

# Solving mathematical word problems using dynamic assessment for scaffolding construction

Andi Saparuddin Nur, Kartono Kartono, Zaenuri Zaenuri, Rochmad Rochmad

Department of Mathematics Education, Universitas Negeri Semarang, Semarang, Indonesia

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## ABSTRACT

Students need the ability to solve word problems can connect mathematics with the context of everyday life. However, students experience many difficulties and need assistance in the form of scaffolding can to solve word problems well. Dynamic assessment is an alternative approach to constructing the form of scaffolding that student need to solve mathematical word problems. This study aimed to analyze the students' difficulties in solving word problems and the required form of scaffolding through dynamic assessment. The subjects of this study consisted of 177 students spread across 10 public junior high schools in Jeneponto Regency, South Sulawesi Province, Indonesia. There was a four-word problem tested and analyzed using dynamic assessment. Student solutions were grouped based on the type and form of scaffolding needed: level 5 (no solution), level 4 (without analysis/unrepresentative), level 3 (computational error), level 2 (incomplete procedure), level 1 (lack of thoroughness in the final stage). The form of scaffolding is constructed to help students solve mathematical word problems step by step at each level. The use of scaffolding accompanied by instructions helps students develop word problem-solving skills. Dynamic assessment can be considered to be integrated with the mathematics learning process that supports scaffolding construction to solve students' word problems.

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## Corresponding Author:

Andi Saparuddin Nur

Postgraduate Program, Department of Mathematics Education, Universitas Negeri Semarang

Kelud Utara III Street, Petompon, Gajahmungkur 50237, Semarang, Indonesia

Email: andisaparuddin@students.unnes.ac.id

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## 1. INTRODUCTION

The problem-solving ability has become a prominent mathematics learning goal in recent decades [1], [2]. However, many students have difficulty developing mathematical problem-solving skills [3]. Several factors are the cause, including the level of complexity to solve the problem requires more times [4], requires logic [5], sufficient knowledge base [6], and requires contextual understanding [7]–[9]. The definition of a problem can be interpreted as a situation that has a gap of available resources to be solved. A problem is a task that does not have a solution available with routine procedures so that it requires a meta-cognitive strategy [10]–[12]. Based on the type of solution, mathematical problems can be classified into three categories [13]: i) Solvable mathematical problems namely mathematical issues that require solutions to use certain algorithms; ii) Unsolvable mathematical problems namely mathematical issues with limitations on the availability of procedures, universe space, and sufficient information so that they cannot produce solutions; and iii) Non-mathematical problems namely ordinary problems without involving mathematical concepts. Mathematical problems that can be solved are further divided into two categories, namely textual problems

and non-textual problems. Textual problems that can be solved by applying mathematical concepts, rules, or techniques are word problems [11].

Word problems are usually used as a link mathematics and real-world situations so that students can develop skills in applying mathematics [1], [14], [15]. The choice of problems in the form of word problem aims to make students recognize, understand, explain, and solve problems according to contexts [16]. Galbraith and Stillman [15] distinguished word problems into four categories based on the nature of the solution, i.e., unrealistic problems, problems separated from context, implementation problems, and genuine problems with modeling. Meanwhile Fuchs, [17] classified the word problem model based on the level of intervention required, i.e., algorithmic form, realistic, and complex. The three models have differences in the way of solving and the approach used. A common difficulty experienced by students when facing problems in the form of word problem is how to make a mathematical model [11], apply appropriate computational procedures [3], limited vocabulary [11], [18], and weakness in mathematical communication [15]. Students who have difficulty solving word problems provide opportunities for various errors [15], [19], e.g., transformation errors, errors in translating sentences in the model, dependence on the use of mathematical operations, and ignoring realistic considerations in solving word problems.

Problem-solving requires a series of strategies to be implemented properly. Training problem-solving skills can be done using cognitive and metacognitive strategies [10]. Students need to be familiarized with various contexts so that they can grow their knowledge, metacognition, and belief in the problem-solving strategies used [11], [20], [21]. Solving word problems requires one's ability to understand the contextual situations include in the problem, trace information, relate the meaning behind the numbers in the structure of the storyline, then calculate [8], [22]. Some ways that can be used to solve word problems are to make diagrams through visualization and representation [19], [23], using heuristic strategies [11], [20], and build models according to context [3], [14], [24]. Students can solve word problems by following steps [16]: reading, understanding, planning, drawing (if needed), calculating, verifying, and answering questions.

Word problem solving requires various strategies. Students must have linguistic, transformation, literacy, and argumentation skills to construct problems and solve them according to context. Students' abilities can be approached from an assessment perspective that is integrated with the learning processes. In general, assessments are only carried out to distinguish students based on their solutions, but rarely reveal the potential behind the solutions [25], [26]. According to Fuchs [17], the principal assessment purpose is to predict learning success and identify the form of intervention needed so that each student can achieve competence according to their potential. Dynamic assessment is an alternative assessment form that can be used to analyze students' mathematical word problem-solving solutions.

Dynamic assessment is a form of diagnostic assessment to find out what students can and cannot do and how to optimize their potential in learning [25]. The dynamic assessment provides an opportunity for teachers to identify students' potential in more depth through teaching accompanied by feedback in the testing process, including the ability to word problem solving [17], [26]–[28]. The basic principle of dynamic assessment departs from Vygotsky's thoughts regarding student learning development. Vygotsky [17], [29] argued that each student is likely to need help completing assignments at different levels. Identifying dynamic assessment forms is needed to help students solve word problems proportionally [30].

Dynamic assessment can provide an overview of metacognitive strategies and interventions that help students build a better understanding [26], [29]. However, studies involving dynamic assessments in mathematics learning, especially solving word problems are still rarely carried out [26]. Various valuable information is needed to reveal more findings related to the dynamic assessment in helping students solve mathematical word problems. The purpose of this study was to explore the difficulties experienced by students in solving word problems and the form of assistance in the scaffolding form that could potentially be used in learning. In general, dynamic assessment is still considered foreign and has not been widely explored as a technique for constructing the scaffolding form. The findings in this study can provide the learning approach used so that teachers know how to effectively help students solve mathematical word problem.

## 2. RESEARCH METHOD

This study was conducted in 10 public junior high schools in Jeneponto Regency, South Sulawesi Province, Indonesia involved 177 students (110 female and 67 male). The research subjects were in the range of 12-14 years who were assumed to have studied arithmetic operations with integers, percentages, social arithmetic, and comparisons. Students aged around 12 years are considered to have maturity in learning related to graphic visualization accompanied by literacy skills in managing word problems [23]. A qualitative approach is used to explore solutions to students' word problem-solving. Furthermore, the construction of the scaffolding form is analyzed based on the solution provided using dynamic assessment.

There are four-word problems given to students to be completed in 60 minutes. Word problems involve realistic contexts and are close to the student's environmental conditions. The construction of questions considers the level of complexity that requires intervention but is still within the cognitive reach of students. The validity of the instrument was carried out through an expert assessment consisting of one lecturer with a doctoral degree in mathematics education, and one professional teacher with a tenure of more than twenty years. Expert validation aims to obtain considerations related to the readability of the questions, the suitability of the material substance, and the emergence of problem-solving indicators. The validator provides suggestions for added an image to each question. Furthermore, the validator suggested that the information in the word problems clearly describe the mathematical problems related to the context. The construction of word problems used the professions context such as salt farmers, fisherman, traditional food sellers, and wagon drivers. The mathematical word problems tested is shown in Table 1.

Table 1. Mathematical word problems

Number	Question
1	A salt pond is done by a salt farmer from the pond owner with a 30% share of the harvest for the pond owner. Salt ponds can only be cultivated in the dry season. If the weather is sunny in a week, salt farmers can harvest 120 kilograms, but if the weather is uncertain then salt farmers can only harvest 40 kilograms. Determine how many kilograms of salt will be the share of the pond owner if, in a month, there is one week of erratic weather?
2	A fisherman returns home with his catch from the sea with 10 liters of diesel fuel, a boat, and a net. The purchase price of diesel is IDR 5,500 per liter and the cost of maintaining the boat and nets is IDR 100,000. The caught fish are tied using rattan for sale and the result is 12 bundles with a profit of IDR 9,000 for each tie. What is the selling price of all fish caught by the fishermen?
3	Each stove can be used to cook 20 <i>lammang</i> in one burning for 20 minutes. If 800 <i>lammang</i> are burned every day using two stoves, how long will it take to burn? ( <i>Lammang</i> is a kind of traditional food in South Sulawesi)
4	A coachman charges IDR 2,000 for every 1 kilometer of his wagon journey for each passenger. The wagon can carry a maximum of 4 adults. A vegetable seller, two fish sellers, and a meat seller will ride a wagon to the market together. The distance between where they ride the wagon and the market is 3 kilometers. How much does it cost for all passengers?

The test conditions were carried out in a classroom containing a maximum of 15 students with a room capacity of 30 students. All schools that were used as research sites implemented health protocols due to the time when data collection was carried out during a pandemic. The class situation during the test was set to be quiet, spaced, and the time provided was sufficient to solve all the questions. The implementation of data collection is strived to be ideal according to the dynamic assessment instructions [25]. After the students collected the test results, the researcher made coding on the worksheets by writing "S - sequence of worksheets - school initials". The data obtained from the word problem-solving solutions are grouped by subject, gender, school origin, questions order, answers variations, difficulty description, and level of scaffolding required. The collected data is used to identify the form of scaffolding based on dynamic assessment. The results of student answers were analyzed descriptively and grouped according to dynamic assessment scores [30] used rubric as shown in Table 2.

Table 2. Dynamic assessment scores

Score	Description
0	Unable to provide a solution (blank answer), writing is not clear, meaningless
1	Only rewrite the information, without analysis, and not representative
2	Using part or all of the numbers in the problem as a computational tool
3	Analyze the problem given partially, the procedure is incomplete and ignores some of the information on the question
4	Analyzed the problem well, but made the wrong decision in the final stage, was not thorough, did not verify the solution
5	The complete, correct solution, no help needed

Student scores for each question used the rubric in Table 1 for identified minimal scaffolding needs. The researcher prepared an answer grid for each step in the question and matched it with student responses. In addition, each response was grouped into a dynamic assessment score. Dynamic assessment is used to construct the required scaffolding form based on the description of the students' answers. The higher the score obtained in the dynamic assessment it is assumed that less scaffolding is needed. For example, students who score 0 mean that they need the most scaffolding, followed by students with scores of 1 to 4, while students with a score of 5 are assumed to not need scaffolding. Therefore, scaffolding construction is hierarchical with the assumption that assistance is given in stages.

### 3. RESULTS AND DISCUSSION

#### 3.1. Analysis of student word problem solving used dynamic assessment

Four questions are tested related to the concept of proportion, social arithmetic, worth comparison, time, distance and capacity. The solutions given by students were identified based on the scaffolding level indicators in each number as shown in Table 3. It appears that the word problem number 3 was answered most completely and correctly by students, but it was also the most answered question without analysis. Most students have difficulty solving word problem number 2 because it involves many components so that many procedures are incomplete, without analysis, and not representative. Many students gave unclear answers in each number, except for number 4. Word problem number 4 did not require too much analysis, but many students failed to understand the context of the question and ignored important information related to the problem. Student solutions were analyzed based on dynamic assessment techniques. Overall, students need most of the help to solve word problems. The scores obtained by students indicate the need for dynamic assessment to identify the scaffolding form needed.

Table 3. Number of students based on scaffolding level indicators in each word problem

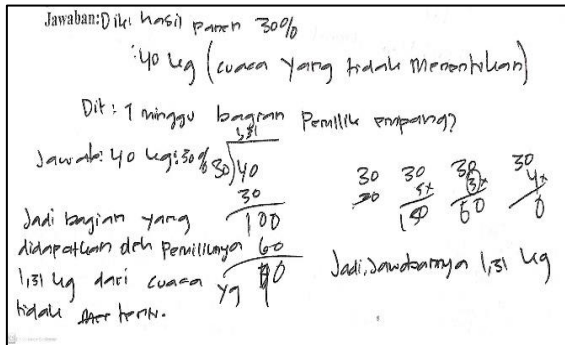
Indicator	Word problem number			
	1	2	3	4
No solution (empty)	4	5	16	20
Incomplete procedure	17	36	6	7
Computational error	26	24	10	7
Not representative	72	49	38	21
No analysis	49	57	81	66
Ignoring the information on the question	2	1	1	46
The complete and correct solution	7	5	25	10
Number of students	177			

#### 3.2. Scaffolding construction on students' mathematical word problem solving solutions

Solving mathematical word problems requires the ability to understand questions based on information in the text. Many students who have difficulty at the stage of understanding the problem lead to the inability to make the right strategy. Students have difficulty identifying information because the gap in the problem space is too wide so students need help understanding concepts [31]. This condition ultimately makes students unable to provide answers or solutions that are given without analysis and are not representative. The identifying difficulty the relationship between mathematical concepts and problems is also an obstacle to finding strategies. Students have problems using mathematical symbols based on the text as a tool to solve word problems. Most students use the wrong notation or even wrong in the calculation processes. Building solutions from word problems helps students improve conceptual and procedural knowledge [32].

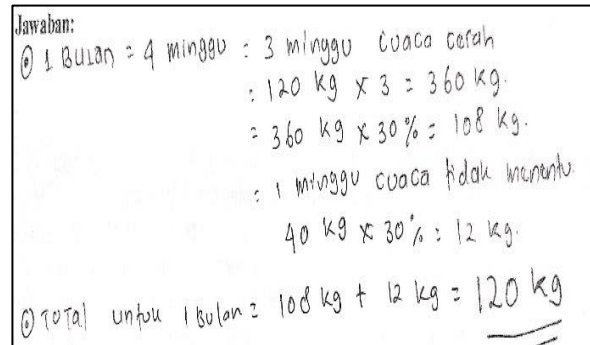
Four students did not provide a solution to word problem number 1. This was due to the limitations of translating words into mathematical models so that it was difficult to identify information on the problem, and did not have procedures. The limitation of translating words is the main factor in the failure of students to make strategies so that they are unable to think about anything related to the story. Even though students give responses, the solutions are given only repeat the information on the questions. According to González-Calero, Berciano, and Arnau [24], students need the syntax to be able to convert words into equation models. Furthermore, there is a group of students who can only write down information on the problem, knowing the missing information, but could not communicate any information to obtain a solution. Students group at this level only write down known and asked information. The problem-solving procedure used is unclear, unrepresentative, and far-fetched. In line with this, the main difficulty of students in solving problems is the stage of identifying and organizing the necessary information from the context [31].

Most of the students who managed to find the strategy in question number 1 were stuck at the equivalence of one month into five weeks. There is doubt in determining the time conversion which results in an error in relating the time to the amount of salt harvested each week. Students who use time conversion correctly will find a solution of 400 kg, but the problem is not solved and ignores important information in the problem. Many students have difficulty understood the proportion of 30% as shown in Figure 1. There are two ways that students use to understand the proportion of 30%, namely by first finding the total amount of salt harvested for one month, and determining 30% of each harvest each week. However, students used the wrong arithmetic operation in determining 30% because they used division. Furthermore, students who understand the proportion of 30% means that 30 parts of the total 100 units use multiplication operations and successfully solve the problem as shown in Figure 2.



Translation:  
Given 30% harvest, 40 kg (erratic weather).  
Question: 1 week for the pond owner? Answer: 40 kg. So, the share that the pond owner gets is 1.31 kg from the erratic weather.

Figure 1. Solution S-18-T in question number 1

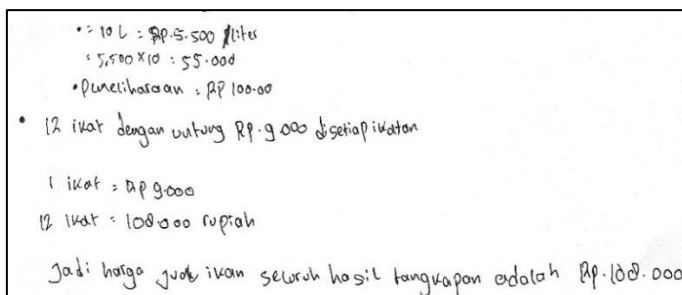


Translation:  
1 month=4 weeks (3 weeks of sunny weather), 120 kg x 3=360 kg, 360 kg x 30%=108 kg. 1 week of erratic weather 40 kg x 30%=12 kg. Total for 1 month: 108 kg + 12 kg=120 kg.

Figure 2. Solution S-164-BR in question number 1

Students who have good problem-solving analysis and procedures still need a few assistances could to communicate solutions in context. Groups of students with few assistances were identified made mistake in using inappropriate terms in the questions. In line with the results of this study, students could be made mistakes in determining decision variables, and use notation to solve word problems [33]. Students could not consistently distinguish the meaning of "kilogram" as a unit of weight with "sack" as a term commonly used in daily life contexts. Students who are often stuck in terms will result in many misconceptions.

Moving on to question number 2 related to the concepts of social arithmetic, capital, selling price, and profit. Many students consider this question the most difficult because it involves a lot of information. Apart from the many empty solutions, without analysis and unrepresentative as the group most in need of scaffolding, many students' solutions stop at the failure to interpret the word "profit". The information asked is the selling price, but most of the students think the selling price is profit. Differences in point of view related to the selling price and profit have something to do with culture, habits, and everyday choice of words. Emphasis on terms that cause ambiguity in the minds of students is an effective way to avoid misinterpreting the text. Students who have analysis and procedures for coherently solving problems can experience bias as shown in Figure 3.



Translation:  
10 liters=IDR 5,500 x 10=IDR 55,000,  
maintenance=IDR 100,000  
12 bundles with a profit of IDR 9,000 in each bundle  
1 bunch=IDR 9,000  
12 bunches=IDR 108,000  
So, the cost of selling the whole fish caught is IDR 108,000

Figure 3. Solution S-75-BN in question number 2

It can be seen that students identify all the information on the questions well. However, students conclude that the fish catch is a solution to the selling price instead of adding up all the information that has been found. Meanwhile, students who needed more scaffolding were identified using all the numbers in the problem as a computational tool. Students assume that the number in the problem is a means of reaching a solution. Meanwhile, there are a small number of students who experience counting errors at the end of the problem-solving stage as shown in Figure 4.

Jawaban:  
 nelayan bermadalkan solar 10 liter.  
 harga jual beli solar Rp. 5.500 per liter =  $5.500 \times 10 = 55.000/10$  liter  
 biaya pemeliharaan perahu dan jaring Rp 100.000 + 55.000 = 155.000  
 $12 \times 9.000 = 108.000 + 155.000 = 283.000$

Translation:

Fishermen have 10 liters of diesel. The purchase price of diesel is IDR 5,500 per liter=IDR 55,000. Boat and net maintenance fee IDR 100,000 + IDR 55,000 =IDR 155,000.  $12 \times 9,000=108,000 + 155,000=283,000$ .

Figure 4. Solution S-117-A in question number 2

Each step was completed well, but the students miscalculated in the final stage. The solutions provided are interconnected and follow the flow of the text on the problem, but students are less thorough. The form of scaffolding required is less than students who experience pseudo in determining the selling price, but students need to emphasize the importance of the evaluating solution. Furthermore, some students used each visualization unit without writing down the information explicitly. Identifying the specific characteristics of word problems that are related to functional thinking can help students construct more sophisticated strategies [34]. Students seem to master the arithmetic operations used along with the easiest way to get a solution.

Unlike the previous question, word problem number 3 is related to the comparison concept and quantity in time units. The analogy is perfect way to solve this problem, but many students are unable to provide solutions. Improving the ability to solve word problems can be done by training working memory, used representation skills, and scaffolding [11]. The groups that need the greatest scaffolding are students who immediately write down answers, without analysis, and are not representative. There are two variants of solutions in this group, i.e., students with correct solutions, and invent solutions. Although there are students with correct answers, they are not accompanied by a flow of completion so that they are likely to be obtained through cheats or knowing only based on intuition. Students with invent solutions produce an irrelevant answer and rely heavily on the early stages of understanding the problem [31].

The next group is students who could be write down information and make analogies but convert the time incorrectly. Students who succeed in making analogies use all components in the problem correctly. Students understand that using two stoves will result in a shorter time required. The use of metacognitive strategies and instruction schemes is needed to solve word problems [14]. Students generalize functional relationships used their own words or general case examples [34]. Teachers can train students to think of their strategies when solving problems as a means of fostering self-regulation and performance outcomes [1]. However, the conversion of minutes to hour is an obstacle for some students so that they did not get relevant solutions. Some students did not even convert time from minutes to hours even though the solution is still acceptable.

The last question is related to the concepts of distance, capacity, and cost. There is important information that students must pay attention to, namely the capacity of the wagon, but many ignore it. The problem in number 4 is relatively easy and does not require much analysis, but most students give blank answers. The number of blank answers indicates that students need more interventions related to word meaning, translation, and modeling. However, there are also quite a several groups who directly give answers. Students giving direct answers show two things, namely the problem is considered normal so it does not require a sequence of completion, or the resources availability is not sufficient to make a sequence of completion. Furthermore, there is a group that writes down information on the problem, makes a solving procedure, but it is not complete. Students only write down the travel costs for each kilometer and ignore the distance. There are two answers variants for this group, namely including the coachman as a passenger, and assuming the coachman is not a passenger, thus ignoring the wagon capacity. Most students assume the total cost of the trip is four passengers when there should only be three passengers.

Information related to the wagon capacity is mostly ignored by students and does not realize that the coachman is included as a passenger even though there is no travel fee for the coachman. Students generally consider the numbers listed on the questions to be a must to be included in the calculation process. Students ignore the wagon capacity because the number of prospective passengers in the question is four and there is the word "cost" which is considered a factor that benefits the coachman. Students need scaffolding assistance so that they can consider various information on the questions so that they do not conflict with each other and become rational. The provision of scaffolding helps students perform mental actions that cannot be done alone and gradually decreases along with the transfer of greater responsibility given to students [31].

The students' word problem-solving solutions were analyzed using dynamic assessment and categorized based on the form of scaffolding required for each level as shown in Table 4. The scaffolding construction in Table 4 describes the required interventions through clinical interviews. However, assessing students' problem-solving results through interviews still leaves a weakness because the solutions given can vary at different times [4]. Students need time could explain the thought process in solving word problems and put them in written form. Information bias can appear when students start thinking about the question. The longer time required will result in the loss of information related to the scaffolding form needed. This is in line with the opinion Powell, Berry, and Benz [14] that students who received intervention in solving word problems we're able to provide better strategies than those who only received instruction. The scaffolding form with a hierarchical structure will facilitate the transition process [17]. Scaffolding is given in stages, if students have not been able to solve a problem at a certain level, it will continue at the next level until the problem can be solved.

Table 4. Scaffolding forms for each level

Level	Scaffolding forms	Description
5	Asking a simpler problem  Starting from information known, inquire, and the adequacy of the information  Thinking about related concepts	Using equivalent problems with fewer words, more specific problem spaces, and sentences that are easier for students to understand  Read the questions again, capture ideas from known sentences, and ask questions. If not able, students are asked to "rewrite" the questions and separate each information. Mapping any information, including its adequacy in solving problems  Using information that has been compiled to connect with mathematical concepts. If students are not able to, then an "illustration" is given that is close to the context of the problem
4	Made a suitable analogy/ mathematical model Conjecture  Thinking strategy	Finding the right word to analogize the problem, helps students find mathematical models from the context  Explore various possibilities, work backward, all required information has been obtained or not, result of using certain procedures  Estimate strategies that fit the problem, create doodles, diagrams, tables, or visualizations. If not able, students are asked to explain the problem in their own words
3	Analyze relationships  Problem decomposition, breaking down into units  Explain the rationality of each step	Each information is then compiled, developed, and analyzed in a structure to find logical relationships. Start by asking "are these and that components related?" "Is it enough to find that just knowing this?"  Looking for possible problems can be broken down into smaller units. Start by asking "is it possible for this problem to consist of simpler problems?", "can the unit problem solutions be applied to the original problem?"  Finding the validity of each stage, thinking about the continuity of each process, if possibly students use alternative procedures.
2	Thinking about the completeness of the procedure  Make judgments from any information found	Ensure every piece of information has been managed in solving problems. Asking the questions "Is there any missing information?", "Is there any unimportant information in the problem?", "Is the current procedure sufficient to solve the problem?"  Connecting the solution obtained at each step with the problem to be solved. Checking "is the existing solutions sufficient to answer the problem?", "Is there any information that requires consideration for further analysis?"
1	Checking the correctness of each step  Evaluating solutions	Ensure that there are no errors in each step, "Is this step calculated correctly?" If in doubt then use an alternative procedure.  Communicate the solutions obtained. Interpret the solution "did it solve the problem?", "Is there another way that can be used to solve the problem?"

#### 4. CONCLUSION

Students need some assistance in the scaffolding form to solve mathematical word problems. Students' have needed different scaffolding forms. Students' solutions with empty, unclear, and meaningless answers require a simpler context. Students who only rewrite the information on the problem, without analysis, and are not representative need assistance making analogies, compiling mathematical models, and conjectures. Students with computational errors and procedural errors require in the mapping form the relationship between information, solving problems, and explaining the rationality of each stage. Less scaffolding is given to students who can perform analysis but the procedure is not complete and ignores some of the information. Students who need accuracy at the final stage are given the most basic scaffolding. Scaffolding construction shows the hierarchical order of assistance from each level. Therefore, the provision of scaffolding is greatly determined by the minimum level needed by students to solve word problems. The findings in this study have a contribution related to the effective scaffolding strategy carried out by the teacher in helping students develop word problem-solving skills. Further studies are needed to see the effect of providing scaffolding and anticipating alternative strategies used in solving mathematical word problems.

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## BIOGRAPHIES OF AUTHORS






**Andi Saparuddin Nur**    is a doctoral student in Mathematics Education at the Universitas Negeri Semarang. He is a lecturer at the Department of Mathematics Education, Universitas Musamus, Indonesia. He wrote several articles related to ethnomathematics, mathematical word problems, learning and instruction, assessment and evaluation in mathematics education. He can be contacted at email: andisaparuddin@students.unnes.ac.id; andisaparuddin@unmus.ac.id.






**Kartono**    is a lecturer and Professor of evaluation in Mathematics Education at Universitas Negeri Semarang, Indonesia. His research is mostly related to assessment and evaluation in mathematics education, instructional design, and instrument development. He can be contacted at email: kartono.mat@mail.unnes.ac.id.



**Zaenuri**    is a lecturer and Professor of environmental science at Universitas Negeri Semarang, Indonesia. He has published several articles research is related to ethnomathematics, learning and instruction, and environment-based learning model. He can be contacted at email: zaenuri.mat@mail.unnes.ac.id.



**Rochmad**    is an associate professor and senior lecturer at Universitas Negeri Semarang, Indonesia. His research interests include: model of teaching, learning and instruction, mathematical skill, creative and critical thinking. He can be contacted at email: rachmad\_manden@mail.unnes.ac.id.