Exploring Student's Problem Solving Ability According to the Structure of the Observed Learning Outcome Taxonomy: Linear Algebra Problems

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Abstract. Each individual has different level of understanding in solving problems. The Solo taxonomy aims to distinguish the thinking ability level of an individual in solving problems. This study aimed to describe students' ability to solve problems based on the Structure of the Observed Learning Outcome (SOLO) taxonomy level. The type of research uses a descriptive study with a qualitative approach. The research subjects were 103 students of the Mathematics Education Program in Yogyakarta. The instrument used in this research was a linear algebra problem. Data were analyzed by data reduction, data presentation, and conclusion. The results showed a lack of conceptual understanding level in finding solutions to linear algebra problems. The understanding level of the subject in solving problems at the uni-structural level is classified as high. Nevertheless, the multi-structural and relational levels were classified as moderate. Instead, the abstract level was in the low category. Hence, the ability to think conceptually in order to generalize knowledge and other experiences is required in the problem solving process. Further research can be conducted to find other characteristics in other courses in solving problems.

Keywords: Problem solving, Solo taxonomy, Linear algebra

1 Introduction

The assessment of learning outcomes is carried out after the implementation of the learning process. Assessment of learning outcomes aims to determine the strengths and weaknesses of individuals in following the learning process [1], [2]. Various assessments have been suggested in helping teachers to improve the quality of classroom learning and to obtain information in the learning process [3]–[5]. The assessment is used by teachers in providing information on the individual's achievements [6],[7]. One aspect to ensure the effectiveness of the assessment in learning is to apply taxonomy in designing assessment activities in the learning process [5].

The instrument for measuring the level of children's thinking skills in obtaining information on the problem-solving process is called taxonomy [8]–[10]. There are two types of taxonomy in education, namely Bloom's and the Structure of the Observed

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Learning Outcome's (SOLO's) taxonomies. Bloom's taxonomy has not been able to distinguish the categories of factual, conceptual, and procedural knowledge [8], [11]. The SOLO taxonomy aims to address this problem. The SOLO taxonomy can support the ability to think in-depth and provide information in accordance with the description of the type of questions that require solving a variety of problems [8], [12].

The use of problems with various solutions can indirectly determine the level of a student's understanding of solving various problems to describe the development of the student. The level of understanding defined by [13] is called the SOLO Taxonomy. The SOLO taxonomy is an individual response evaluation instrument that aims to measure an individual's level of understanding [11], [14], [15]. The individual response instrument can measure the competence of an individual's learning outcomes and make it easier for teachers to obtain the quality of the individual responses in solving problems [13], [16]. The quality of individual responses can be categorized based on the SOLO taxonomic level. There are several categories of SOLO taxonomy, namely: 1) pre-structural, 2) uni-structural stage, 3) multi-structural stage, 4) relational stage, and 5) extended abstract stage [11], [13], [16].

Students' difficulties in solving algebraic problems occur because of the identification of algebraic concepts. Some efforts are required to identify errors in solving algebraic problems in depth [17]. One of the factors that cause students' errors in solving algebraic problems is the lack of conceptual understanding of algebra [18]. Errors made by students can be overcome by knowing the location of the errors and finding the right solution. Teachers need effective learning strategies to support algebraic problem solving skills [18]. Mathematical problem solving is the main basis for individuals in studying mathematics, which aims to build and reflect on the stages of the solution of a problem [19]–[21]. Problem solving is one of the main focuses in supporting higher order thinking skills, emphasizing formative characters in the mathematics learning process, and evaluating the mathematics learning process [22]. Based on the problem solving process, the SOLO Taxonomy is a systematic way of categorizing and describing an individual's ability to solve a problem [13], [15], [23].

The SOLO taxonomy describes the basic structure of the stages of learning mathematics. This basic structure is able to provide a systematic way for teachers to teach individuals to solve, understand, and evaluate a problem [25]. The benefit of mastering SOLO taxonomy analysis is that individuals are able to know the level of thinking in solving a problem and to determine the level of efficiency of problem solving procedures in the mathematics' learning process [26]. The SOLO taxonomy is able to form an evaluation system in the learning process. Therefore, the SOLO Taxonomy is the most effective tool in describing the level of individual's understanding of the learning process [15], [26].

The description above shows the importance of exploring linear algebra problem solving abilities on students based on the SOLO taxonomy levels. This study is designed to expand the previous results and provide new knowledge about how students understand linear algebra problems. On the other hand, we look at the factors affecting algebraic problem solving ability mapped to different levels of the SOLO's taxonomy proposed by [13]. Thus, the following questions are used to guide our research: i) What is the pre-structural level from the results of solving linear algebra problems? ii) What

is the uni-structural level from the results of solving linear algebra problems? iii) What is the multi-structural level from the results of solving linear algebra problems? iv) What is the relational level from the results of solving linear algebra problems? v) What is the extended abstract level from the result of solving linear algebra problems? and What are the differences in the results of solving linear algebra problems in terms of each level of the SOLO's taxonomy?

2 Methods

2.1 Research Design

This study was a descriptive study with a qualitative approach. Qualitative research was conducted to describe problem solving abilities based on the SOLO taxonomy level. The qualitative research aimed to understand various new phenomena needed in new science through research using appropriate methodologies [28].

2.2 Participants

The research was conducted in Yogyakarta upon mathematics education students who were taking linear algebra courses. The research sample used was stratified purposive sampling method. A total of 103 participants were carrying out this research.

2.3 Research Instruments

The research instrument used was linear algebra problems. The research test consisted of 3 items of descriptive problems containing the SOLO taxonomy level. This field note aimed to record in detail, carefully, and in depth the results of interviews and observations made by researchers to determine the research subjects at each university. Documentations were used as valid and actual evidences in this study.

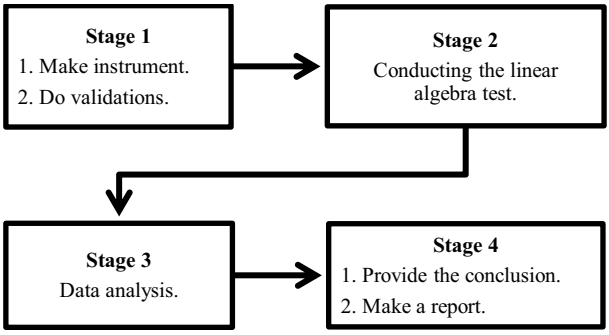

Fig. 1. Research Procedure

2.4 Procedure

The research procedure was divided into 4 phases as shown in Figure 1. First, the researcher prepares the research instrument and conducted validations upon the data. The second phase was the implementation of a problem-solving ability test containing linear algebra questions. In the third phase, the researcher carried out data analysis from the results of the linear algebra tests and described the problem solving based on the SOLO taxonomy. Finally, in the last phase, the researcher made a report and provided the conclusion.

2.5 Data Analysis

The data obtained were analyzed to get a conclusion. The data analysis was carried out when the data collection had been completed. Activities that supported the data analysis [29] were as follows: i) data reduction; ii) data display; and iii) conclusion drawing or verification. The indicators of student response in the problem solving process were based on the level of the SOLO taxonomy following the indicators from [15] which have been validated by experts. These indicators can be seen in Table 1.

Table 1. SOLO Taxonomy Level Indicators

SOLO Taxonomy Level	Indicator
Pre-structural	Students do not understand the information in solving problems.
Uni-structural	Students provide limited information in solving problems.
Multi-structural	The ability of students to find concepts and do not yet have integrated knowledge in solving these problems.
Relational	Students link concepts or processes so that all relevant information is connected and the relevant conclusion is obtained.
Extended Abstract	Students think conceptually and are able to generalize to a domain of knowledge and other experiences.

3 Results And Discussion

This research was conducted in Yogyakarta where the subjects were students who took linear algebra courses as many as 103 students. Each student worked on the linear algebra questions as many as 3 questions. The three items have been validated by 2 appointed experts. The test results are presented in Table 2. The information obtained is that most student responses are in the uni-structural level and the least student responses are in the extended abstract level. In the uni-structural level, students consistently answered the linear algebra problems where as much as 99.03% of the students were able to solve the problems. Meanwhile, student responses in other SOLO taxonomy levels completed each item with varying abilities.

Table 2. SOLO Taxonomy Level Grouping Results

SOLO Taxonomy Level	Problem 1		Problem 2		Problem 3		Total	
	n	(%)	n	(%)	n	(%)	n	(%)
Pre-structural	0	0.00	1	0.97	1	0.97	2	0.65
Uni-structural	102	99.03	102	99.03	102	99.03	306	99.03
Multi-structural	92	90.29	68	66.02	69	66.99	229	73.14
Relational	-	-	49	47.57	58	56.31	107	48.54
Extended Abstract	-	-	12	11.65	-	-	12	11.65

Notes: n = number of students, % = percentage of students

The overall response of students in the pre-structural level on the linear algebra test was 0.65%. Regarding items number 2 and 3 only one student each is at the pre-structural level. This means that the student's response to questions number 2 and 3 is 0.97%, while question number 1 is 0%. This shows that few students are in the pre-structural level.

At this pre-structural level, students have not been able to apply and obtain information to solve problems related to linear algebra. So that at the pre-structural level: (1) they obtain information without understanding concepts and using inappropriate strategies [27], (2) they work on questions in an unstructured and unorganized manner [16] and (3) they are often distracted by things that are not relevant to the question [15]. This is in line with the results of a study by [26] regarding student's responses in solving problems at the pre-structural level, namely (1) they understand problems that are not relevant to the questions given, (2) lack of information in making problem strategies, and (3) misunderstandings in solving significant problems.

Student responses to items number 1 to 3 at the uni-structural level are 99.03%. This means that out of 103 students, only 1 student that is unable to solve the linear algebra problems in each item. Overall, student response in the uni-structural level is 99.35%. This shows that many student responses in the uni-structural level on all questions have no difference at all. Student responses in the uni-structural level in solving algebra problems include several indicators, namely: (1) they are only able to understand one concept through a certain type of representation in solving problems [30], (2) they explain the correct understanding of several concepts but have not been able to cover all aspects of the existing problems [26], [31], and (3) they obtain one information in solving problems but do not relate concepts [11]. In this level, students have limited ability to understand concepts in solving problems. This is in line with a study conducted by [27] that problem-solving skills in the uni-structural level have limited understanding so that the answers produced are limited and incomplete.

Student responses in the multi-structural level on questions number 1, 2, and 3 are 92, 62, and 69 students with percentages of 90.29%, 66.02%, and 66.99%, respectively. Overall, the response of students who are at the multi-structural level is 73.14%. The response of students who solved the problem of item number 1 has a higher level of understanding than items number 2 and 3. There are several indicators of student response in solving algebra problem in the multi-structural level, namely: (1) they get some information, but are unable to relate some existing concepts [32], (2) they are able to provide some information, however the information is not integrated [11], [15], and (3) they make some informational relationships, but these relationships are imprecise

and the conclusions are irrelevant [32]. This is in accordance with the research conducted by [26] that the problem solving ability according to the SOLO taxonomy in the multistructural level is obtained by gaining information from the problem without focusing on the relationship between existing concepts. This is in line with [30], which states that understanding several different concepts affects their level of understanding in solving different problems.

The overall student response at the relational level has a percentage of 48.54%. Their level of understanding in solving questions number 2 and 3 is not too much different. In number 2 there are 49 students who are able to reach the relational level with a percentage of 47.57%, while in job number 3 there are 58 students who are at this level with a percentage of 56.31%. Student responses that reach the relational level have the ability to plan several strategies in solving problems. Therefore, the indicators of students at the relational level are: (1) they are able to link separate pieces of information into problem solving solutions [33] and 2) they use a lot of information in applying problem concepts to draw relevant conclusions [32]. Based on this description, the relational level of items number 1 and 3 does not have a significant difference in problem solving ability. The difficulty of students is influenced by the lack of ability in connecting several concepts to get the right and relevant solutions. These results are in line with the research conducted by [32], which states that students in the relational level are able to connect a lot of information in applying concepts to obtain the relevant conclusion.

The question that refers to the extended abstract level is only in item 2. In this item, 12 students can solve the linear algebra problem with a percentage of 11.65%. This means that the level of mastery of solving linear algebra problem at the extended abstract level is at a low level. Student responses in the extended abstract level show: (1) they use a lot of information by generalizing the results obtained in a relevant manner [27], (2) they are able to integrate the problem solving process conceptually [16], and (3) they develop several strategies and apply them to a wider context by comparing other concepts [34]. In this level, students have low problem solving abilities because they have the ability to solve problems with a percentage of only 11.65%. This is influenced by the lacking ability of generalizing the solutions of relevant problems. This description is supported by the opinion in [26] that students' responses in dealing with a problem are by connecting several concepts.

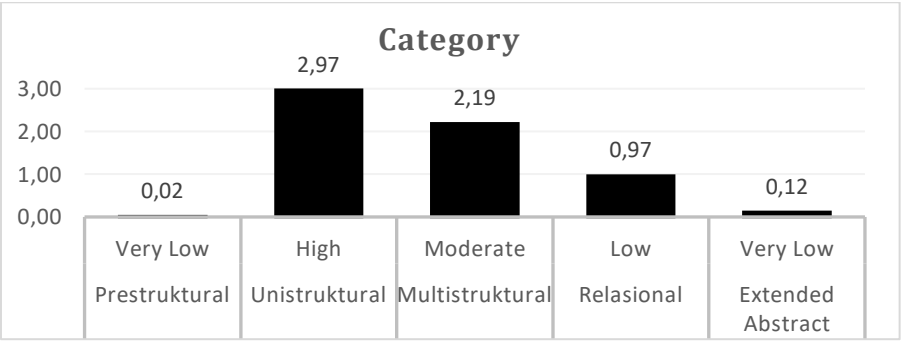

Fig. 2. Problem Solving Category in SOLO Taxonomy Level

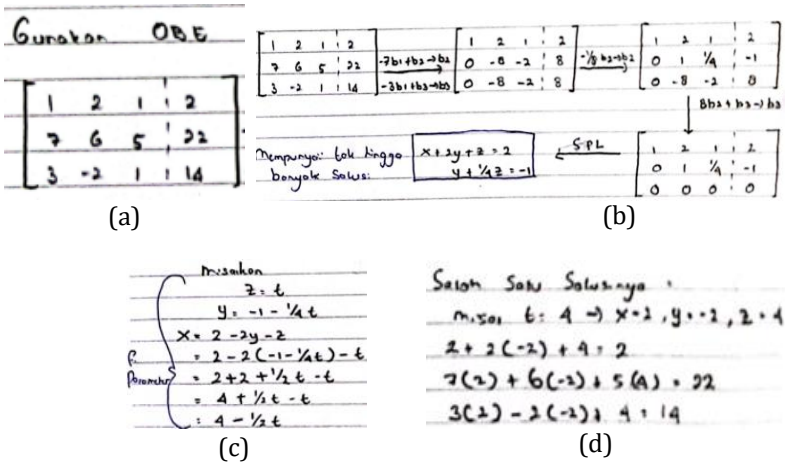

Fig. 3. Student's Work on the (a) Uni-structural; (b) Multi-structural; (c) Relational; and (d) Extended Abstract Levels.

The linear algebra problems consist of 3 questions. Question number 1 is in the uni-structural level to the multi-structural level, question number 2 is in the uni-structural level to the relational level, and question number 3 is in the uni-structural level to the extended abstract level. In the uni-structural level, the overall average of students in solving three algebra questions is 2.98. This means that the uni-structural level is in the high category (shown in Figure 2). This is opposite to the problem solving ability of students in the extended abstract level. In the extended abstract level from 2 linear algebra questions, the average mastery is 0.61, which is in the low category. There are 2 moderate categories in solving this algebraic problem, namely the multi-structural and relational levels. The averages of multi-structural and relational levels are 2.46 and 1.97, respectively. This is in accordance with the research conducted in [33] that students who have low problem solving abilities are only able to be in the unistructural level and stduents who have high abilities are in the extended abstract level. Meanwhile, students with moderate abilities are in the multi-structural and relational levels.

The uni-structural level is the subject's way of providing limited information on the questions that have been given. In this level, the subject is to focus on one statement and provide a correct understanding of only one concept [26]. This method is done by the subject to provide limited information by converting the system of linear equations into an extended matrix. This is supported by the opinion in [35] that the uni-structural level is the process of obtaining results from some of the relevant aspects of a problem that is understood and focused. At this level, these aspects are information that is known, asked, or the relationship between the two.

The next step is to implement problem-solving strategies in the multi-structural level. In this level, the subject is able to write more than one piece of information as well as the way he knows and in accordance with what is known in the problem [15].

At the multi-structural level, the subject finds a problem-solving strategy by finding x, y, and z using Gaussian elimination. The subject is able to find a solution to the problem using only 1 concept; hence the subject is in the multi-structural level. This opinion is supported by [27] stating that multi-structural level aims to provide two or more information that is used but cannot connect every aspect. In this work, the subject obtains a solution with linear equations, namely $x + 2y + z = 2$ and $y + 1/4 = -1$. This means that the work requires a further step to the relational level.

The relational level is the stage where the subject is processing some information and using several methods in solving a problem to obtain the relevant conclusion. At this level, the subject is able to think inductively. According to [25], students in the relational level are able to compare similarities and differences, predict cause and effect, or analyze the strengths and weaknesses of concepts. This is shown by the ability of the subject to make a consideration of x, y, and z to connect the concepts, which is found with the concepts obtained previously so that all relevant information is connected and the relevant conclusion is obtained. The work requires a concept that can be integrated so that it can be applied to new situations [15].

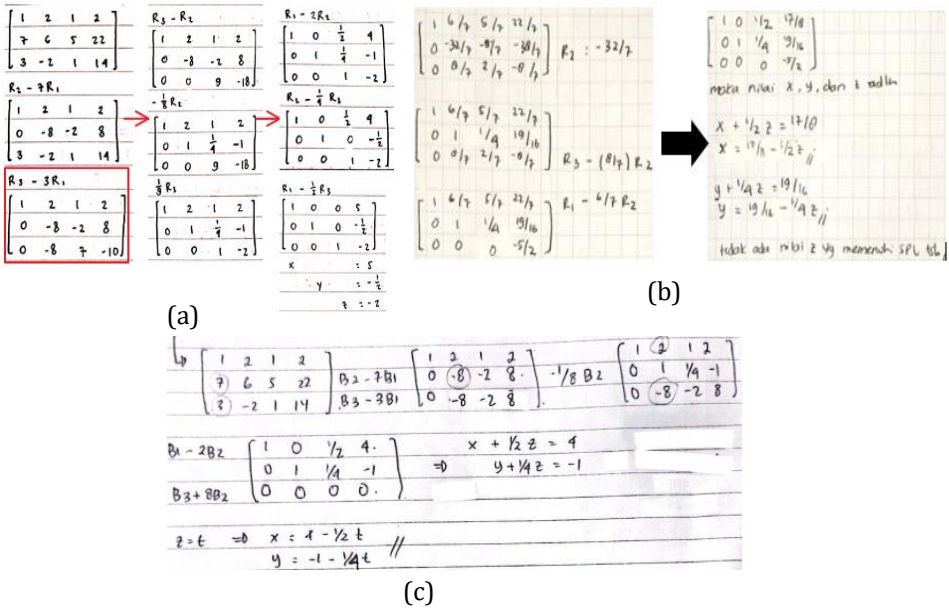

Fig. 4. Mistakes by the Subject in the (a) Multi-structural; (b) Relational; and Extended Abstract Levels.

Finally, in the level of extended abstract, the subject is able to generalize on the domain of knowledge and other experiences. The extended abstract level can develop key competencies, namely multifunctional abilities needed to master both relevant

problems and concepts and have the ability to generalize beyond the given subject [15]. This step is shown by considering t is a random number. In this step, the subject makes one example of t : 4. This method is done to check the solution of the problem, i.e.: whether it is true that it has an infinite solution or not.

Figure 4(a) shows a mistake by the subject in the multi-structural level. The mistake is seen when the subject is performing calculations on the matrix. The mistake is made when the subject calculates R3 – 3R1. Hence, this produces an error in the calculation in the 3rd row and the 3rd column, i.e.: 1 - 3 = 7 is obtained and in the 3rd row and 4th column the, i.e.: 14 - 6 = -10. In each calculation, the correct values should be 1 - 3 = -2 and 14 - 6 = 8. This means that the subject is not able to interpret the problem correctly. It can be concluded that the subject's error in the problem solving process in the multi-structural level occurrs because the subject is unable to relate some relevant and correct data [26]. Figure 4(b) describes the subject's mistake in solving linear algebra problems at the relational level. This occurs due to an error in calculating the matrix. If the subject makes a calculation error during the problem solving process in Figure 4(b), then the subject is unable to write down some information to find a solution to the relevant problem. It is found that the subject made an error because the subject was unable to write more than one part of the information and in accordance with what is known in the question [15]. The subject's mistake in solving the problem in the extended abstract level can be seen in Figure 4(c). In the figure, the subject states the answer, namely $x = 1 – 1/2\ t$ and $y = - 1 - 1/4\ t$. The subject is not able to conclude the answer because the subject has not been able to integrate different methods and concepts into a coherent whole [13].

4 Conclusion

We report the results of this study in describing the problem solving ability of linear algebra according to the SOLO taxonomy level. Student responses of the problem-solving abilities are in the high category in the uni-structural level with a percentage of 99.35%. However, different results are obtained in the extended abstract level with a low category with a percentage of 30.10% of students mastered this ability. In the multi-structural and relational levels, student responses are in the medium category with percentages of 82.20% and 65.37%, respectively. To be able to reach the highest category in the extended abstract level, students need to improve their ability to relate several concepts and generalize to another domain of knowledge and experience. This study can be used in maximizing problem solving abilities. This research can also be used as a guide in conducting research with different contents, such as Geometry, Real Analysis, Calculus, and Statistics. Based on the ability to solve problems based on the SOLO taxonomy, the abstract aspect is low compared to other aspects. This requires an effort to improve the ability to think reflectively, especially in the extended abstract aspect.

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