The SOLO taxonomy: classify students’ responses in solving linear program problems

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ABSTRACT. The aim of this study is to classify students' responses in solving mathematical problems. Using the taxonomy by Biggs and Collis in 1982, called taxonomy is SOLO (Structure of Observed Learning Outcomes). In the SOLO taxonomy, there are five levels of students’ responses, such as pre-structural, uni-structural, multi-structural, relational, and extended abstract. Every student has different abilities, one of the ability is to understand mathematical concepts because sometimes students make misconceptions that result in students not being able to solve mathematical problems correctly. The concept in a linear program problem is that students can change story problems into mathematical modeling after that student can solve with the procedures that have been learned. This study used descriptive qualitative research and the selected of subjects is senior high school students in the City of Kediri and then used purposive sampling techniques. One of the chosen class consisting of 35 students was selected 5 students to represent each level of SOLO Taxonomy. The results from this study are: (1) Pre-structural level: Students cannot process information properly, (2) Uni-structural level: Students do not make the most of available information, (3) Multi-structural level: Students understand one concept which is example with variables and can model mathematics, (4) Relational level: Students can process information appropriately, and (5) Extended abstract level: Students can understand concepts well. With the levels of students’ response can be known to what extent students understand mathematics so they can solve mathematical problems.

1. Introduction

Students' views to date, mathematics is considered as a subject that is less attractive to students or can be interpreted as a "scary" subject. All elements of the special mathematics educator are expected to be students who prefer math, in the sense that mathematics is useful for all can not be used but can be accessed but that can help attention for all. Through teaching towards the target will make a change, one of which is very possible if students who have talent will be easier to progress while students who have difficulty will choose time with a little longer in following a subject [1]. Various kinds of views ranging from the views of students, parents to teachers about mathematics as follows: (1) Students' view, mathematics is a collection of truths and rules where the student's task is to find the correct answer using the method used by the teacher, (2) Parents' view, the ability to conquer mathematics is an innate ability so that if a child is not gifted in mathematics then he will not succeed in mathematics, (3) The teacher's view, students are said to understand mathematics if students can memorize formulas and rules so that they can find the correct answer [2].

Some views that represent students, parents, and teachers, can be said that mathematics is basically what is the science of numbers, the relationship between numbers, procedures used in solving mathematical problems. One branch of mathematics, algebra, on the algebraic subject from several
studies considered students to have difficulties and problems. Facts from elementary school to advanced, it was found that there were problems in generalizing a pattern, the fact that young children did not understand what is meant by algebraic statements, and students should be given basic knowledge about algebra first [3]. What needs to be considered in learning mathematics is that the provision of algebra material should be given to students from the beginning to get to know mathematics because the nature of algebra has an important role. NCTM provides several algebraic standards among them: (1) understand patterns, relationships, and functions; (2) represent and analyze situations and structures using Mathematical algebraic symbols; (3) apply mathematical modeling to substitute and rule a concepts in quantitative terms; (4) changes in analysis in various ways [4]. However, understanding the concept of variables can sometimes prevent students from understanding an algebraic idea [5].

The process of solving mathematical problems contains elements of operation or workmanship. The fact is students have difficulty in working if they persist in seeing algebra as "general arithmetic". Common mistakes made by students in working on solving algebra problems are: (1) Arithmetic and algebra do use the same symbols and signs but have different meanings [6], (2) The use of letters in algebra and arithmetic is different [7], (3) Alignment of two different symbols in algebra and arithmetic [8], (4) Students experience cognitive difficulties when applying procedural operations as part of the answers [9], and (5) The focus of students in arithmetic problems is to identify the operations used in solving problems, while the focus of students in algebraic problems is to represent problem situations using expressions or equations [10].

Solving mathematics problems is perfecting a problem that must be solved related to numbers. The problem-solving activity sometimes has a constraint that is generally obtained from failures in: (1) carrying out mathematical operations, (2) choosing an effective method, (3) analyzing, (4) understanding the point of the problem, and (5) monitoring and controlling the operations used [11]. Based on the description of definitions and research that has been done, solving problems is an important part of learning mathematics because it can develop the cognitive domain of students. Students can utilize the information obtained from the teacher and the knowledge that has been obtained before by applying it to mathematical operations to solve mathematical problems.

One of the elements that can be studied in problem-solving activities is that students must be able to understand the mathematical concepts learned and can apply in solving any problems. The concept is an idea or understanding that is extracted from a concrete occasion, while understanding has the meaning of the process, method, act of understanding. Learning mathematics cannot be separated from the name of basic knowledge or students must be able to understand the basic concepts of a subject, students who have a good conceptual understanding will be easier to solve mathematical problems. Conceptual understanding can be used to test the level of student responses that represent the importance of mathematics in the problem of symbolizing and applying algorithms [12]. Student responses are not only focused on a right or wrong answer but more on the arrangement of a series of answers in solving mathematical problems. The level of students' thinking responses can be seen from the characteristics of students in solving a problem.

Differences in response to solving mathematical problems due to different student abilities, student responses in solving problems can be known by using the classification of levels contained in SOLO (Structure of Observed Learning Outcomes) taxonomy. SOLO taxonomy was first developed by Biggs and Collis in 1982. Generally, the level in the SOLO taxonomy has five levels [13]. Measurement of the level used in SOLO taxonomy is very appropriate for the advancement of competency, where the hierarchical and linear arrangement that makes it a good taxonomy for the field of analysis [14]. The development of students from the beginning could not become expertise formed from a very complex understanding, in SOLO there are levels at each level that students are expected to achieve [15]. The way students solve problems contained in the answer sheets can be used as material for classifying the quality of student responses in the SOLO taxonomy [16].

Student mistakes that often occur if students cannot understand a concept is a misconception of a subject. The misconception is a conception that is not in accordance with what was stated by scientists
and cannot be generalized. Many students fail or do not give good results in lessons because they do not understand how to learn efficiently and effectively, they are easier to try to memorize lessons and enter knowledge without any prior screening, so do not understand the concept of sequences correctly [17]. It is possible for even the highest level of SOLO taxonomy to make students misconceptions [18]. The main key in learning mathematics is that students must understand a basic concept so that misconceptions do not occur and then students can continue with the algorithms used to solve mathematical problems correctly.

SOLO taxonomy can be used because (1) Simulates the stages of competency development in the cognitive domain, (2) Formulating or releasing the results of learning, (3) Determining objectives in teaching, (4) Enabling the achievement of results, and (5) Assessing in learning [19]. SOLO taxonomy provides the means to make a point quickly and spontaneously from students' conceptual understanding and to be able to see a view of progress in learning [20]. The following are the five levels described in the SOLO taxonomy [21]:

1. **Pre-structural**: Students have very little information that is not even interconnected, so it does not form a unified concept at all and does not have any meaning.
2. **Uni-structural**: Students can simply respond to the questions given but cannot understand the responses given by students,
3. **Multi-structural**: Students who have the ability to respond to problems with several separate strategies. Many relationships that they can make, but the relationships are not right,
4. **Relational**: Students can break a unit into parts and determine how the parts are linked to several models and can explain the equality of those models, and
5. **Extended Abstract**: Students have mastered the material and understood the questions given so well that students can realize the concepts that exist.

Based on the description of the five levels that exist in the SOLO taxonomy can be seen that students can find out how the process of using information obtained in the problem and then can be used to solve mathematics problems. Position of understanding concepts that take an important role for students in solving mathematical problems and can be used to test student responses, student responses can be categorized into five levels contained in the SOLO taxonomy.

2. **Methods**

This research was conducted at the 8th Senior High School in Kediri City and the subjects used in this study were 11th grade students. This type of research is descriptive qualitative. In general, qualitative research is research that explores and understands an individual's meaning related to social problems [22]. Used a sampling technique in this study is purposive sampling with the following criteria: (1) Students who have received subject about the linear program, (2) Based on information from the teacher, students who have the potential to meet the characteristics of the level of response and conception possessed. The instruments used in this study were written tests about the linear program and unstructured interviews. Written tests are used to determine students' responses in solving linear program questions, while interviews based on interview guidelines that keep adjusting to "flexible" student answers are used to find out more about responses. The stages in this study are: (1) Choosing a class that has been set on the recommendation of the teacher, there are 35 students in a class, (2) Given written questions about a linear program, (3) From the answers of students categorized into five levels of SOLO taxonomy, (4) Taking 5 subjects in one class representing each category in accordance with SOLO Taxonomy's level, (5) Conducting interviews with 5 selected students, and (6) Analyzing student answers and interviews.

3. **Results and Discussion**

3.1 **Results**

Data were obtained from written questions about linear program in the form of student answers and then the data were analyzed by using the SOLO taxonomy’s level criteria in a class consisting of 35 students who are one population. From this class five levels of SOLO taxonomy can be found, the following is the distribution of SOLO taxonomy’s levels: (1) Pre-structural level: 2 students, (2) Uni-
structural level: 2 students, (3) Multi-structural level: 15 students, (4) Relational level: 5 students, and (5) Extended Abstract level: 11 students.

Based on the categorization of these levels, it can be seen that the class has five levels of SOLO taxonomy, this is different from the research conducted by Laisouw on Junior High School students who place student response levels on uni structural, multi structural, relational, and extended abstract. Pre structural level in the study did not exist [23]. Sampling in each level category with consideration from the researcher and looking at the results or process of student work written on the answer sheet obtained 5 students representing each level category. An analysis of student responses with five levels of SOLO taxonomy, as follows:

3.1.1 Student with pre-structural level (S1)

![Figure 1. Photograph of S1 subject’s answers in solving problems](image)

| Fund of shrimp crackers | $= 50,000$ |
|-------------------------|------------|
| Fund of fish crackers  | $= 75,000$ |
| Mom’s fund             | $= 2,500,000$ |
| Production result      | $= 40$ kg |
| Profit of shrimp crackers| $= 25,000$ |
| Profit of fish crackers | $= 30,000$ |

Division of fund:
- shrimp crackers: $= 1,250,000$
- fish crackers: $= 25$ kg per shrimp crackers

Result of profit:
- Shrimp: $= 25 \times 2500 = 62,500$
- Fish: $= 15 \times 30,000 = 450,000$

The profit:
- $= 2,500,000 - 1,075,000$
- $= 1,425,000$

The biggest percentage of profit:
- $= \frac{1425000}{2500000} \times 100%$
- $= 1.75%$

Excerpt from S1 Interview:

P : How much fund does Mom have? You can know where the shrimp crackers = 1,250,000 ?
S1 : Mom’s fund 2,500,000, then which is produced by two types of crackers, and then I divided the two. So dividing 2,500,000 by 2 and the result is 1,250,000.
P : So the fund of shrimp crackers is 1,250,000? You wrote at the beginning of fund shrimp cracker is 50,000 How can it change?
S1 : That's what I don't know. Miss. I cannot do.
P : Meaning you can't determine the mathematical model?
S1 : That's how, Miss. Which is usually x and y? I do not understand!

(P = researcher, S1 = Student with pre-structural level)

In Figure 1 and interview excerpts, a student with the initials S1 in rewrited any information that is in the problem. S1 does not write an example and use variables at the same time, but S1 used words. Through interviews, S1 does not understand about variables and the function at the same time. In the answer sheet, S1 divides the obtained funds into two funds directly because S1 though there are two types of crackers. S1 chose a step to find the number of fish crackers by reducing the total amount of 40 kg with shrimp crackers and then S1 found as much as 25 kg, S1 got shrimp crackers as much as 15 kg. S1 get the number of shrimp crackers as much as 25 kg from divided the results of the division of fund worth 1,250,000 with 50,000 shrimp cracker’s fund. S1 continues its steps by looking for the results of the benefits of each cracker by multiplying the number of crackers by profit, from the results of each profit from shrimp crackers and fish crackers S1 adds. To find the biggest percentage of profit
S1 has a settlement step divided the fund owned by Mother by adding the results of profits from both crackers, S1 gets 1.75%.

3.1.2 Student with uni-structural level (S2)

![Mathematical modeling]

| Shrimp crackers | Fish crackers |
|-----------------|---------------|
| Mathematical modeling |
| Target function | \[ \text{Max} \] |
| \[ 10,000x + 15,000y \leq 500,000 \] | \[ 25,000 + 30,000 \] |
| \[ x \geq 0 \] | \[ y \geq 0 \] |

| Center point | 25,000 + 30,000 | \( c \) |
|--------------|-----------------|--------|
| \( (33.5, 560) \) | 832,500 + 1,500 | 834,000,000 | \( \rightarrow \text{Max} \) |
| \( (675, 750) \) | 15,625 + 22,500 | 18,125,600 |

Figure 2. Photograph of S2 subject’s answers in solving problems

Excerpt from S2 Interview:

| P | What is the intended target function? Is that equation? |
|---|--------------------------------------------------------|
| S2 | As far as I know, the target function will be sought after Miss. |
| P | How to look for it? |
| S2 | I searched the points first to draw a graph. |
|  | First I search for a point \( x \) to dividing 500,000 by 10,000, value of \( x \) found 50. |
|  | Second I search for a point \( y \) to dividing 500,000 by 15,000, value of \( y \) found 33.33. |
| P | And then point \( x = 750 \) and \( y = 625 \) where it comes from? |
| S2 | Forgot Miss. I think that is 750 from dividing 15,000 by 20 and 625 from dividing 10,000 by 16. |

(P = researcher, S2 = Student with uni-structural level)

In Figure 2 and interview excerpts, a student with the initials S2 can only write an example and to rewrite whatever information is in the question S2 has not written it on the answer sheet. S2 can use an example by using the variable \( x \) as shrimp crackers and \( y \) as fish crackers. S2 models the mathematics by writing fund for shrimp crackers plus fund from fish crackers less than the same as Mom’s fund. S2 does not simplify to the simplest equation. When wrote the objective function S2 is not exact in writing it. S2 statement with interview-based student’s answer. S2 explains how he got the points that will be drawn on the graph. Unfortunately, S2’s statements and answers are still not precise in found the points because S2 provided arguments that are incorrect or can be called ways that are not to find the points, it is clear that the resulted points are not quite right. S2 makes use of the results of finding its points by drawing the graph to found the area of the settlement set.
3.1.3 Student with multi-structural level (S3)

In Figure 3 and interview excerpts, a student with the initials S3 utilized the variable $x$ which represents shrimp crackers and the variable $y$ represents fish crackers. S3 models the mathematics by writing a target function that is less than the same as Mom’s fund, it is clear that the equation is written not right. S3 goes on to choose the equation of shrimp cracker fund plus fish cracker fund which is the same as Mom's fund, S3's statement about how he writes his mathematical model, S3 does not provide a significant reason, S3 does not understand what is meant by the target function. The selected step is actually appropriate to be done by elimination, S3 can find the value of $x$ and $y$. The next step is to look for points that will be used to draw graphics. Statement of S3 with interview-based student’s answer, S3 explains how he got the points that will be drawn on the graph. Unfortunately, S3’s statement and answer are still not precise in finding the points because S3 is placed in the wrong column, so the point he found is incorrect.

| P   | What you wrote in the mathematical model section, is it correct? Then what is called the target function? |
|-----|---------------------------------------------------------------------------------------------------|
| S3  | Yes, true. What is the target function?                                                          |
| P   | Isn’t that the point of linear program subject?                                                   |
| S3  | I forgot, Miss. I write what is known in the matter.                                              |
| P   | You search $y = 20$ use what? Because you didn’t write the equation in the mathematical model.   |
| S3  | I used shrimp cracker fund plus fish cracker fund as Mom’s fund.                                  |
| P   | How do you look for other points?                                                                |
| S3  | I search for it                                                                                  |
|     | If $x = 0$ so $y = 33,33$ and If $y = 0$ so $x = 50$.                                             |
| P   | Actually your steps are correct, but you are writing it incorrectly, so the points are not quite right. |
| S3  | Which one, Miss?                                                                                 |
| P   | You should have written it down $y = 33,33$ it’s in the first column not below $x = 0$. So that you write the point is also not quite right. |
| S3  | Yes, Miss.                                                                                       |

(P = researcher, S3 = Student with multi-structural level)
3.1.4 Student with relational level (S4)

Figure 4. Photograph of S4 subject’s answers in solving problems

Excerpt from S4 Interview:

\[\begin{align*}
\text{P} & : \text{You use variables } x \text{ and } y, \text{ what do you mean by that? The problem is you don't write an example.} \\
\text{S4} & : \text{Oooo yes, Miss. Suppose } x \text{ is shrimp crackers and } y \text{ is fish crackers.} \\
\text{P} & : \text{Your goal is to take steps for elimination?} \\
\text{S4} & : \text{To find the value of } x \text{ and } y \text{ Miss.} \\
\text{P} & : \text{Once known value of } x \text{ and } y, \text{ what do you do next?} \\
\text{S4} & : \text{I am looking for other points so they can be applied to the graph.} \\
\text{P} & : \text{What does the graph work for?} \\
\text{S4} & : \text{To find the set settlement area. Then the maximum value is sought by substituting points within the settlement set area into the target function.} \\
\text{P} & : \text{What's the biggest profit formula? That's you right away.} \\
\text{S4} & : \text{Because the biggest profit, so I think the maximum value divided by the largest fund. Is that right, Miss?} \\
\text{P} & : \text{That's right, it's just that you don't just write down the formula.}
\end{align*}\]

(P = researcher, S4 = Student with relational level)

In Figure 4 and interview excerpts, a student with the initials S4 apply for example by using the variable \( x \) represents shrimp crackers and the variable \( y \) represents fish crackers, on the answer sheet S4 does not write the equation. S4 in modeling the mathematics is correct. The next step used by S4 is to found the values of \( x \) and \( y \) by using the elimination-substitution method, strangely S4 does not simplify the equation. The points that have been searched by S4 are then applied to the graph to find the area of the settlement set. S4 knows which points are in the settlement area and then looks for the maximum value by using the target function substituted with these points. So far the steps used by S4 have been detailed and systematic, the maximum value obtained is 1,100,000. S4 looks for the biggest profit in percentage not writing down what formula is used, the student statement says that the biggest profit is the maximum value divided by the largest fund multiplied by 100%. S4's answer was able to fulfill what was asked by the problem, unfortunately S4 did not write a conclusion. Why is the conclusion important? Because in solving problems about story problems, students must be able to draw conclusions.
3.1.5 Student with extended abstract level (S5)

In Figure 5 and interview excerpts, a student with the initials S5 begin to answer by writing an example used variable \( x \) represents shrimp crackers and \( y \) represents fish crackers. S5 modeling the mathematics is also right by writing the equation of production results in one day, fund of shrimp crackers plus fund of fish crackers is less than equal to Mom’s fund, and the terms of the linear program if \( x \) and \( y \) are positive integers. S5 utilized of existing information by continuing to select the steps used by way of elimination-substitution to find the values of \( x \) and \( y \). The next step, it is known which points will be traversed by the graph, S5 is right in found the area of the settlement set and is also correct in using the symbol \( \leq \) because of the principle of the linear program, if the equation is known \( \leq \) then what should be shaded is the right line as well otherwise.

3.2 Discussion

Based on answers and interviews conducted to the five students’ selected based on SOLO taxonomy’s level, students give different responses. Starting from students with the lowest level of response is pre-structural level, there is from the results of answers and interviews with undergraduate student that have been analyzed can be said that these students fall into the category of pre-structural level: (1) The student cannot process information properly, (2) Perform misconceptions, (3) The steps used have no meaning, and (4) Tend not to give the results given to the problems. Student answers are not sufficient, where the problem does not lead to the desired solution, the way chosen by students does not lead to the desired solution, and the algorithm does not correspond to a higher level [24]. The concepts and processes of processing information are irrelevant [25].

Next to second level is uni-structural level, from the results of answers and interviews with S2 that have been analyzed can be said to be the student included in the uni-structural level category: (1) Students do not make the most of available information, (2) Only focus on what will be sought
without understanding the value or meaning contained in the equation, (3) only connects information rationally, and (4) The results found are less precise. Students focus only on problems, using relational steps, do not understand the value of existing data and do not understand the relationship between data and others, resulting in inconsistent student answers [24]. Students can do the initial process that begins with an example until the selection of steps used, but students do not understand exactly how the real problem [25].

Third level is multi-structural level, from the results of answers and interviews with S3 that have been analyzed can be said to be the student included in the category of multi-structural level: (1) Students understand one concept that is example with variables and can model mathematics, (2) But still do not understand about the concept of the target function, (3) The elimination step that is used is appropriate, (4) It is less precise in finding points, (5) Finding the maximum value is less precise, and (6) resulting in students' answers not fulfilling. Actually students have been able to apply some data that can lead to ideas in the use of rare-steps to find solutions but have not been able to understand the relationship contained in existing information, consequently student answers become inconsistent [24]. Students can understand what is asked by the problem, but students have not been able to connect information with existing concepts [25].

The fourth level is relational level, from the results of answers and interviews with S4 that have been analyzed can be said to be the student included in the category of relational level category: (1) Students can process information appropriately, (2) Choosed steps in an algorithmic and systematic manner, (3) Students understand concepts that exist, (4) The answers generated are already fulfilling and correct, and (5) Unfortunately, students have not been able to draw conclusions from these questions. Students can use all information so that they can provide answers to problems and students understand the meaning of overall information and can understand the relationship between data, consequently students can build structures consistently [24]. Students can connect concepts that exist as a whole with a harmonious and meaningful [25].

The last level is extended abstract, from the results of answers and interviews with the analyzed S5 can be said to be in the extended abstract level category: (1) Students can understand concepts well, (2) The information contained in the questions is put to good use, (3) The relationship between concepts and the application of information has been arranged properly, (4) The steps used are algorithmically, (5) the answers given have fulfilled what was asked by the problem and are correct, and (6) Students provide conclusions from the problem story. Students' thinking is very high in using steps to solve these problems and can generalize, and students can create new thoughts [24]. Overall concepts and information are generalized to a higher abstract level [25].

Based on the results of students' answers and interviews it can be seen that S1 cannot apply the mathematical model, S1 only rewrites what the words are known to in the problem, and S1 cannot find the correct answer and S1 experiences a misconception as a result the work does not have any meaning. The subjects S2 and S3 can only apply some information, as a result S2 and S3 have problems with the concept. S3 has been able to apply the elimination- substitution method, the weaknesses that S3 cannot find are the points to be used. S4 and S5 can use the information well, the steps chosen to solve the problem are already correct, and the resulting answers are actually correct, the weakness of S4 is not to write down the conclusions obtained from the story problem. The student with the initials S5 has a high level of responses because they can solve problems with the algorithm and provide conclusions from the given story problem.
4. Conclusion

Based on data obtained from test and interview questions, students’ responses can be analyzed based on the level of SOLO taxonomy. This research is different from existing research because it produces five levels in one class. Then from each level selected one that represents the consideration of the researcher, the subjects in this study were narrowed down to five students.

Based on the results that have been analyzed it appears that each level has different student responses criteria, here are the conclusions from the results of this study at each level:

(1) Pre-structural: (a) The student cannot process information properly, (b) Misconceptions, (c) The steps used have no meaning, as well, and (d) Tends not to give the results given to the problems,

(2) Uni-structural: (a) Students do not make the most of available information, (b) Only focus on what will be sought without understanding the value or meaning contained in the equation, (c) Only link information that exists rationally, and (d) The results found are not right,

(3) Multi-structural: (a) Students understand one concept which is example with variables and can model mathematics, (b) But still do not understand about the concept of the target function, (c) The elimination step used is appropriate, (d) Not precisely in finding points, (e) Finding the maximum value is not quite right, and (f) Resulting in students’ answers not fulfilling,

(4) Relational: (a) Students can process information appropriately, (b) Election steps are algorithmic and systematic, (c) Students understand the concepts that exist, (d) The answers generated are already fulfilling and correct, and (e) Unfortunately, students have not been able to draw conclusions from these questions, and

(5) Extended Abstract: (a) Students can understand concepts well, (b) The information contained in the matter is put to good use, (c) The relationship between the concept and application of information is well ordered, (d) The steps used are algorithmically, (e) The answer is given has fulfilled what was asked by the problem and is correct, and (f) Students give conclusions from story problems.

The implication of this research is to embed basic concepts in students is not something that can be underestimated. It is the understanding of concepts that has to be improved in every teaching of mathematics or other fields of science. The level of students’ responses in the SOLO taxonomy can actually help the teacher know how students solve mathematical problems. At each level of response based on SOLO, teachers can used to design models or learning strategies to determine the causes of misconceptions.

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