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Developing Instrument of Essay Test to Measure the Problem-Solving Skill in Physics

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Abstract

This research was developmental research with the final product is test instrument to measure the students' physics problem-solving skills of the Senior High School. The problem-solving aspects measured contained of understanding the problem, organizing the knowledge, carrying out the plan, and evaluating the solution. This research used a modified Oriondo & Dallo-Antonio Development model that comprised of (1) planning test, (2) trying out the test, (3) determining the validity, and (4) determining the reliability. This research was done in the Senior High School in Sleman regency. The result of this research showed that there were two packages of test of which each package consisted of 12 questions included 4 anchor questions. The test was an essay test which the scoring used PCM model based on the five categories of Polytomous data. The item analysis of the test was done first to prove the assumptions that became the basic theory of item response that were one dimensional, local independence, and invariance parameter. The quality of developed test item is good category which the range of mean square score is 0.96 – 1.08 and the difficulty level is -0.7 to 0.41. Based on the information score function and SEM, the developed instrument was good to be implemented for the test participant with the medium ability.

Key words: Developing test, essay test, physics problem-solving skills, Partial Credit Model

INTRODUCTION

The problem-solving skill is one of the skills in 21st century relates to the physics subject (Walsh et al., 2007; Wagner, 2008). Many researches are finished to increase the students' problem-solving skill especially for physics subject (Gok & Silay, 2008; Troyer, 2011; Sujarwanto & Hidayat, 2014; Putri et al., 2019). Nevertheless, the majority only focuses on the using of one learning model, and there are few of them who concern with the assessment quality whereas the assessment quality as an important role to increase the education quality (Mardapi, 2017).

The assessment quality is only observed on the validity and reliability of instrument used occasionally. None the less the suitability between the test form and the assessment purposes also has important role towards the quality of assessment result (Miller, Linn, & Gronlund, 2009). Nowadays, the measurement of problem-solving skill is done by using multiple choices test mostly (Nadapdap & Istiyono, 2017; Sirait et al., 2017) while this type of test has the shortcoming that makes the students can expect the answer (Kubiszyn & Borich, 2013).

The measurement of problem-solving skill is influenced by guessing factor can make the measurement accuracy result become decrease. As a result, many students are able to answer physics questions correctly but do not know the physics concepts related to the questions. (Henderson, Heller, Heller, Kuo, & Yerushalmi, 2001). Besides, the multiple choice test does not consist of many information because it only raises the final answer of the students (Kastner & Stang, 2011). Therefore, another type of the test is needed by problem-solving skill in order to make the evaluator find out the students' quality while doing test (Moeen-uz-Zafar-Khan & Aljarallah,

2011). In this case, essay test became fit in to represent students' high level cognitive skill (Haladyna & Rodriguez, 2013).

Essay test is considered to measure the complex cognitive level of the students which they must be able to arrange, to interpret and unite the knowledge, and use information in solving new problem, or to be original and innovative in problem solving (Kubiszyn & Borich, 2013). The essay test is used for students tends to push them to activate high order thinking skill in answering the question. (Baig, Ali, Ali, & Huda, 2014). Hence, the essay test is suitable to measure the students' problem-solving skill.

Essay test (Polytomus scoring) can be used to analyze one ability with Partial Credit Model (PCM) (Retnawati, 2014). PCM is one of the item response models theory to analyze the test item that needs several steps to complete it**.** (Istiyono, Mardapi, & Suparno, 2014). PCM has the assumption that each steps of difficulty level does not have to be sequential and has the similar difficulty level in each step because one step can be more difficult than other steps. (Hambleton, Swaminathan, & Rogers, 1991). The category of scoring in PCM represents several steps done to answer the item of test correctly. Someone who has score in high category means that he/she has the ability that is higher than one with low category of scoring (Retnawati, 2014).

Woolfolk (2016) defines problem-solving as an activity to formulate the new answer from facts or rules learned previously to achieve the goal. Meanwhile, Anderson (2009) emphasizes that it needs several thinking skills such as analyzing, interpreting, reasoning, predicting, evaluating and reflecting to solve the problem. Therefore, the using of memory is not adequate to solve the problem since people must be able to find the correct action based on the situation faced (Esen & Belgin, 2017).

The activities of problem-solving is the series of process that consist of several steps. The steps can be consisted of different steps but basically cover same steps such as deciding the problem, analyzing, and finding out and implementing the solution (Memduhoglu & Keles, 2016). According to Polya (1971), the activities of problem-solving contain of understanding the problem, making plan, doing the plan of settlement, and reviewing the settlement. Physics has a close relationship with mathematics, but using mathematics only in physics can block students from learning other key parts of how to solving physics problem (Redish, 2005). So, teachers need to help students to construct knowledge into understanding. In the other opinion, Docktor (2009) mentions five steps in solving the problem of physics such as the useful descriptions, the approaches of physics, the specific applications of physics, the appropriate mathematics, and the logical progression.

This research is aimed to develop the instrument of test in form of essay test to measure the students' problem-solving skill toward the physics subject.

METHOD

This study was a developmental research. The final product of the research was instrument to measure the problem-solving skill in the physics subject for the eleventh-grade students of science major in Senior high school. This developmental research used a modified by Oriondo & Dallo-Antonio model (1998) that covers four stages, those are (1) planning test, (2) trying out the test, (3) determining the validity, and (4) determining the reliability.

Planning test

Planning test means as deciding the objectives of the test, deciding the test materials, deciding the form of test, writing the test grid, writing the item of the test, arranging the scoring guideline, validating the test item, and revising the test item.

The objective of the test was to measure the students' problem-solving skills in physics. The test topics discussed were rotational dynamics, elasticity, static fluid, dynamic fluid, and heat and temperature that displayed in an essay test. The test was equipped with the grid that presented in tables and contains some information such as

materials, indicators problem-solving skills, and indicators item. İn this research, scoring guidelines was using the analytical rubric scoring.

Content validation was carried out by experts using Aiken formula. Instrument validation activities included a review of the grid, items and scoring rubrics. The results of expert judgment were used to make improvements based on expert advice. The item was valid if the coefficient validity is more than 0.8 (Retnawati, 2016).

Trying out the test

The try out test was done in three Senior High School with same level placed in Sleman regency on March to April, 2019. The sample was 256 students. The sample number in the try out was based on Bond & Fox (2007) that stated the number of sample in analysis using IRT was started from 30 to 300 participants. Meanwhile according to Hariadi (2007), a minimum sample of 250 people ~~is~~ was needed to get the results of a stable estimated difficulty from the test items with scoring 5 categories.

Determining the validity

The data of the try out results were applied to prove the assumptions that underlies the item response theory that were one-dimensional, local independence, and parameter invariance. After the assumptions was completed, then the analysis of item to find out the quality and parameter of item can be finished. The item of test has good quality if the range of mean square is 0.77 to 1.30 (Adam & Khoo, 1996) and the range of difficulty level was -2 to 2 (Hambleton & Swaminathan, 1985).

Determining the reliability

In this study, reliability was illustrated by graphs of information functions and standard error of measurement (SEM) based on the results of item analysis using the item response theory.

RESULTS AND DISCUSSION

Development Result

The planning step in this research got the result of instrument to measure the students' problem-solving skills in physics. The instrument consisted of two packages of essay test in which each package consisted of 12 items. From 12 items, there are four items of anchor become equating between Package A and Package B. The topic tested in the instrument is the topic of the eleventh grade at first semester such as rotational dynamics, elasticity, static fluid, dynamic fluid, and temperature and heat.

In this research, the researcher concluded that the four steps must be done to solve the problem. First, the problem was understood by them**.** On solving the problem, there were not enough to equip the information, but test takers had to be able to choose the meaningful information needed in the problem-solving activities (Argelagós & Pifarré, 2012). The activities resolved in this step were understanding what was needed to solve the problem and understanding what became the main problem.

Second step was organizing the knowledge. The problem of physics can be finished by several principles or physics' concepts occasionally. This condition could make the problem solver confused to find out the correct physics' concept. So that, they needed to have an ability to sense and discover the most correct approach used based on the context of the problems (Mason & Singh, 2016). This step involved of looking for the correct approaches of physics, making the similarities of mathematics, making the sketch from the problems, and choosing the correct concepts of physics.

Third step was implementing the solution related to the students' skills while doing the mathematics' operation (Docktor, 2009). The examples of this step are doing the multiplication, division, simplification, substitution, and others. The fourth step was evaluating the solution that covered of reconsideration, checking the answer, finding out the argumentation and conclusion from the process of solving problem done. Evaluating the solution is very important to be done to make sure that the solution found has the strong argumentation (Polya, 1971). The matrix of developing instrument and the example of item test can be seen in Table 1 and Figure 1.

Table 1. The matrix of developing instrument

Problem solving aspects	Physics material				
	rotational dynamics	elasticity	static fluid	dynamic fluid	temperature and heat
Understanding the problem	1A, 1B	5*	9A, 9B		
Organizing the knowledge	21, 2B			10*	6A, 6B
Carrying out the plans	3*			11A, 11B	7A, 7B
Evaluating the solutions		4A, 4B	12A, 12B		8*

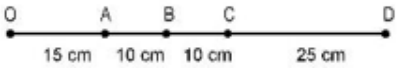
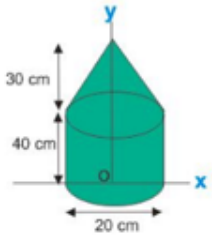
Problem solving aspects	Indicator	Topics	Item test
Understanding the problem	Classify the quantities needed and not needed in calculating stress	Stress	A wire with an initial length is 1 meter and a cross-sectional area of 2 mm2 is being pulled by a force of 60 N so that its length increases by 1 cm. Based on this information, classify which quantities are used and which are not used to calculate the amount of stress
Organizing the knowledge	Create a mathematical equation relating to the moment of inertia based on known situations	moment of inertia	Four particles A, B, C, and D each with a mass of 100 grams, 200 grams, 300 grams, and 400 grams are arranged as shown below  Construct a mathematical equation to calculate the moment of inertia for each particle based on the above system when the center of rotation is at the end of the rod
Carrying out the plans	Analyze the center of gravity of the combination of several objects	Center of gravity	The following figure shows a solid cylinder with a diameter is 20 cm and a height is 40 cm. The top is stacked with a solid cone whose diameter is equal to the diameter of the tube and 30 cm high. Determine the coordinates of the center of gravity of the object! 
Evaluating the solutions	Evaluate the question statement regarding the change in spring length	Hooke's Law	Dina was asked by her teacher to arrange three springs which have the same spring constant as a pendulum with a mass of 24 grams. If the teacher wants the arrangement of springs to be made is a mixed spring arrangement, then state the possible arrangement of springs and what is the arrangement of springs that must be made by Dina to produce the smallest length change? Give the reason

Figure 1. The example of item test

The instrument was validated by four physics experts and measurement experts to fill up the experts validity (experts judgement). Based on Aiken analysis, the range of Aiken index 0.92 to 1. The result of content validation can be shown in Table 2.

Table 2. The result of content validation

Aiken index	Item
0.92	3, 4A, 5, 7A, 12A, 4B, 7B, 12B
1	1A, 2A, 6A, 8, 9A, 10, 11A, 1B, 2B, 6B, 9B, 11B

Based on Table 2, all items have good content validity. After revising the suggestions item of the experts, the instrument was stated to be appropriate to the students' try out. The trials were carried out to prove the assumptions of item response theory that also functioned as empiric validity (Bashooir & Supahar, 2018).

The Result of Try Out

The developed instrument is analyzed by the polytomous item response theory. In this theory, there were some assumption needed to be completed previously to know the item parameter.

The assumption of unidimensional

This assumption is proved through the exploratory factor analysis. The result of exploratory factor analysis can be shown in Table 3.

Table 3. The result of KMO and Bartlett Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.983
Bartlett's Test of Sphericity	Approx. Chi-Square	11305.523
	Df	190
	Sig.	.000

Table 3 shows that the value of KMO > 0.5. It means that the sample size used fulfil the requirement, hence the analysis factor can be continued (Hair, Black, Babin, & Anderson, 2009). The total variance explained through the instrument of test can be shown in Table 4.

Table 4. Eigen value toward the physics problem-solving skill test

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	15.20	76.00	76.00
2	1.45	07.24	83.23
3	.92	04.57	87.81
4	.87	04.35	92.15

Table 4 shows that the instrument contains two factors which one factor is dominant. The total variance that can be declared by the instrument of the test is 82.23%. The result of factor analysis is presented into scree plot in Figure 2.

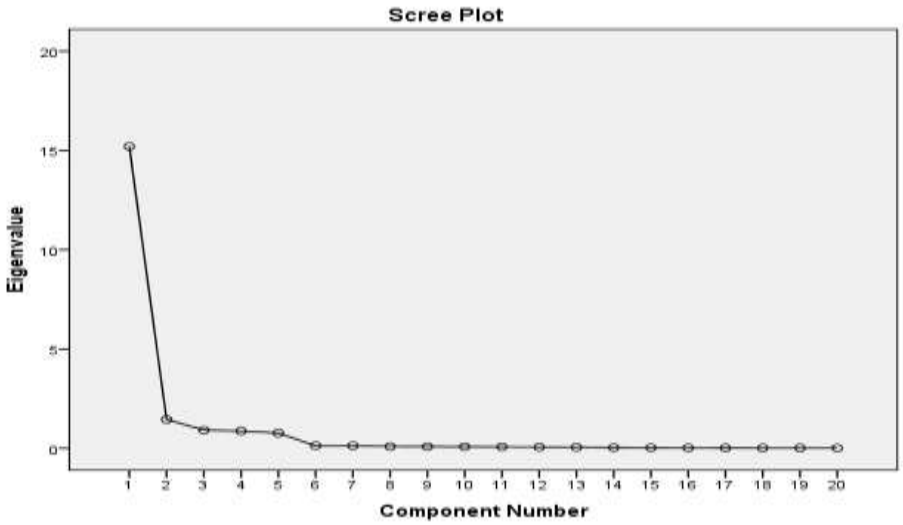


Figure 2. Scree plot factor analysis

Figure 2 shows the scree plot of package A and B of the instrument. Based on Figure 2, it can be cleared that the graphic gets the sharp decreasing from the first factor to second factor then it is sloping, so scree plot formed almost makes the right angle. It shows that the developed instrument of the test only contains one dominant dimension, so the assumption of one-dimensional is fulfilled (DeMars, 2010).

The assumption of local independence

The second assumption is local independence that is proved by making the ~~of~~ covariance matrix of the ability between groups. This assumption can be proved when the covariance value of the ability between the participants is closes to 0. The result of covariance can be shown in Table 5.

Table 5. The matrix of covariance toward the physics problem-solving skill

No	Group 1	Group 2	Group 3	Group 4
Group 1	0.00439			
Group 2	0.00118	0.00287		
Group 3	-0.00014	-0.00001	0.00087	
Group 4	0.00031	0.00065	0.00064	0.00427

Based on Table 5, it can be clarified that covariance value placed in the diagonal table is closes to zero. So that, the assumption of local independence in the instrument is fulfilled. This is related with the statement of DeMars (2010) that the assumption of local independence automatically will be fulfilled when the assumption of unidimensional is fulfilled.

The assumption of parameter invariance

Assumption of parameter invariance is proved by dividing the subjects or items into two groups then make scatter plot and line with the slope 1. This assumption consists of two things that are the item parameter invariance and the ability parameter invariance. The result of item parameter invariance can be seen in Figure 3.

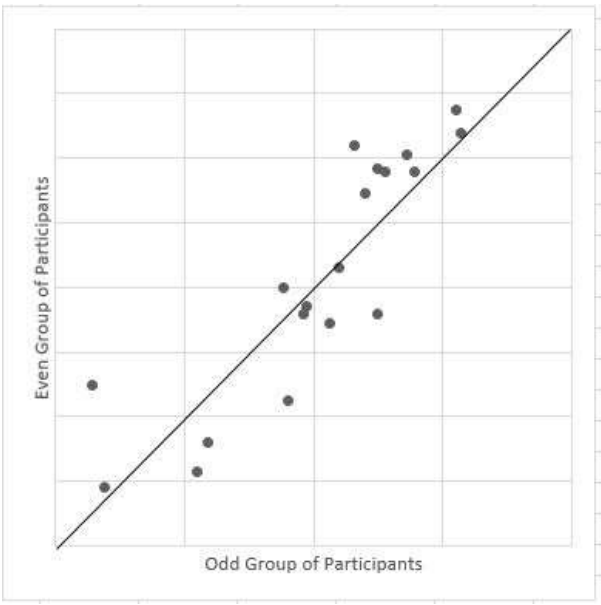


Figure 3. Item parameter invariance

Based on Figure 3, the data distribution closes the line that the slope level is 1, so the assumption of item parameter invariance is fulfilled. Thus, the proof result of ability parameter invariance can be seen in Figure 4.

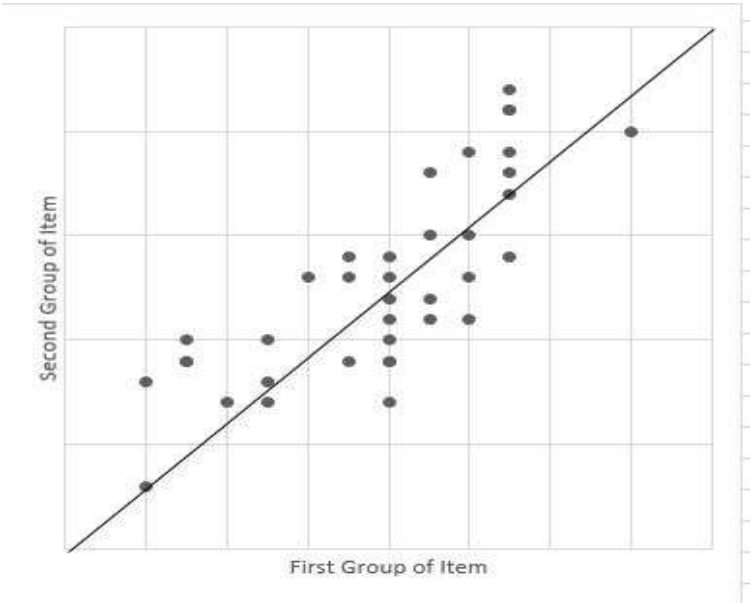


Figure 4. Ability parameter invariance

Based on Figure 4, the data distribution closes the line that the slope level is 1, so the assumption of ability parameter invariance is fulfilled.

Item Fit

An item of test is called suitable with model when it has INFIT MNSQ value from 0.77 to 1.30 (Adam & Khoo, 1996). Based on the analysis, it gets the item fit in Table 6.

Table 6. Item fit

Item	INFIT MNSQ	Item	INFIT MNSQ
Item 1 (1A)	1.02	Item 11 (8)	1.05
Item 2 (2A)	1.04	Item 12 (10)	1.06
Item 3 (4A)	1.07	Item 13 (1B)	0.98
Item 4 (6A)	1.03	Item 14 (2B)	0.98
Item 5 (7A)	0.97	Item 15 (4B)	1.03
Item 6 (9A)	0.99	Item 16 (6B)	0.99
Item 7 (11A)	0.97	Item 17 (7B)	0.97
Item 8 (12A)	0.97	Item 18 (9B)	0.97
Item 9 (3)	1.03	Item 19 (11B)	1.01
Item 10 (5)	1.02	Item 20 (12B)	1.01

Table 6 shows the gotten value of infit mean square from each item of the test. Based on Table 6 the item test has value of infit mean square from 0.97 to 1.07, so all items of test are suitable with the Partial Credit Model.

Item Parameter

Based on Table 6, the item is suitable with Partial Credit Model (PCM). In PCM, it has assumption about the discriminant value in each item is similar whereas the difficulty index in each step does not have to in order and similar. The estimation result of item parameter from the try out can be seen in Table 7.

Table 7. Item parameter estimation

Item	Difficulty	Item	Difficulty
1 (1A)	-0.51	11 (8)	-0.13
2 (2A)	-0.26	12 (10)	0.47
3 (4A)	0.41	13 (1B)	-0.85
4 (6A)	0.34	14 (2B)	-0.29
5 (7A)	-0.33	15 (4B)	0.4
6 (9A)	-0.05	16 (6B)	0.29
7 (11A)	0.39	17 (7B)	-0.34
8 (12A)	0.29	18 (9B)	-0.08
9 (3)	-0.06	19 (11B)	0.35
10 (5)	-0.38	20 (12B)	0.33

Based on Table 7, the parameter of difficulty from all items in the instrument of the test is in range -0.85 to 0.47. The parameter fulfil good criteria based in Hambleton & Swaminathan (1985) because the difficulty index of the item is still in range $-2 < b < 2$.

There are four items of anchor that become equating between Package A and Package B, namely item 3, 5, 8 and 10. Each anchor items were distributed to each aspect of physics problem-solving.

The comparison of the parameter of the difficulty level in each item of the test between test package A and package B can be seen in Figure 5. Figure 5 shows that the comparison toward the difficulty index in package A and package B. Mostly the difficulty index between both packages are relatively similar. The equality of item difficulty

between both packages can also be proven by statistics in Table 8. The item of the test that shows the big difference of difficulty index can be seen in item 1.

Figure 5. The comparison of item difficulty in package A and package B

Table 8. The t-test of item difficulty

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Item difficulty	Equal variances assumed	.39	14	.70	.09	.24	-.42	.60
	Equal variances not assumed	.39	13.28	.70	.09	.24	-.42	.60

Information Function and SEM

The information function explains about the reliability of the item in the test. An item can be stated as good item when the value of its information function was higher than the value of its standard measurement error (SEM). Based on the analysis, it gets the value of information function and SEM from the instrument of test that can be seen in Figure 6.

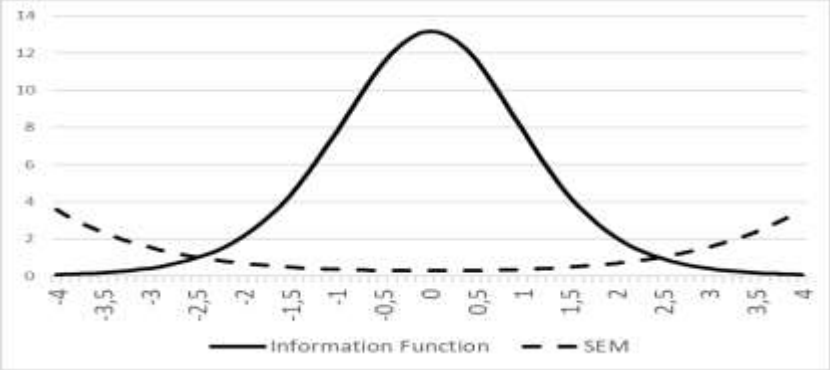


Figure 6. The information function of the test

Based on Figure 6, it shows that value from the information function is higher than the value from SEM in range -2.4 to 2.4 of the ability. Therefore, the developed instrument of test is suitable if it is implemented to measure the problem-solving skill of the students in range -2.4 to 2.4 of ability level. It means that the instrument is suitable for students with medium ability.

CONCLUSION

The developed test consists of two packages include 12 questions with 4 anchor items. The instrument is an essay test with the scoring which is using partial credit model based on the five categories in the polytomous data. All developed items have good category. Based on the information function and SEM, the developed instrument is suitable to be used for the test participant with the medium ability.

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