from the formula (CC). However, the solving process was not carried through to completion. This indicates that S-A failed to apply the concept algorithmically in problem-solving. Subsequently, the researcher conducted an interview with S-A as follows.

P : "For question number two, you used the weighted average formula—why did you choose that?"

S-A: "Umm (thinking for a moment). Because that's usually how it is, ma'am. So, for this kind of question (points to the problem), as far as I understand, we use the weighted average formula."

P : "Alright, then why didn't you finish your answer?"

S-A: "I got confused, ma'am, with the operation on the left side: 144p – 75p – 70p. And I saw that the right side would end up being negative. I thought it didn't make sense for the number of students to be negative, so I stopped there."

Based on Figure 8 and interview results, it appears that S-A was unable to provide logical reasoning for using the combined average formula in solving the second problem. S-A also failed to correctly solve the algebraic equation 144p - 75p - 70p = 420 - 432. In fact, S-A immediately concluded that if the right-hand side yielded a negative value, the equation's solution must necessarily be negative. This demonstrates that S-A has not yet developed the ability to connect algebraic concepts - such as operations on algebraic forms and properties of linear equations - with understanding the problem's context. Consequently, S-A has not optimally met the indicators of relational understanding in the **AL**, **RM**, and **CC** aspects.

For the reading-style learner (S-R), S-R began solving the second problem by accurately recording the given information **(AL)**. Using variables to represent the average scores and the number of male and female students **(AL)**, S-R correctly solved the problem by applying the combined average formula with proper substitution and calculation steps **(CC)**. S-R appropriately implemented the distributive property and followed correct procedures in solving the algebraic equation **(AL, CC)**, arriving at 12 male students. Following the given information that there were six more female students, S-R added 6 to the number of male students, resulting in 18 female students, making a total of 30 students **(AL, CC)**. S-R's complete solution is shown in Figure 9**.**

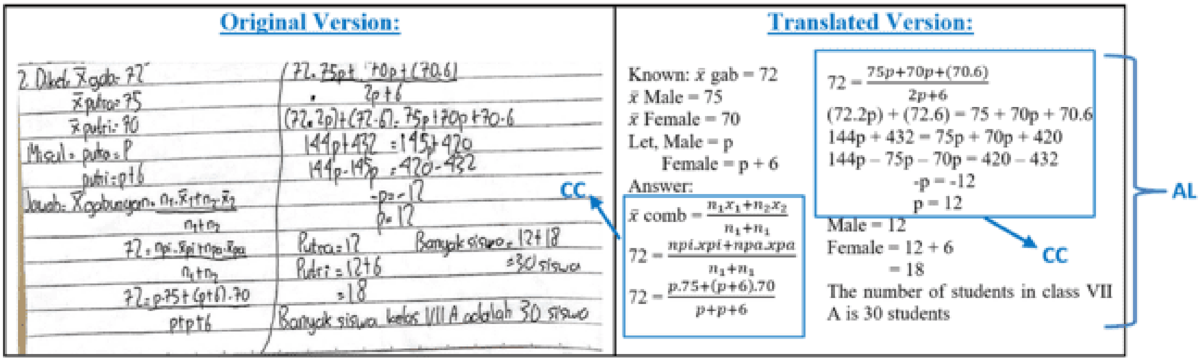


Figure 9. S-R's Answer to the Second Problem

To further examine S-R's problem-solving process in depth, the researcher conducted an interview with S-R as detailed below.

P : "I see that your answer to question number 2 is correct. But try to explain why you used that method to solve it."

S-R: "In that question, the students' individual scores weren't given like in question 1, ma'am, so the average couldn't be calculated by adding all the values and dividing by the total number of scores. However, the average score of male and female students and the overall average were given." **(RM)**

P : "Alright. Then, try to explain how you completed the solution all the way to the end."

S-R: "Um, like I said earlier, I used the combined average formula. Then I plugged in all the known values here (points to the known part), and for the female students, I replaced it with P + 6. That led to a multiplication where I had to use the distributive property, ma'am, so I applied that **(CC)**. After that, I continued calculating until I got the final result like what I wrote here (points to the answer sheet)." **(CC, AL)**

Based on the interview, S-R demonstrated clear understanding in explaining the rationale behind using the combined average concept to solve the problem **(RM)**. Therefore, both from the problem-solving results (Figure 9) and the interview, S-R showed the ability to: (1) algorithmically apply the combined average concept **(AL)**, (2) justify the selection of this formula as a solution strategy **(RM)**, and (3) connect it with previously acquired algebraic concepts **(CC)**. Thus, S-R successfully met all indicators of relational understanding across the **AL, RM**, and **CC** dimensions.

Furthermore, for the kinesthetic learning style student (S-K), S-K began solving the second problem by accurately documenting the given information and employing variables to represent both the average scores and the numbers of male and female students **(AL)**. S-K correctly applied the combined average formula, demonstrating proper substitution and calculation techniques **(AL, CC)**. The student also appropriately implemented the distributive property and accurately solved the algebraic equation. S-K determined there were 12 male students, then added the 6-student difference to arrive at 18 female students, resulting in a total of 30 students **(AL, CC)**. Additionally, S-K's complete solution to the second problem is presented in Figure 10.

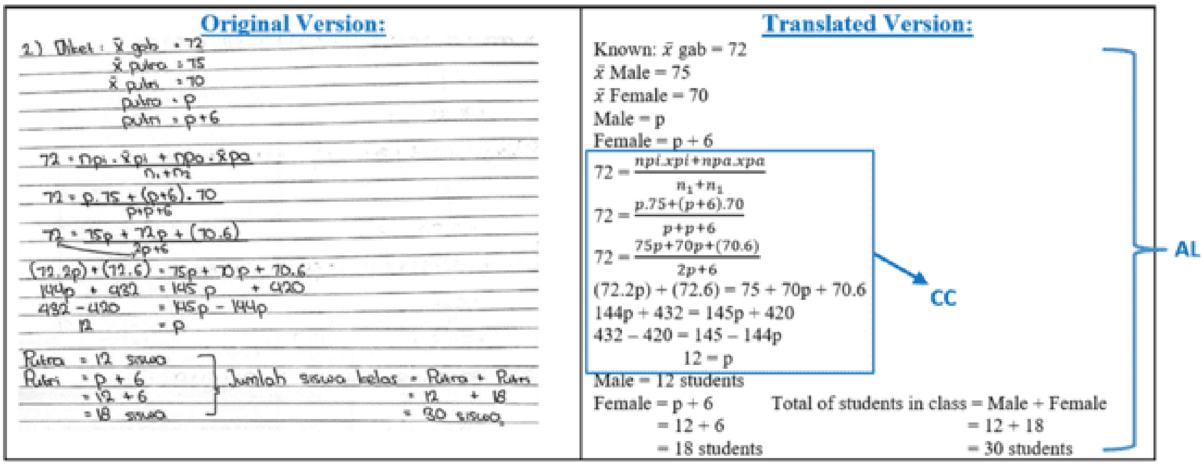


Figure 10. S-K's Answer to the Second Problem

To gain deeper insight into S-K's understanding, the researcher conducted the following interview.

P : "You were right to use the combined average concept to solve question number 2. But try to explain why you used that method."

S-K: "Umm (thinking for a moment). I used the combined average formula because when we practiced similar problems before, we used that formula, ma'am. So I just used it again here."

P : "So, it's because that's usually how it's done, right? Okay, then after using the combined average formula, what was your next step?"

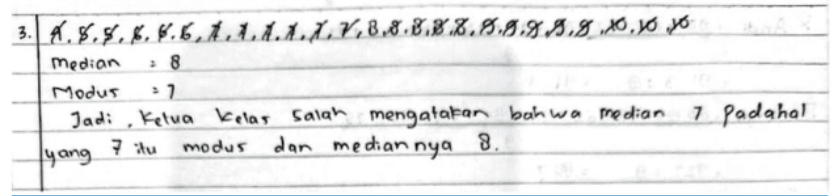
S-K: "Yes, ma'am, just like what I wrote here (points to the answer sheet). I directly substituted the known values from the question into the formula. Then, I did the algebraic operations and finished solving it until I found that the number of male students was 12." **(CC, AL)**

The interview results revealed that S-K was unable to provide logical justification for using the combined average formula in problem-solving. The student relied solely on prior experience without comprehending the underlying rationale or meaning behind the formula's application. Therefore, based on both written responses and interview findings, S-K met the relational understanding indicators for **AL** and **CC** aspects, but failed to demonstrate the ability to explain the meaning or reasoning behind the mathematical procedures and formulas used.

3. Indicator 2–4: Applying, Explaining, and Connecting Concepts

This indicator refers to students' ability to determine and formulate the necessary and sufficient conditions of a mathematical concept. In solving the third problem, the visual learner (S-V) immediately calculated the median and mode of the singular dataset before justifying that the class president's statement in the problem was incorrect. Figure 11 presents S-V's solution to the third problem.

Original Version


3. 4, 5, 5, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, 8, 8, 8, 8, 9, 9, 9, 9, 9, 10, 10, 10
Median : 8
Modus : 7
Jadi, Ketua kelas salah mengatakan bahwa median 7 padahal yang 7 itu modus dan mediannya 8.

Translated Version

4, 5, 5, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, 8, 8, 8, 8, 9, 9, 9, 9, 9, 10, 10, 10
Median = 8
Mode = 7
So, the class president was wrong to say that the median is 7, whereas 7 is the mode and the median is 8.

Figure 11. S-V's Answer to the Third Problem

According to Figure 11, S-V did not provide a complete answer. S-V proceeded to directly calculate the median of the singular dataset using the correct computational method based on the median concept. Subsequently, the researcher conducted an interview with S-V to further explore the student's conceptual understanding. The interview process was as follows.

P : "For question number 3, do you think the class leader's statement is correct?"

S-V: "No, ma'am."

P : "Why not?"

S-V: "Because as far as I know, the value that appears the most is called the mode, not the median." **(NS)**

P : "Then what is the median? How do you find it?"

S-V: "The median is the middle value in the data, ma'am. You find it by arranging the data from the smallest to the biggest, then looking for the one in the middle." **(NS)**

Based on Figure 11 and the interview results, S-V demonstrated a solid understanding of the necessary and sufficient conditions underlying the concepts of mode and median **(NS)**. Specifically, S-V accurately explained that a data point is considered the mode when it appears with the highest frequency compared to other values in the dataset, while the median represents the middle value in an ordered sequence of data arranged from smallest to largest **(NS)**. This clear articulation of both concepts indicates that S-V has successfully met the relational understanding indicator for establishing the necessary and sufficient conditions of mathematical concepts. The responses not only reflect procedural knowledge but also reveal a deeper conceptual grasp of these statistical measures, as evidenced by S-V's ability to properly define and distinguish between these fundamental concepts in statistics.

Next, for the auditory learner (S-A), the student's solution to the third problem was incomplete. As shown in Figure 12, S-A only provided calculations for determining the median without further justification. To explore this limitation in greater depth, the researcher conducted a follow-up interview with S-A, as detailed below.

P : "In question number three, you were actually asked to explain why the class leader was wrong, right? Also, you were asked to explain what the median is and how to determine it. But you didn't answer all of that completely. Try explaining it now."

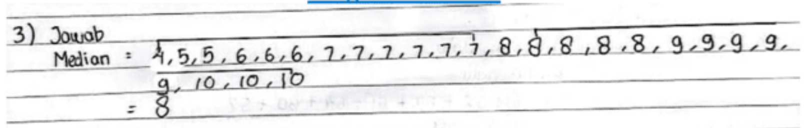
S-A: "Umm (thinking for a moment). I think the class leader was wrong, ma'am. Because the value that appears most often is called the mode, not the median **(NS)**. The median is the middle value of the data, ma'am."

P : "Is it just the middle value? Are there any other rules?"

S-A: "Umm. Usually the data has to be ordered, ma'am, like from smallest to largest, or the other way around. But I kind of forgot."

Based on Figure 12 and interview results, the analysis reveals that S-A correctly understands the mode as the data value with the highest frequency of occurrence. However, S-A demonstrated incomplete understanding of the conditions required for determining the median. While S-A accurately noted that data must be ordered, the student incorrectly stated that either ascending or descending order would suffice **(NS)**. This represents a conceptual gap, as proper median determination strictly requires data to be arranged in ascending order (from smallest to largest) to correctly identify the middle position. Consequently, S-A has not fully developed the necessary and sufficient conditions for the median concept, though demonstrating adequate understanding of these conditions for the mode concept.

Original Version:



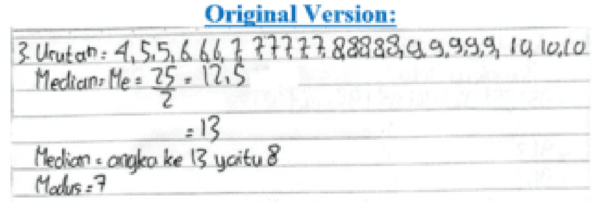
Translated Version:

3) Answer
Median = 4, 5, 5, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, 8, 8, 8, 8, 9, 9, 9, 9, 9, 10, 10, 10
= 8

Figure 12. S-A's Answer to the Third Problem

The reading-style learner (S-R) provided an incomplete solution to the third problem. As documented in Figure 15, S-R's response consisted solely of procedural steps for calculating the median and identifying the mode from the given dataset. In determining the median, S-R divided the total number of data points by 2 to locate the central position. However, this methodology proved problematic as the dataset contained an odd number of observations, making this approach mathematically inappropriate for accurate median determination. The student's complete written response to this problem is presented in Figure 13.

Original Version:



Translated Version:

Order: 4, 5, 5, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, 8, 8, 8, 8, 9, 9, 9, 9,
9, 10, 10, 10
Median = Me = 25/2 = 12.5
= 13
Median = the 13th number is 8
Mode = 7

Figure 13. S-R's Answer to the Third Problem

For a more comprehensive understanding of S-R's conceptual grasp, the researcher conducted an in-depth interview with S-R as detailed below.

P : "In question number 3, your answer was incomplete. Now try to explain: do you think the class president was wrong? What is your reason? Then also explain what median actually is and how to find it."

S-R: "Umm. I think the class president was wrong, ma'am. Because the value that appears most often is called the mode, not the median **(NS)**. So, the value 7 is the mode. Meanwhile, the median is the middle value of data that has been ordered from smallest to largest, ma'am **(NS)**. I determine the middle value by dividing the total number of data by 2, because as far as I know, to find the middle, you have to divide by 2 to see where the center is."

Based on the interview, S-R demonstrated an understanding that the mode represents the most frequently occurring value in a dataset **(NS)**. S-R also correctly recognized that the median is the middle value of an ordered dataset. Although S-R arrived at the correct median value, the procedural approach employed was not fully accurate. Specifically, S-R divided the total number of data points (25, an odd number) directly by 2, yielding 12.5, which was then rounded to 13. However, the formal method for determining the median position in an odd-sized dataset requires the formula $(n + 1)/2$. Thus, while S-R was able to articulate the necessary and sufficient conditions of the concept, the implementation of these conditions—both procedurally and conceptually—in the problem-solving context was not entirely precise.

For the kinesthetic learner (S-K), the student correctly resolved the third problem by accurately identifying the class president's statement as mathematically incorrect. S-K demonstrated conceptual understanding by explaining that the median represents the middle value of an ordered dataset rather than the most frequently occurring value **(NS)**. The student then procedurally executed the median determination through appropriate step-by-step calculations, arriving at the correct solution (see Figure 14). To further investigate S-K's depth of understanding, the researchers conducted a structured interview as presented in the following section.

P : "You wrote that the median is the middle value of ordered data. What do you mean by that?"

S-K: "Ordered data from smallest to biggest, ma'am." **(NS)**

P : "If the value that appears most often isn't the median, then what is it called?"

S-K: "The mode, ma'am." **(NS)**

The interview and problem-solving results demonstrate that S-K possesses a robust understanding of the necessary and sufficient conditions that define median and mode concepts **(NS)**. Specifically, S-K exhibited dual competency by both accurately articulating the theoretical definitions and correctly applying procedural methods to determine median and mode values. This comprehensive performance confirms that S-K has fully satisfied the indicators of relational understanding regarding the establishment of necessary and sufficient conditions for mathematical concepts, as shown in Figure 14.

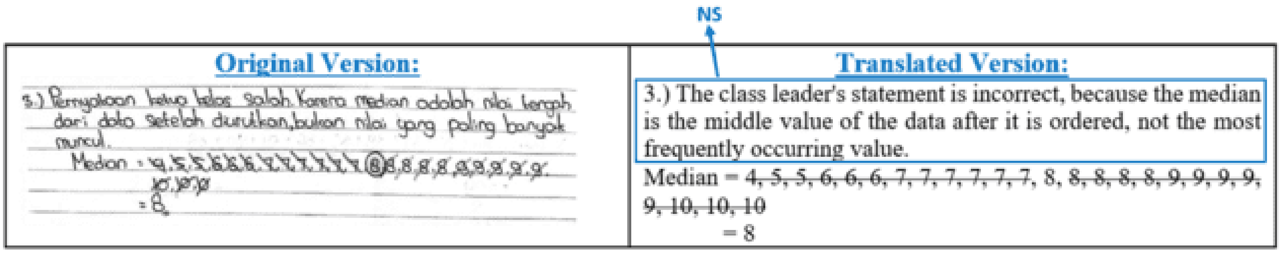


Figure 14. S-K's Answer to the Third Problem

Furthermore, Table 4 presents a comparative analysis of the characteristics of relational understanding demonstrated by students with visual, auditory, reading, and kinesthetic learning styles.

Table 4. Similarities and Differences in the Characteristics of Students' Relational Comprehension Abilities Based on Learning Styles

Indicators	Visual	Auditory	Reading	Kinesthetic
CO	Students can classify objects based on the necessary and sufficient conditions for concept formation.	Students demonstrate the ability to classify objects according to the defining attributes of a concept.	Students can categorize mathematical objects based on the formal definition of the concept.	Learners showed difficulty in both proper conceptual classification of objects and articulating the reasoning behind their categorization decisions.
AL	Students demonstrate the ability to apply concepts algorithmically when solving problems.	Students demonstrate limited algorithmic reasoning when applying conceptual knowledge to problem-solving tasks, indicating underdeveloped procedural fluency.	Students demonstrate the ability to algorithmically apply conceptual knowledge in problem-solving contexts.	Students demonstrate algorithmic application of concepts in problem-solving contexts.
RM	Learners can explicitly justify the use of specific mathematical procedures and formulae, indicating deep conceptual understanding of problem-solving strategies.	Students exhibit significant difficulties in verbalizing both the conceptual justification and operational logic of mathematical procedures during problem-solving, suggesting limited relational understanding.	Students demonstrate the ability to articulate both the conceptual meaning and mathematical rationale for employing specific formulas and procedures when solving mathematical problems.	Students fail to provide valid justifications for applying specific mathematical formulas or procedures when solving problems, demonstrating only procedural execution without conceptual understanding.
CC	Students demonstrate the ability to establish meaningful	Students demonstrate suboptimal ability to establish meaningful	Students demonstrate exceptional proficiency in	Students demonstrate the ability to establish meaningful

Indicators	Visual	Auditory	Reading	Kinesthetic
	connections between mathematical concepts when solving problems.	connections between concepts when solving problems.	establishing meaningful conceptual connections when solving problems, indicating advanced relational understanding.	conceptual connections when solving problems.
NS	Students demonstrate the ability to articulate both necessary and sufficient conditions of mathematical concepts.	Students can state the necessary and sufficient conditions of concepts, though their explanations remain incomplete or insufficiently explicit.	Students can identify the necessary and sufficient conditions of a concept, but demonstrate incomplete accuracy in procedurally and conceptually implementing these conditions within problem-solving contexts.	Students demonstrate the ability to articulate both the necessary and sufficient conditions that define a concept.

Based on the results of the data analysis, students with visual, auditory, and reading learning styles could classify objects based on whether or not the concept-forming requirements were met. In contrast, students with kinesthetic learning styles did not show this skill. This is because kinesthetic students cannot grasp all the information in mathematical problems, making it challenging to precisely classify objects based on specific conceptual requirements. This is in line with the opinion of Sulisawati et al. (2019) that students with kinesthetic learning styles tend to learn better through direct experience and physical activity, so they are less optimal in understanding the information conveyed in writing or abstract. Meanwhile, Machromah et al. (2021) state that visual learners tend to organize information through spatial representations to more easily recognize the relationships and structures underlying a concept. Furthermore, Rosyada & Wibowo (2023) stated that although auditory students are used to learning through verbal explanations, they can often process written information into internal verbal understanding that supports the concept classification process. Meanwhile, students with the reading learning style tend to understand written information in depth because they are used to processing texts and symbols independently, thus supporting their ability to identify the conceptual conditions of the given problem (Amrullah et al., 2024).

Furthermore, students with visual, reading, and kinesthetic learning styles fulfilled the indicator of applying concepts algorithmically in problem-solving, whereas auditory learners did not meet this indicator. This is in line with the opinion of Apipah et al. (2018) and Ulum & Siswono (2020), who stated that students with visual and kinesthetic learning styles tend to be able to follow procedural steps in sequence because they are used to understanding information through visualization of structures and hands-on practice. In this study, visual and kinesthetic students write down known information, decipher variables, synthesize them into compound mean formulas, apply distributive properties, and solve algebraic equations correctly until they get the final answer. Similarly, students with a reading learning style demonstrate an algorithmic understanding through the accuracy of completion steps based on written texts that are independently analyzed. In contrast, auditory students can only formulate the initial form of the equation but do not complete it entirely due to confusion in the operation of algebraic forms. This weakness is likely due to the limited tendency of auditory students to learn procedural learning independently without verbal stimulus or dialogical learning. This is reinforced by Nisa & Zaenal's (2023) research, which found that auditory students are more optimal in understanding procedures if they are delivered orally and discussed in joint discussions, compared to symbolic representations that require independent visual processing.

Furthermore, students with visual and reading learning styles met the indicator of being able to explain the meaning and justification for using a mathematical formula or procedure. On the other hand, auditory and kinesthetic learners were unable to provide logical and precise explanations for the procedures they used. Visual students can explain in sequence reasons using the combined average formula. Reading students can also provide strong justification regarding the relevance of the formula used and explain the stages of the work meaningfully. On the other hand, auditory students stated that they used the formula only because "it usually is" without understanding the appropriateness of the context of the question. Similarly, kinesthetic students rely only on previous problem experience and cannot explain the reasons behind using specific formulas, even though they can complete the calculations. These findings are in line with the statements of Anggraini et al. (2021) and Rosyada & Wibowo (2023) , who revealed that students with kinesthetic and auditory learning styles tend to follow procedures based on previous learning habits or experiences without examining the mathematical meaning of the steps taken.

Furthermore, students with visual, reading, and kinesthetic learning styles can connect one concept with another when solving problems, while auditory students do not have these skills optimally. This is in line with the findings of Ramadoni et al. (2024), who found that students with visual and kinesthetic learning styles tend to be better able to integrate mathematical concepts because they are used to seeing the relationships between ideas through visualization and direct experience. Similarly, reading students build conceptual relationships through deep processing of textual information, allowing them to see the connections between mathematical procedures or principles (Fleming & Mills, 1992). Meanwhile, students of the auditory learning style, in the context of this research, did not complete the process until the end due to confusion in algebraic operations and were unable to relate the algebraic structure to the information provided in the problem. This is in line with the findings of Indraswari et al. (2018) that auditory students struggle to connect algebraic concepts with other mathematical representations because they rely more on verbal comprehension than abstract symbolic relations.

Furthermore, students with visual and kinesthetic learning styles could fulfill the indicator related to explaining a concept's necessary and sufficient conditions. This is in line with the research of Arni et al. (2024), who found that visual and kinesthetic students tend to understand the essential characteristics of a concept more easily because they can construct concrete or visual representations that help identify the logical relationships between concept elements more clearly. Meanwhile, auditory students can mention the necessary and sufficient requirements, but the explanation is incomplete and not delivered explicitly. This is relevant to the opinion of Erbeli et al. (2017) that individuals who learn with an auditory approach tend to rely on oral comprehension without always being able to pour it into the form of systematic written reasoning. Reading students can also identify the necessary and sufficient requirements of a concept. However, it is not entirely appropriate to implement these requirements procedurally and conceptually in the context of problem-solving. Fleming & Mills (1992) said that students with a reading learning style are more effective in understanding information through reading and writing but can experience difficulties when the information must be applied in contextual situations or requires deep conceptual understanding and a high level of abstraction.

D. CONCLUSION AND SUGGESTIONS

This study investigates students' relational understanding of mathematical concepts through the lens of visual, auditory, reading, and kinesthetic learning styles. Students with visual and reading learning styles tend to demonstrate more complete relational understanding, particularly in connecting concepts and applying procedures logically. In contrast, students with auditory and kinesthetic learning styles show more fragmented understanding, with conceptual justification and reasoning difficulties emerging. This research fills a gap in the literature by offering a qualitative, indicator-based analysis of students' relational understanding across different learning styles an area previously explored mainly through statistical correlations. It provides new insights into how cognitive preferences shape students' mathematical thinking, particularly in solving non-routine statistical problems.

This study has several limitations. The small and localized sample limits the generalizability of the findings. Furthermore, variations in students' prior knowledge and classroom experiences may have influenced their performance, which can affect the internal validity of the results. The findings highlight the importance of differentiated instruction in mathematics learning. Teachers are encouraged to implement multimodal strategies such as visual representations, verbal explanations, and hands-on activities primarily to support auditory and kinesthetic learners. Future research should involve more diverse student populations and examine how tailored instruction can enhance relational understanding more effectively.

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