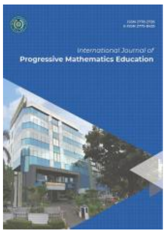

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Structure of Students' Ability in Solving Mathematical Problems Based on SOLO Taxonomy

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Abstract

This study aims to implement the Structure of Observed Learning Outcomes (SOLO) Taxonomy to describe the structure of students' mathematical problem-solving abilities and to explain their thinking processes regarding the problem of the System of Linear Equations with Two Variables (SLETV). A framework to examine the structure of students' mathematical problem solving skills is essential, because their understanding of basic mathematical ideas is useful in everyday life. This research methodology uses descriptive qualitative applied to eighth grade students at SMPN 5 Malang. To determine the structure of students' skills, we collected information through interviews and responses from problem solving tests. The findings revealed that students' competencies were broken down into unistructural, multistructural, and relational levels, without students reaching a complex prestructural or abstract level. This study innovatively presents visualizations of students' problem-solving frameworks, grounded in Chick's (1998) theory. The results of the study indicate that most students are at the multistructural level, namely, they can recognize relevant information but have not achieved the ability to integrate concepts comprehensively. This study provides guidance for educators to analyze students' abilities in solving mathematical problems using an effective evaluation tool, namely using the SOLO taxonomy.

Keywords: Problem Solving, Taxonomy SOLO, Linear Equation Problem, Students' Ability

Abstract

Penelitian ini bertujuan untuk mengimplementasikan Taksonomi Structure of Observed Learning Outcomes (SOLO) untuk mendeskripsikan struktur kemampuan pemecahan masalah matematika siswa dan menjelaskan proses berpikir mereka terkait masalah Sistem Persamaan Linear Dua Variabel (SLETV). Kerangka kerja untuk mengkaji struktur keterampilan pemecahan masalah matematika siswa sangat penting, karena pemahaman mereka terhadap ide-ide matematika dasar berguna dalam kehidupan sehari-hari. Metodologi penelitian ini menggunakan deskriptif kualitatif yang diterapkan pada siswa kelas delapan di SMPN 5 Malang. Untuk mengetahui struktur keterampilan siswa, kami mengumpulkan informasi melalui wawancara dan tanggapan dari tes pemecahan masalah. Temuan penelitian mengungkapkan bahwa kompetensi siswa dipecah menjadi tingkat unistruktural, multistruktural, dan relasional, tanpa siswa mencapai tingkat prastruktural atau abstrak yang kompleks. Penelitian ini secara inovatif menyajikan visualisasi kerangka kerja pemecahan masalah siswa, yang didasarkan pada teori Chick (1998). Hasil penelitian menunjukkan bahwa sebagian besar siswa berada pada tingkat multistruktural, yaitu mereka dapat mengenali informasi yang relevan tetapi belum mencapai kemampuan untuk mengintegrasikan konsep secara komprehensif. Penelitian ini memberikan panduan bagi para pendidik untuk menganalisis kemampuan siswa dalam memecahkan masalah matematika menggunakan alat evaluasi yang efektif, yaitu menggunakan taksonomi SOLO.

Kata Kunci : Pemecahan Masalah, Taksonomi SOLO, Soal Persamaan Linear, Kemampuan Siswa https://doi.org/10.22236/ijopme.v4i2.18655

1. Introduction

Mathematical problems that require critical thinking are often encountered by students in their daily lives. Some examples of these challenges are estimating the cost of travel or determining the amount of materials needed for a job. The reasoning steps that students go through to understand, plan, solve, and evaluate a mathematical problem are referred to as the structure of mathematical problem-solving skills. Because it can provide insight into how students comprehend, process, and apply concepts in a variety of contexts, it is important to determine the structure of each student's mathematical problem solving abilities (Pongsakdi et al., 2020; Umi et al., 2021). Identifying the structure of students' mathematical problem-solving abilities is very important. It can provide insight into how they understand, process, and apply concepts in different situations (Kolar & Hodnik, 2021). By understanding the structure of students' thinking, educators can identify the difficulties students have at each stage of problem solving, from understanding the problem, to choosing the right strategy, to evaluating the answer. This allows teachers to design more effective learning strategies, adjust teaching methods, and provide interventions that meet students' needs. In addition, identifying students' thinking patterns can help develop critical and reflective thinking skills, which ultimately improve students' ability to solve problems independently and creatively (Aizikovitsh & Amit, 2010; Rodgers C., 2002; Yayuk et al., 2020).

The Structure of Observed Learning Outcomes (SOLO) taxonomy is a method for measuring students' responses as they solve mathematical problems. In mathematics education, it serves as a valuable tool for assessing and improving students' conceptual understanding of mathematical ideas. In addition, the SOLO Taxonomy can also be a tool for analyzing the complexity of questions and for guiding instructional strategies aimed at improving students' cognitive development (Liu & Zhang, 2022). The SOLO taxonomy has 5 levels of student ability, consisting of prestructural, unistructural, multistructural, relational, and extended abstract levels (Halimah et al., 2020; Satmaz & Yabanova, 2024).

Previous research that has paid attention to the structure of students' thinking in problem solving has been extensive. Various studies have highlighted students' errors, their level of understanding based on the SOLO taxonomy, as well as effective teaching strategies to improve students' conceptual understanding. Azmia & Soro (2021) conducted research on students' errors in solving mathematical problems. They concluded that the types of errors were based on students' ability levels using the Solo taxonomy. Pesona & Yunianta (2018) described the readines of the students to solve linear equations of two variables and concluded the student' abilities level with SOLO taxonomy by looking at the low, medium, and high abilities. Fitri et al. (2021) describe student responses in the SOLO taxonomy for low, medium, and high ability students. Ghunaimat & Alawneh (2024) Ghunaimat & Alawneh (2024) present something new by utilizing SOLO taxonomy in mathematics learning and designing learning strategies for coordinate geometry materials. However, from the existing research, no one has presented a visual explanation of the structure of students' problem solving abilities, although visualization can help to understand the thinking patterns and stages of solving that students do more clearly. Karahan & Ergene (2023) conducted research on SOLO Taxonomy in mathematics education in Turkey with the result that the multistructural level is more dominant than other levels of student abilities.

The purpose of this study is to examine students' ability to solve mathematical problems through analysis of their solutions and interviews to explore their thinking. Chick (1998) framework was used as a reference in identifying and analyzing students' solution structures because it provides a systematic approach to understanding how students construct their conceptual understanding. This framework is relevant to this study because it helps to categorize the problem-solving strategies used by students and to assess the extent to which they are able to connect mathematical concepts in problem solving. Using a descriptive qualitative approach, this research seeks to comprehensively understand how students construct their understanding of a mathematical problem, specifically in the topic of System of Linear Equations with Two Variables (SLETV).

2. Research Method

Through solution analysis and interviews, this study examines students' ability to solve mathematical problems. Chick (1998) framework was used to identify and analyze students' problem-solving structure. The approach used was descriptive qualitative to obtain an in-depth description of the structure of students' mathematical problem solving. This research was conducted in SMPN 5 Malang. The research subjects were 7 students of SMPN 5 Malang who were in grade VIII. The subjects were selected from several junior high school students because at this level, students have recognized algebraic forms from the previous grade. The selection of 7 students was based on the recommendation of the mathematics teacher. Since this research requires oral and written explanations from the students, the subjects are preferred to students who able to communicate orally and in writing well. The research data consists of two types, namely the results of the written test of mathematical problem-solving ability and the results of interviews with sample students according to the level in the SOLO taxonomy. The math problems posed to students in this study are as in the following statements.

> "Amir saw advertisements for two cell phone companies. The first cellular operator offers a base fee of Rp 20,000 per month and an additional call fee of Rp 100 for every minute used. The second cellular operator has no monthly base fee but charges a call fee of Rp 500 per minute. If Amir asked you to identify the most cost-effective cellular operator, how would you respond?"

Data analysis in this study used Glaser and Strauss's fixed comparison method, which includes data reduction, categorization, synthesis, and preparation of working hypotheses. Data reduction was done by identifying meaningful units, assigning codes based on levels in the SOLO taxonomy, and comparing codes repeatedly. The results of this analysis are used to develop a working hypothesis that describes the students' abilities level in solving problems that can develop according to the research findings. Indicators of the leveling of students' problem-solving skills by means of the SOLO taxonomy Ekawati et al., (2013), Sriati et al. (2021) are as follows:

Table 1. Indicators of student ability on SOLO Taxonomy

Level	Indicator
Prastructural	Students employ inaccurate data or solution procedures, which leads to unsuitable or irrelevant conclusions. Students find minimal data and sometimes not related, resulting in a disjointed concept with no meaning. Students have been unable to accomplish the assigned activities in an appropriate manner, implying that they lack the necessary skills.
Unistructural	Students apply at least one piece of material and one notion or solution process. Students employ a technique based on selected facts to solve problems correctly, but the results are unimportant.
Multistructural	Students utilize certain data and information; however, the lack of connections between the data prevents the drawing of relevant conclusions. The student is able to establish certain connections from the data and information presented; however, these connections

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Level	Indicator
	lack appropriateness, resulting in conclusions that are not relevant.
Relational	Students utilize data and information, apply concepts and processes, present preliminary results, and integrate additional data and processes to derive pertinent conclusions. Students check concepts and processes to ensure that all data used is relevant and reach correct conclusions.
Extended Abstract	Students utilize data and information, subsequently applying concepts and processes to yield preliminary results. Students then integrate the findings with additional data and processes to make appropriate and generalized conclusions from the outcomes obtained. Students engage in conceptual thinking, allowing them to generalize across various domains and experiences.

3. Finding and Discussion

a. Finding

This study involved seven students as a sample. Analysis of their work revealed variations in thinking skills based on the SOLO taxonomy. The students' abilities were distributed in three main levels, namely unistructural, multistructural, and relational, while no students were found at the prestructural or extended abstract levels. This chapter will reveal the results of the students' responses and interviews to confirm the students' thinking process from the information obtained to the solution results.

1) Unistructural

The unstructured level in problem solving was found in RD students. RD was able to find relevant information from the given problem. RD wrote what he knew on the answer sheet as like figure 1.

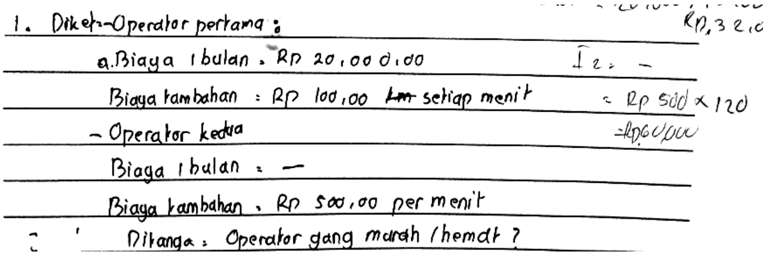


Figure 1. The information obtained by RD for problem

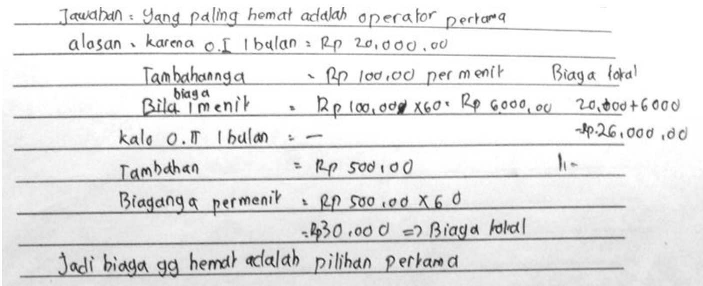


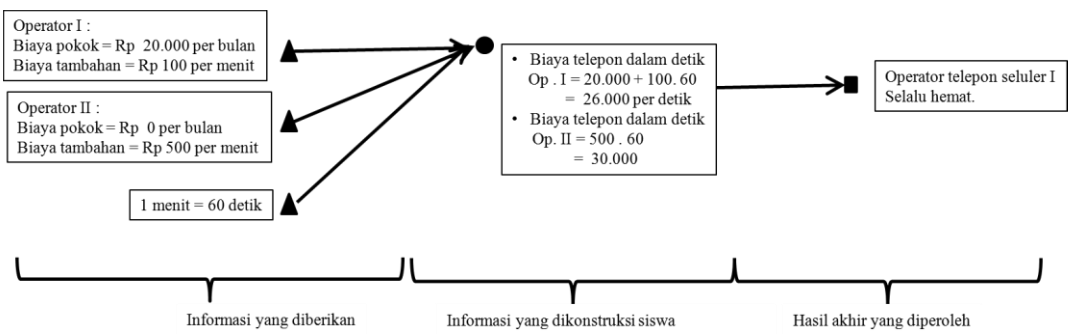
Figure 2. RD's answer to the problem

Figure 2 shows that RD has been able to see the interconnectedness of the information provided, but the interconnectedness is still written in an arithmetic representation. To solve the problem, RD calculates the cost of each operator using arithmetic operations. To calculate the cost of calling operator A, RD first calculates the additional cost and then adds it to the basic cost charged. Before the call is made, RD makes a decision that the first mobile operator is more economical.

RD uses the relationship between minutes and seconds in solving problem. RD knows that 1 minute is 60 seconds, but in his procedure for solving Problem 1, there is an error in the use of the unit. RD is certain that his procedure is mathematically correct. The error in changing the unit from minutes to seconds caused the cost to be incorrect. The following is an excerpt from an interview the researcher conducted with RD about the steps in solving the problem.

P	*: Iya, bagaimana caramu menentukan yang lebih hemat?*
SE 3	*: Saya pilih yang operator I*
P	*: Mengapa begitu?*
SE 3	*: Saya anggap 1 menitnya 60 detik. Terus saya cari dulu biaya tambahannya yang Rp 100 per menit, saya kali dengan 60 detik, sehingga biaya tambahannya Rp 6.000. Terus ditambah biaya pokoknya Rp 20.000 dengan biaya setiap telepon Rp 6.000, Jadinya Rp 26.000*
P	*: Sebentar RD, kan Rp 100 per menit kok jadi dikali 60 detik, 60 menit apa detik?*
SE 3	*: Saya anggap 1menit 60 detik, jadi saya anggap Rp 100 dikali 60 detik jadinya Rp 6.000 per menit*
P	*: per menit jadinya Rp 6.000, yakin?*
SE 3	*: eh nggak, Rp 6.000 per detik*
P	*: Baiklah lanjutnya bagaimana*
SE 3	*: Kalau yang iklan kedua tidak dikenakan biaya pokok per bulan, tapi biaya tammbahannya Rp 500 per menit. Saya anggap lagi satu menitnya 60 detik, jadinya 500 kali 60 sama dengan 30.000 totalnya. Antara Rp 26.000 dan Rp 30.000 saya pilih yang Rp 26.000,*
P	*: Oh begitu, jadi biaya untuk satu menit brapa?*
SE 3	*: Yang operator pertama kena biaya Rp 26.000 dan yang kedua Rp 30.000.*

RD made a mistake in converting minutes to seconds. The error made in converting minutes to seconds makes the first mobile operator more efficient for phone usage after 0.668 seconds. Since 0.668 seconds counts as one minute due to rounding, the first mobile operator is always more efficient. RD has failed to integrate different information into a coherent process. RD has not been able to combine the information he collected to make a general decision. According to the solution explanation and the researcher's interview with RD, RD's solution structure is as follows. Figure 4 shows that RD's solution structure is considered unstructured. In this case, RD was able to identify the information given and find the relationship between the information obtained, but there was an error in the process of translating the cost from minutes to seconds.



Information:

▲ Data provided

● Ideas that are relevant to the given problem

■ Operator selection decisions

→ Connection

Figure 3. RD answer structure that describes the unistructural level

2) Multistuctural

. Figure 4 is the information found by EQ. EQ successfully finds relevant information.

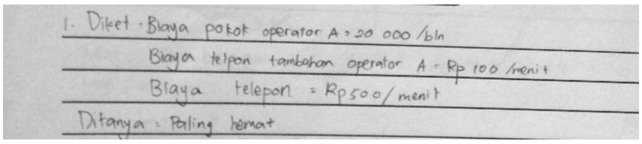

1. Diket : Biaya pokok operator A = 20 000 /bln
Biaya telpon tambahan operator A = Rp 100 /menit
Biaya telepon = Rp500/menit
Ditanya : Paling hemat

Figure 4. Information obtained by EQ

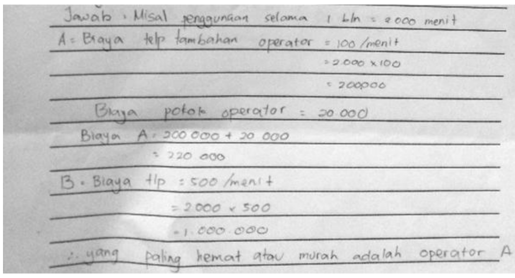

Jawab : Misal penggunaan selama 1 bln = 2000 menit
A = Biaya telp tambahan operator = 100 /menit
= 2.000 x 100
= 200000
Biaya pokok operator = 20.000
Biaya A = 200 000 + 20 000
= 220 000
B = Biaya tlp = 500 /menit
= 2.000 x 500
= 1.000 000
∴ yang paling hemat atau murah adalah operator A

Figure 5. The EQ's answer

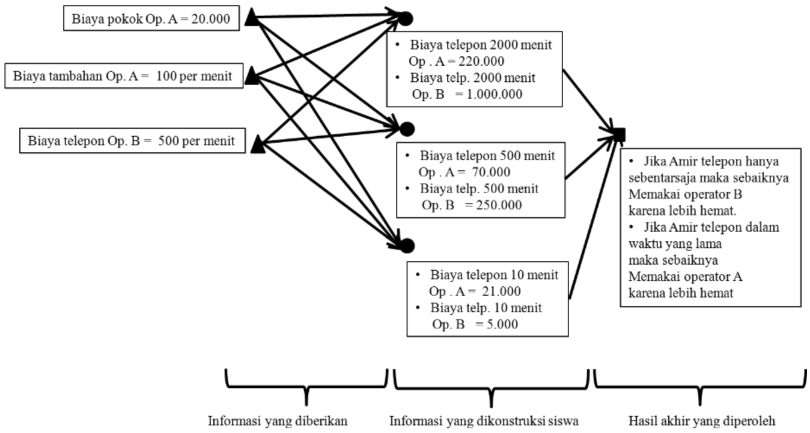
After determining what information EQ received, the researcher explored the interconnectedness of the information EQ received to solve problem. EQ did not explicitly write down the interconnectedness of the information he received.

The following is an excerpt from the interview conducted by the researcher with the EQ.

P : *Baiklah sekarang coba kamu ceritakan, menggunakan informasi tersebut, bagaimana kamu menggunakannya untuk menyelesaikan soal I?*
EQ : *Jawabnya pakai pemisalan gitu, misal penggunaan dalam satu bulan 2000 menit, berarti kan biaya tambahan telpon yang operator A kan Rp 100 per menit berarti kan 2000 x 100 = 200.000 ditambah biaya pokok Rp 20.000, berarti 200.000 + 20.000 = 220.000*
P : *Baik, selanjutnya bagaimana?*
EQ : *iya, terus biaya telepon yang B itu cuma biaya tambahan saja, Rp 500 per menit, berarti 2000 x 500 = 1.000.000 , sehingga biayanya lebih murah operator A.*
P : *Mengapa EQ menggunakan 2000 menit?*
EQ : *Ya biar gampang ngitungnya*
P : *Oh gitu. Coba untuk bilangan yang lain*
P : *Oh gitu. Coba untuk bilangan yang lain*
EQ : *(Mengeluarkan polpen dan kertas untuk mencoba nilai menit yang lain)*
P : *ambi menit berapa?*
EQ : *500 menit*
P : *Biaya untuk operator A Rp 70.000 dan yang B Rp 250.000, berarti yang mahal operator B untuk pemakaian telepon 500 menit. Apakah mungkin EQ, untuk pemakaian telepon dalam satu bulan hanya beberapa menit saja? misal Amir seorang pelajar dan hanya telepon 10 menit saja dalam satu bulan?*
EQ : *Bisa jadi*
P : *Berarti untuk pemakaian 10 menit, operator mana yang lebih murah?*
EQ : *Emmmmm, yang B (Terdengar ragu-ragu)*
P : *Bisa dipastikan dulu ya*

To solve this problem, EQ arithmetically calculates the cost of each operator. To calculate the cost of a call from operator A, EQ first calculates the additional cost. Then add it to the basic fee charged. EQ's expression indicates that it was unable to determine the relationship between the information. To ascertain which operator is more cost-effective, EQ only used the value once prior to conducting additional interviews. The final answer from EQ was that operator A was the most economical. EQ showed her doubt about which operator was the most efficient. However, in the next interview, EQ could not find the time interval where Operator A's cost is higher than Operator B's cost or Operator A's cost is lower than Operator B's cost. This indicates that EQ could not make a combination of information to determine the time interval, which is the limit where Operator A's cost is higher than Operator B's cost or Operator A's cost is lower than Operator B's cost.

The figure 7 is a description of the problem-solving framework that EQ implemented, which is based on the explanation of the solution as well as excerpts from the interview that the researcher conducted with EQ. The diagram 7 shows that the solution structure performed by EQ is at the multistructural level. The ability of students at this level shows the ability to use two or more pieces of information that are connected into separate ideas.. In this case, EQ is able to utilize more than one data, namely information about the cost of both operators for 2000 minutes of phone time and 10 minutes. However, EQ is unable to find a combination of these pieces of information to find with certainty the time interval where the cost of Operator A is greater than the cost of Operator B, and where the cost of Operator A is less than the cost of Operator B.



Information:

- ▲ Data provided
- ● Ideas that are relevant to the given problem
- ■ Operator selection decisions
- ⟶ Connection

Figure 6. EQ's answer structure

3) Relational

A student named VO demonstrated the relational level, the fourth level that indicates a high level of ability. VO managed to find relevant information from the given problem. VO wrote down what he knew on the answer sheet. In understanding the given problem, VO tries to relate it to conditions in the everyday world. The solution to the problem given by VO is presented in verbal form because VO feels confused about writing the solution mathematically. Below is the solution given by VO.

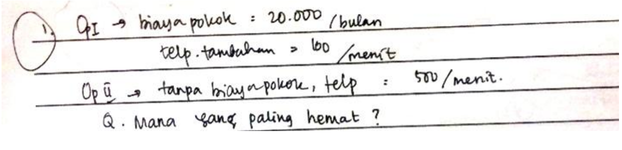


Figure 7. VO Received Information

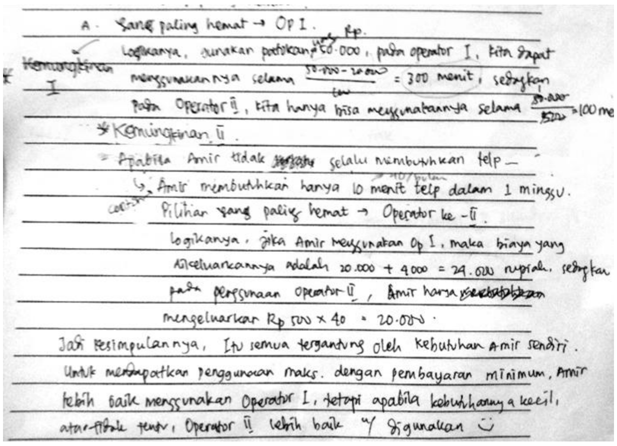


Figure 8. VO's answer

Although VO expressed his confusion in writing the solution, VO was able to explain what he thought about the solution he made. VO was able to see the connection between the information he was given and the ideas that were relevant to the problem. Below is an excerpt from the interview that shows VO was able to make the connection between the information given.

P : Apa yang diminta oleh soal ini? Coba ceritakan apa yang kamu lakukan VO. Bagaimana kamu berpikir tentang ini?

VO : Operator mana yang paling hemat. Caranya dengan mengumpulkan banyak kemungkinan.

P : Baik, kemungkinan pertamanya apa?

VO : Ya kalau kerjanya butuh telepon terus-terusan yang paling hemat ya yang mengeluarkan biaya telepon paling murah, yang paling murah itu operator pertama dan misalkan pakai teleponnya tidak terlalu sering, sudah membayar biaya awalnya dan biayanya jadi lebih, jadi ndak nutupi uangnya.

P :VO menuliskan informasi yang didapat adalah, untuk operator I biaya pokok Rp 20.000 per bulan dan biaya tambahan Rp 100 per menit. Sedangkan untuk operator kedua, tanpa biaya pokok dan biaya tambahan Rp 500 per menit. Bagaimana menggunakan informasi ini VO ?

VO : Dimisalkan punya uang Rp 50.000, dengan menggunakan operator I bisa telepon selama 300 menit, dan dengan operator II hanya 100 menit. (Prosedur yang digunakan ditulis pada lembar jawaban VO)

P : Baiklah, mari kita hitung-hitung lagi. Jika telepon 20 menit, berapa biayanya untuk masing-masing operator?

VO : (Menghitung di kertas biaya telepon untuk 20 menit) untuk operator I Rp 21.000, dan operator II Rp 10.000, berarti untuk 20 menit murahan operator II

P : Bagus, jika untuk 45 menit

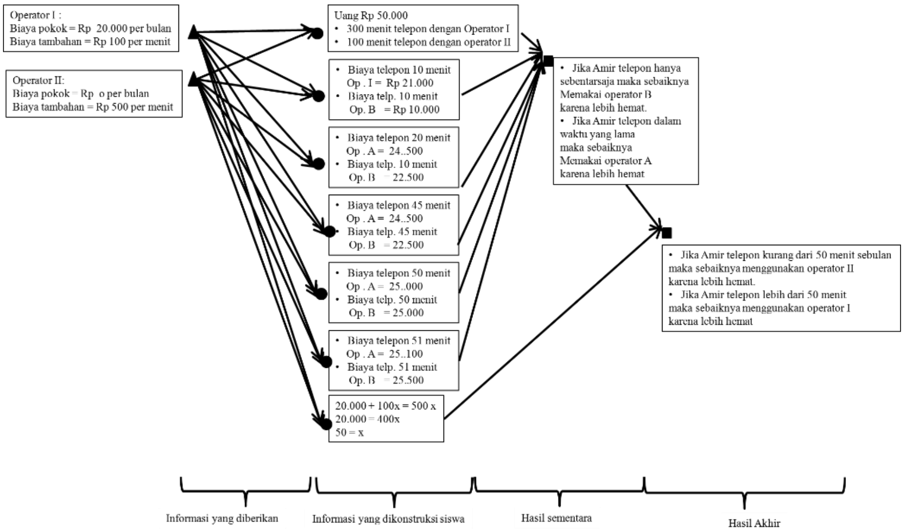
VO : (Menghitung di kertas biaya telepon untuk 45 menit) masih murahan yang operator II, Rp 24.500, operator II kan Rp 22.500

P : Berarti apa kesimpulanmu?

VO : Batas waktunya 50 menit, jika teleponnya kurang dari 50 menit sebulan maka hematan yang operator II, jika lebih dari 50 menit sebulan, hematan pakai operator I.

The pattern obtained by VO was that for a time of more than 50 minutes, cellular operator I provided more economical costs, while for a time of less than 50 minutes, operator II provided more economical costs. The following is an interview excerpt that supports VO's ability to see the cost patterns of Cellular Operators I and II. VO was able to use the substitution method to find the solution of the SLETV of the costs of the two mobile operators. This shows that VO is able to create a combination of constructed information. The following is an excerpt from an interview that shows VO's ability to create a combination of relevant information that has been constructed.

The problem-solving structure performed by VO, based on the explanation of the solution and extracts from the researcher's interview with VO, can be described as follows.



Information:

Data provided

Ideas that are relevant to the given problem

Operator selection decisions

Connection

Figure 9. Structure of the VO response at the relational level

The above scheme shows that the solution structure carried out by VO is on the relational level. VO is able to combine separate pieces of information into a coherent procedure structure. The information constructed by VO is an equation for the cost of each mobile operator to become a SLETV. VO combines the information using the substitution method to obtain a solution of the SLETV it constructs. The decision made by VO regarding the two operators has not been supported by the identification of the properties of each equation in the SLETV it constructs, either in terms of the form of the equation or its graph. Up to this point, VO has capabilities at the relational level.

Students who were the subjects of the study, there were 5 students with ability levels in the SOLO taxonomy at the multistructural level, this result is consistent with the research conducted by Karahan & Ergene (2023) that students at the secondary school level are dominated by students at the multistructure level. This study also found that students who could retrieve relevant information like RD, EQ, and VO did, but not always their answers would be correct. This finding supports the findings of previous studies conducted by Samosir et al. (2024) and Sutini et al. (2017) who found that most students in solving problems, select useful information from the problem statement, but this does not guarantee success in solving problems. Students who are less successful in solving problems only look at the surface features of the problem, while students who are successful in solving problems focus more on the structure of information relationships and represent the problem more meaningfully.

There are several difficulties experienced by students when solving verbal problems, one of which is that they have difficulty converting the values of different sizes. This finding is in line with previous research by Mainali (2020) that some students have difficulty in translating problems into mathematical symbols in the form of difficulty in converting values. This difficulty generally occurs when students are faced with problems involving subtraction and division operations. In verbal form problems, most students use the strategy of using cases. Most students have difficulty in constructing mathematical models in the form of linear equations. This finding supports the findings of previous studies by Jupri & Drijvers (2016), Nurjanah & Angraini (2024),Hastuti et al., (2021) and Pradini & Winarsih (2020). Many students have difficulty formulating linear equations from verbal problems due to inappropriate strategies, weak reading comprehension, and limited understanding of the complexity of the problem. Translating verbal problems into mathematical models remains a challenge for most students. This finding can inform teachers that it is necessary to provide a deeper understanding of the basic concepts of linear equations before students are asked to apply them in solving verbal problems. This can be done through an exploratory approach, such as using analogies from everyday life or concrete examples that are closer to students' experiences.

4. Conclusion

This study found that students' abilities to solve verbal mathematics problems can be categorized into the SOLO taxonomy. This study found students' abilities at the unstructural, multistructural, and relational levels. Meanwhile, the pre-structural and extended abstract levels were not obtained from the 7 students who were the research subjects. Students with unistructural level were able to find relevant information but had difficulty translating it into the correct mathematical representation. Meanwhile, students with multistructural level were able to use more than one piece of information but could not connect them systematically to obtain the correct solution. Students with relational level showed the best ability to integrate different information, build a coherent mathematical model, and solve the SLETV using the substitution method. Most of the students in this study were at the multistructural level, which is consistent with previous research findings that secondary school students tend to be at this level. The students' main difficulty was in translating verbal problems into mathematical models, especially in forming linear equations. Common errors are unit conversion errors and understanding the data structure in the problem.

The implications of these findings emphasize the importance of learning strategies that can help students improve their understanding of the basic concepts of linear equations before applying them in verbal problem solving. Teachers are encouraged to use exploratory approaches such as visualization, graphing, and case studies from everyday life to help students better connect information. In addition, scaffolding and problem-based learning strategies can be used to improve students' relational thinking skills. As a result, students become more resilient in building mathematical models and improve their problem-solving skills.

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6. Conflict of Interest (Optional)

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