Analysis of physics questions based on HOTS criteria: the result of physics teacher training

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Abstract. In the 21st century, higher-order thinking skills (HOTS) is a must-have for everyone. Teachers should train HOTS in learning physics. In the assessment of physics learning, every teacher must make a measuring instrument to measure the student's ability in the form of physics questions. HOTS-based physics questions are needed to measure the student's HOTS ability. Therefore, training was conducted for physics teachers in Mojokerto in August 2019 to make HOTS-based physics questions. This study aimed to analyze physics questions produced by the training participants based on HOTS-based question criteria. The method of this study used qualitative descriptive analysis. Physics questions from the results of physics teacher training analyzed one by one based on the HOTS criteria. The results show that most of the items produced had not presented contextual stimulation so that students had started to think at a higher level when reading the question stem given. Most of the problems are numerical solutions. It does not rule out that HOTS questions do not require numerical calculation but rather reasoning based on the physics concept that has been studied by students.

1. Introduction
Assessments for learning outcomes are vital tools for governments to evaluate their education systems' effectiveness, guide education quality reforms, and compare local youth's achievements to those other countries. Chamisah investigates the influenced of the assessment to the education improvement [1]. In the 21st century, higher-order thinking skills (HOTS) is a must-have for everyone. Teachers should train HOTS in learning physics. In the assessment of physics learning, every teacher must make a measuring instrument to measure students' abilities in the form of physics questions.

Based on the results of an international study, the Program for International Student Assessment (PISA) shows that in general, the ability of Indonesian students is deficient in understanding complex information, theory, analysis, and problem solving, use of tools procedures and problem-solving, and conducting investigations [2]. HOTS has been poorly trained and accommodated by the teacher during learning, which affects all aspects of knowledge [3]. Based on the facts, it is necessary to change the learning assessment system into the HOTS-based review.

HOTS questions' characteristics include measuring HOTS, based on contextual problems, and various forms of items [4-5]. HOTS problems aim to hone the skills of students in carrying out higher-order thinking processes [6]. The dimension of the thought process in Bloom's Taxonomy as refined by Anderson and Krathwohl consists of the ability to remembering, understanding, applying, analyzing, evaluating, and creating [7]. HOTS questions generally measure the knowledge in the realm of analyzing, evaluating, and making [6,8], and the rest is lower-order thinking skills (LOTS) [9].
The Indonesian national exam (UN) tends to assess students' knowledge at the remember level until applying. It is very different from TIMSS and PISA, which is typical for conducting assessments at a higher level of thinking. Figure 1 compares the cognitive processes of UN, TIMSS and PISA questions analyzed by Wasis et al. [10]. HOTS assessment of UN questions is only at the level of analysis.

![Figure 1. The comparison of cognitive processes on UN, TIMSS, and PISA of science items [10].](image)

Based on these facts, it is necessary to conduct training and self-development for science teachers to conduct HOTS-based learning and assessment. Skills related to higher-order thinking have been poorly trained and accommodated during education, affecting all aspects of knowledge [11]. Components that support HOTS would not develop automatic unless they are well-designed and planned by the instructors [12]. The HOTS-based physics question training held in Mojokerto through training and mentoring strategy. The preparation of these questions then analyzed based on the HOTS criteria submitted to the training participants. This paper aims to investigate the training product in the form of physics questions that have been prepared by the training participants based on HOTS assessment criteria.

2. Method
It is descriptive qualitative research to analyze physics teachers' training in Mojokerto to compile the HOTS-based physics questions. The practice of making the HOTS-based physics questions already implemented in August 2019. The result of that training analyzed based on the HOTS-based assessment criteria. The instrument for HOTS-based assessment criteria is: divergent, involving a variety of thinking skills, using multiple representations to present data/information, and using real-life context stimuli. The analysis also based on the revised Bloom's taxonomy for HOTS level, analysis, evaluation, and creation [6,8]. In the previous study, about 80% of the 50% of participants have compiled HOTS-based physics questions—the analysis based on the participants' data based on their opinion. To find out more, the researcher studied the HOTS-based question analysis developed by the training participants. Thus, it can see in more detail the extent to which the training participants understand HOTS-based questions' characteristics.

3. Result and Discussion
The result of training the making of HOTS-based physics questions analyzed based on the HOTS criteria. Analyzed based on the cognitive process to solve the problems on the items. Cognitive processes reflect high-level thinking when they are independent, have social origins, and are
accessible to their self-awareness [13]. So, it recommends using real-life stimuli in compiling HOTS-based physics questions.

HOTS-based physics assessment analyzed based on the criteria of divergent and involving a variety of thinking skills. HOTS have several aspects: conceptual understanding, systematic thinking, problem-solving, and critical thinking [14]. So, the cognitive process of physics questions based on HOTS applies the knowledge to the contextual problems and uses the physics knowledge to analyze or evaluate the contextual issues with various thinking skills.

The physics teachers have developed several physics questions in Mojokerto after the training of making HOTS-based physics questions. Let us analyze these problems.

**Problems 1**

![The Doppler Effect Phenomena](image)

An ambulance in the city of Garut moves in the middle of heavy traffic at a speed of 60 m/s past motorists who stop at a red light. The ambulance sounds a siren with a frequency of 800 Hz, which the more extended the sound heard, the weaker the motorbike gets. This effect describes the difference between wavelength and frequency. The listener's relative motion or sound source gives the impact of the sound listened by the listener. Thus when the basis of the sound moves away from the listener, its wavelength increases.

Question 1: The phenomenon of the Doppler effect in sound waves

Based on the above discourse, circle 'True' or 'False' for each of the following statements!

| Selection | Question |
|-----------|----------|
| If the motorbike moves in the opposite direction to the ambulance, then the frequency that the person hears increases. | True/False |
| When the ambulance leaves the motorbike, the motorbike's sound decreases because the wavelength is decreasing. | True/False |
| While still at the red light, the wind suddenly moved in the direction of the ambulance at a certain speed. Then the siren frequency that the motorist hears decreases. | True/False |

**Question 2: Phenomena of the Doppler Effect in Sound Waves**

After the light turned green, motorists immediately chased the ambulance with a speed of 10 m/s and the speed of sound waves in the air at that time was 340 m/s.

a. Has the person heard less? Prove your answer through a mathematical equation.

b. What is the frequency of the sound heard by the person?

**Question 3: Phenomena of the Doppler Effect in Sound Waves**

If the frequency of the fs ambulance siren and the siren frequency heard by the motorist is fp, and if between the ambulance and motorbike there is a barrier that reflects sound so that the person also hears the reflected sound of fd, then the following provisions are correct:

A. \( f_p > f_s; \quad f_p > f_d \)
B. \( f_p < f_s; \quad f_p < f_d \)
C. \( f_d = f_s > f_p \)
D. \( f_s = f_d < f_p \)
E. \( f_d > f_p > f_s \)

Three questions are using the contextual problems of sound and siren. Attempts have made to present a representation in this matter. The first question is a HOTS question because it requires thinking through analyzing to evaluating to answer true or false statements on the table. This question used the cognitive function of evaluation (C-5) and the concept of knowledge dimension. The second question looks like analyzing, but actually, the thought process used to answer the question is applying (C-3) knowledge of the Doppler effect to the situation given to the problem. The teacher that
compiler this question assumes that it is a matter of C-4. It is because the teacher thinks that HOTS are complicated, but they are not. HOTS use the though process of analyzing, evaluating, or creating in answering questions [6,8]. The third question is HOTS-based physics question. We use our reason to evaluate (C-5) and conceptual knowledge dimension to answer it.

**Problem 2**
A student measures the thickness of two iron plates, (1) and (2) using a calliper. The scale of the measurement results described as follows:

![Measurement Scale](image)

From these two measurements, it can conclude that

A. iron plate (1) is 0.3 mm thicker than the iron plate (2)
B. iron plate (1) is 0.3 mm thinner than the iron plate (2)
C. iron plate (1) is 0.7 mm thicker than the iron plate (2)
D. iron plate (1) is 0.7 mm thinner than steel plate (2)
E. iron plate (1) is 1.7 mm more delicate than the iron plate (2)

According to the teacher who compiled this question, this question is included in the HOTS question because there is a process of comparing the two measurement results and analyzing which iron plate is thicker or thinner. Solving this problem contains a level of thinking in the realm of analysis (C-4), but it is not convergent, does not use multiple representations because of only image representations. Besides, the questions did not use contextual stimulation. The phenomenon presented is abstract. Iron plate measurements do not know what order it was carried out and for what purpose. So the HOTS criteria that fulfilled are only based on the thought process using Bloom's taxonomy only.

**Problem 3**
Amir and Budi travelled from city A with the aim of City D through cities B and C as in the following figure:

![Travel Routes](image)

From Amir and Budi's travel incident, compare the distance and displacement of the two people!

This problem is a question of application in two conditions. There is no analyzing process in solving the issues of this problem. However, the compilers considered the HOTS question because there was a process of comparing the two people’s distance and displacement. At the level of thinking analyzing; there is a process of breaking material or concept into parts, determining how they relate to one another or how they relate to the overall structure or purpose [7]. The activity of comparing distance and displacement in solving this problem is not included in the realm of analysis, but only at the level of understanding the concept of” distance" and" displacement" (C-2). Thus, this question is not a HOTS question type.
Problem 4
In everyday life, there are many uses of nuts and bolts. The use of nuts and bolts often encountered difficulties when removing or installing them, as in the picture below.

When the bolt has installed for a long time, it will be difficult to remove, while when installing it there can be difficulty tightening it. Various models and sizes of tools called wrenches designed to facilitate the work. One example of fastening a vehicle bolt, a mechanic in a workshop uses a key shown in the picture. The easiest way to tighten these bolts is

A. hands press down on position O.
B. hands pull up to position O.
C. hands press down on the P position
D. hands pull up in the Q position.
E. hands push down in the Q position.

The problem presented in this question comes from the context of everyday life. Thus, HOTS criteria in terms of contextual stimuli have met. The phenomenon explained using verbal representations and image representations, meaning that the multi-representation aspect fulfilled. This multi representation can help students understand the concepts needed to solve the problem [17]. Based on Bloom's taxonomy, the thought process required to answer these questions reaches the evaluation level (C-5). There is only one correct answer in this problem because it is a multiple-choice question, so it does not meet the divergent criteria. The reasoning process used in answering this question involves several thinking skills, analytical skills, mathematical skills, and problem-solving skills. Thus, this question belongs to the HOTS question type.

Problem 5
The coordinates of the ABCDEO centre of gravity in the following figure are ...

A. ( 9/8; 17/4 )
B. ( 9/7; 17/9 )
C. ( 9/5; 17/9 )
D. ( 9/5; 17/7 )
E. ( 9/4; 17/8 )

Based on the report on the results of training and assistance in preparing HOTS-based physics questions, this question's compilers stated that it was the C-4 thinking level (analyzing). If we examine further, this problem is not in a situation that requires a level of analytical thinking in solving. It is necessary to apply the concept and equation of gravity of objects. The idea that has understood is applied based on the data provided by the graph in the questions. So, this problem belongs to the type of concern at the C-3 thinking level (applying). Most of the training participants were still unable to distinguish between HOTS questions and challenging questions. There were always those who thought that HOTS questions were difficult in the process of working on them. Determining the level of thinking based on Bloom's taxonomy has nothing to do with the difficulty level of the question. We are just adjusting the thought process to what thinking level is related to Bloom's taxonomy.

Problem 6
A rocket contains a tank containing liquid hydrogen fuel and liquid oxygen. During the combustion process, hot gas shot down through the
nozzle located at the tail; the rocket body moves up. The final velocity of a rocket depends on the hot gas burst's speed and the amount of fuel it is carrying.

In moving, the rocket emits 100 kg of exhaust gas every second with every exhaust gas that the rocket will get the upward thrust. At the same time, the exhaust gas has a speed of 200 m.s\(^{-1}\). The thrust on the rocket is

A. 1.8 x 10^2 N
B. 2.0 x 10^2 N
C. 1.8 x 10^3 N
D. 2.0 x 10^4 N
E. 3.6 x 10^4 N

The compiler of this problem reported that this item was a C-4 (analysis) problem. This report needs to confirm that this matter is a matter of C-3 thinking (application) only. There is no analysis process in solving this sixth problem. There are two kinds of representation used, namely image representation and verbal representation. Only one thinking skill is used, namely applying Newton's second law concept in solving the rocket problem provided in the issue. At the C-3 thinking level (implementing), the process occurs or uses procedures through implementation or direction [7].

Problem 7
An ideal gas is in a closed vessel with pressure \( P \), volume \( V \) and temperature \( T \). If one day the temperature is changed to \( 2T \), and the volume becomes \( 3V \), then the ratio of initial pressure (\( P_1 \)) to absolute pressure (\( P_2 \)) after \( V \) and \( T \) are changed is ...

A. 1:2
B. 1:3
C. 2:3
D. 3:2
E. 3:4

This question is not a HOTS-based physics question; why? Because the level of thinking used in answering this question is C-3 (applying). There is no multi-representation; there is only one representation, namely verbal representation. Problem is convergent.

Problem 8
Water flows from P to Q in a pipe-shaped like the one in the image below. The water flow velocity in each section is \( v_A \), \( v_B \), and \( v_C \), and the water column height in pipes A, B, and C is \( h_A \), \( h_B \), and \( h_C \). Based on Bernoulli's principle, it can conclude

A. speed \( v_A > v_B > v_C \) and pressure \( p_A > p_B > p_C \)
B. velocity \( v_A > v_B > v_C \) and pressure \( p_A < p_B < p_C \)
C. velocity \( v_A < v_B < v_C \) and pressure \( p_A = p_B = p_C \)
D. velocity \( v_A < v_B < v_C \) and pressure \( p_A < p_B < p_C \)
E. speed \( v_A < v_B < v_C \) and pressure \( p_A > p_B > p_C \)

This problem uses multiple representations, namely verbal representations and image representations. The question does not use stimulation in the context of real-life because the phenomenon is abstract. The thought process in answering this problem is understanding (C-2) by concluding based on the situation's image representation. Thus, it can be supposed that this question is not a HOTS problem. The compilers of this question consider that this problem belongs to the realm of analytical thinking (C-4), even though there is no process of analyzing variables in solving this problem. However, this question becomes difficult if students do not understand the concepts of
quantities or variables in the Bernoulli equation. The teacher's perception that HOTS questions are difficult questions is still an obstacle in understanding physics teachers. HOTS questions are questions that use the level of thinking to analyze, evaluate, or create. HOTS-based questions are not always difficult. Difficult questions are not necessarily HOTS-based questions.

**Problem 9**
Check out the image below!

The graph on the side shows the relationship between the force (F) to the length increase (DL) of the three springs P, Q, and R...

A. spring P has the smallest spring constant
B. spring Q has the smallest spring constant
C. spring R has the smallest spring constant
D. springs P, Q, and R have the same spring constant
E. spring Q has a spring constant smaller than spring R

The question stem is also unclear. There are two kinds of representations, namely graphic and verbal. It used evaluation thinking process (C-5), so it categorized as a HOTS question, but it is still simple, it does not provide stimulation to use some types of thinking skills.

**Problem 10**
A mass load of 20 kg placed at a distance of 1.5 m from foot B (seen in the picture) on a flat table with a mass of 100 kg, which is 6 m long. The force acting on leg A to support the load and the table is

It takes several stages of applying the concepts to the motion system that use Newton's second law to solve this problem. However, that does not mean that they included in the HOTS-based physics group. The physics teacher who compiled this problem stated that this question was one of the items that required a level of analyzing thinking (C-4). If we examine it further, this question falls into the realm of thought of level C-3 (applying). The representations used are verbal representations and image representations. Thus, it can conclude that this question includes open HOTS questions. So it should note that difficult questions do not mean HOTS questions, and neither does it.

**Problem 11**
A lump of ice floating in the sea looks like the picture.

If the seawater density is 1.2 gram/cm³ and a lump of ice is 0.9 gram/cm³, then the volume of a lump of ice immersed (entering) in seawater is equal to the volume that appears.

The compilers of this problem stated that this problem includes in the C-4 category problem. This understanding is not quite right. If we examine more deeply, floating ice is a problem that requires reason (mindset) to apply (C-3) Archimedes' principles. There is no process of analyzing and linking
physical quantities in this case study. Thus, this question is declared not included in HOTS-based items; this question has in the application level (C-3).

**Problem 12**
A tube filled in with a liquid (ideal fluid). There are two small holes (much smaller than the line's cross-section) so that the liquid emits out (as shown in the picture).

![Diagram of a tube with two small holes](image)

The ratio between \( x_1 \) and \( x_2 \) is

\[
\frac{x_1}{x_2}
\]

The solution to this problem uses the equation's gradual application to find the ratio between \( x_1 \) and \( x_2 \). There is no analyzing process between one quantity and another in this problem, according to the physics teacher who collected reports on the results of the preparation of HOTS-based physics questions with cognitive level C-4. This understanding is wrong. The items presented included in the C-3 level of thinking.

The analysis of each question generated by the training participants in making HOTS-based knowledge assessment instruments recapitulates with information (Table 1). Table 1 provides information on the study/question analysis results based on HOTS-based item preparation criteria.

| Problems | Bloom's taxonomy | Divergent | Involve a variety of thinking skills | Use multiple representations | Use real-life stimuli | HOTS-based physics questions? |
|----------|------------------|-----------|--------------------------------------|-----------------------------|----------------------|------------------------------|
| 1 (Q-1)  | C-5              | -         | √                                    | √                           | √                    | Yes                          |
| 1 (Q-2)  | C-3              | -         | -                                    | -                           | -                    | No                           |
| 1 (Q-3)  | C-5              | -         | √                                    | √                           | √                    | Yes                          |
| 2        | C-4              | -         | -                                    | -                           | -                    | Yes                          |
| 3        | C-3              | -         | -                                    | -                           | -                    | No                           |
| 4        | C-5              | -         | √                                    | √                           | √                    | Yes                          |
| 5        | C-3              | -         | -                                    | -                           | -                    | No                           |
| 6        | C-3              | -         | -                                    | -                           | -                    | No                           |
| 7        | C-3              | -         | -                                    | -                           | -                    | No                           |
| 8        | C-2              | -         | √                                    | √                           | -                    | No                           |
| 9        | C-5              | -         | √                                    | √                           | -                    | Yes                          |
| 10       | C-3              | -         | -                                    | -                           | -                    | No                           |
| 11       | C-3              | -         | -                                    | √                           | -                    | No                           |
| 12       | C-3              | -         | -                                    | √                           | -                    | No                           |

Based on Table 1, it knows that none of the questions developed met the divergent criteria. Most of the items created are in the form of multiple-choice so that they are convergent. Most of the questions generated could not provide contextual stimulation. Problems tend to be simple and do not involve some type of thinking skill in solving the problem. Most physics teachers who compiled HOTS-based physics questions had a misunderstanding about difficult questions vs HOTS questions.
Many items in the C-3 domain consider as questions in the C-4 part because the application of equations or concepts carried out in several stages. Most of the questions produced had not presented contextual stimulation so that students had started to think at a higher level when reading the question stem given. Most of the problems are numerical solutions. It does not rule out that HOTS questions do not require numerical calculation, but instead, reasoning based on the physics concept studied.

It recommended using multiple representations in compiling HOTS questions. Students can explain their reasoning very well when they can interpret visual representation [15]. Various terms used to measure the extent of a person's ability. One of the functions of multi-representation is to build a deeper understanding of the concept [16]. Beside it, using HOTS in learning also affects the improvement of students' thinking skills. Kumaz and Azlan found that using various teaching-learning models has a good impact on the students' concept mastery [17]. If students' have a good concept mastery, it will be easy to think in a higher level of thinking. Physics teachers also need to understand that physics teachers prepare students to test HOTS through learning that trains HOTS.

In the last few years, we know that learning in schools refers to the National Examination passing standard, held at the end of each school level. It also impacts the learning process, which relates to questions and drilling which train the skills to apply concepts in problems that are sometimes abstract, not authentic. We also know that HOTS assessment of National Examination questions is only at the analysis level; most of the query used the understanding thinking level [10]. These facts show that it is a logical occurrence if the physics teacher does not really understand deeply about the concept and application of HOTS in the preparation of physics problems, because it is very likely that the physics teachers also do not adequately implement the learning that trains HOTS. It also happens in Malaysia, so Saido et al. found that HOTS has been poorly trained and accommodated by the teacher during teaching-learning [3].

So, we strongly agree with the Indonesian government's new policy to change the National Examination system into a National Competency Assessment, which refers to PISA. The assessment carried out nationally at the mid-school level is expected to contribute to changes in the learning process that can train HOTS and other 21st-century thinking skills. The assessment for learning paradigm application needs to be appreciated by all of us to improve Indonesia's national education system.

As the assessment for learning, this result can be used by the physics teachers as a basis for improving the learning process and assessment planning considering that some physics material in the national curriculum requires basic competence to analyze which is the baseline of HOTS. In addition to waiting for the national minimum competency assessment results and getting recommendations for improving the learning process nationally, physics teachers should start adapting to changes in systems and learning processes as demands in 21st-century learning. Instead, physics teachers begin to study and apply various learning models and strategies to practice HOTS and other 21st-century thinking skills.

Several researchers and education practitioners have developed learning instruments and assessments that refer to students' thinking skills. Its good thing needs doing on a broader scale, even by all education practitioners, to improve the learning process as a whole. Some of them developed a worksheet to enhance the students' competencies [18]. Others set the learning materials to enhance students mastery of learning [19] or scientific creativity [20]. Also, developed and used the various learning media and strategies to improve the students' thinking skills; such as pictorial analogy [21], Maple-based physics computation [22], science-edutainment interactive multimedia [23], Understanding by Design strategy to teach physics [24], flipped classroom [25], etc.

We can also use the learning models in physics learning to train and enhance the students' thinking skills. Such as inquiry learning [18,26], Problem-based Learning (PBL) [27-29], Project-based learning [29]. Also integrated the learning model with an approach or strategy, such as integration of scientific literacy approach on Case-Based Learning (CBL) model [30] or integration of Means-Ends-Analysis strategy on PBL [28]. All of the learning models must synchronize learning objectives, procedures, and evaluation and assessment.

Some researchers in education also developed and implemented the learning models to improve students' thinking skills. Like Local Wisdom Integrated Learning model [31], Group Science Learning Model [32], Creative Responsibility Based Teaching model [33], Collaborative Creativity Learning model [20], Collaborative Problem Based Physics Learning model [34], ORNE Learning model [35],
and so on. Physics teachers can implement those models to enhance the students’ HOTS, besides preparing the HOTS questions to measure students’ knowledge.

4. Conclusion

This study found that most physics teachers who compile the physics questions experienced misunderstanding about HOTS-based physics questions and difficult physics questions. Many items in the C-3 domain considered to queries in the C-4 part because they need several stages to apply the concepts or equations. Only 33.33% of questions produced that fulfilled the HOTS criteria. This finding is an introductory note for teachers and lecturers about how they can compile HOTS-based physics questions. Thus, it is necessary to make more efforts in the learning process at the university level on learning evaluation and increase physics teachers’ competence in learning evaluation.

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