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Research Article

Development of High Order Thinking Skill (HOTS) Oriented Cognitive Problems in Thermodynamics for Senior High Schools

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Abstract

One of cognitive abilities of students that should be trained and developed in the 21st century learning is high-level thinking skills. As higher order thinking skills are emerging trend in education, assessment instruments based on High Order Thinking Skills (HOTS) principles are required. This study aims to develop a high-level thinking ability instrument for Physics subject of senior high schools which is intended to measure HOTS of senior high school students for Thermodynamic Materials in City of Nganjuk in East Java. The study was conducted in three stages, including initial development, trials, and measurement. The initial development stage included compilation, review, and validation, including content validation by experts. There are two sets questions A and B, consisting 20 questions respectively, with anchor items as much as 5 items. The measurement results show that HOTS-oriented test kits of Thermodynamics have obtained empirical evidence are suitable with partial credit model. The difficulty level of the test battery is in the range of -2.0 to +2.0, with the most difficult aspects in the sequence are analyzing, evaluating, and creating. The reliability of HOTS-oriented tests has met the high categorical requirements, and based on the total information function of the tests, it is appropriately used to measure the HOTS of learners with capability -2.3 to +1.6. Based on students' responses, the analysis ability is the highest skills followed by the ability to evaluate and create. HOTS-oriented tests developed can be used as the reference for the teachers to accommodate student's higher order thinking skills.
Keywords*:* *cognitive problem, higher order thinking skills, HOTS, thermodynamics*

Pengembangan Soal Kognitif Berorientasi Keterampilan Berpikir Tingkat Tinggi Materi Termodinamika Pada Siswa Sekolah Menengah Atas

Abstrak

Salah satu kemampuan kognitif peserta didik yang perlu dilatihkan dan dikembangkan dalam pembelajaran abad 21 adalah kemampuan berpikir tingkat tinggi. Untuk mengetahui tingkat kemampuan berpikir tingkat tinggi, maka diperlukan instrument penilaian yang berorientasi HOTS. Penelitian ini bertujuan untuk mengembangkan instrumen fisika keterampilan berpikir tingkat tinggi pada siswa sekolah menengah atas dan mengukur keterampilan berpikir tingkat tinggi siswa pada materi termodinamika di Kabupaten Nganjuk. Penelitian dilaksanakan melalui tiga tahapan, meliputi pengembangan awal, uji coba, dan pengukuran. Pengembangan awal meliputi kompilasi, review, dan *validasi. Validasi performa yang digunakan adalah validasi konten oleh ahli. Terdapat dua paket soal yang dikembangkan, yaitu paket A dan B, masing-masing paket terdiri dari 20 soal, dengan butir anchor sebanyak 5 soal. Hasil pengukuran menunjukkan bahwa perangkat keterampilan berpikir tingkat tinggi termodinamika secara empiris fit dengan partial credit model. Tingkat kesulitas soal termodinamika di antara range -2,0 sampai +2,0. Tingkat kesulitan meningkat mulai dari aspek menganalisis, mengevaluasi, dan mencipta. reliabilitas soal memenuhi persyaratan, dan berdasarkan total fungsi informasi soal keterampilan berpikir tingkat tinggi termodinamika sesuai untuk mengukur siswa dengan kemampuan -2,3 hingga +1,6. Hasil kemampuan siswa untuk kemampuan menganalisis paling tinggi, kemudian diiukuti kemampuan mengevaluasi, dan mencipta. Soal tes HOTS termodinamika yang dikembangkan bisa dijadikan acuan ataupun referensi bagi guru di sekolah untuk mengukur HOTS siswa SMA.*

Kata Kunci: *soal kognitif, keterampilan berpikir tingkat tinggi, termodinamika*

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I. INTRODUCTION

Assessment in education becomes a process of collecting and processing various information from learners to measure their achievement of learning outcomes [1]. The process of collecting and processing of the information related with the achievement of learning outcomes of the students is obtained through measurement. The results of the assessment are accurate if it is carried out using appropriate instrument and procedures. In relation with the teaching of Physics, the assessment requires such method in accordance with the characteristics of the teaching materials; therefore, various assessment methods need to be developed.

Features of educational assessment are mainly divided into two, namely traditional assessment and performance appraisal [2]. Traditional assessment features include basic knowledge, knowledge processes, content knowledge, and problem-solving. On the other hand, performance appraisal features include basic knowledge, group learning, self-assessment, application of skills, creative design, authentic applications, creative products, and application of all the skills of learners.

Given the importance of Physics education in the development of science and technology, it requires learners to have Higher Order Thinking Skills (HOTS). Thus, assessment based on the principles of HOTS is therefore needed. Skills related to higher order thinking have been poorly trained and accommodated during learning, which in turn affect all aspects of knowledge [3]. Therefore, the implementation of physics learning must be in accordance with the learning of physics. It is useful for giving learners the opportunity to be actively involved when learning, science process skills and HOTS.

Higher order thinking skills are categorized into conscious access that becomes a logical precondition for controlling several thing that happen [4]. It is not possible to control several processes unless one is able to consciously think about the activities in this process [5]. Researchers have shown that when individuals are in the process of mastering cognitive activities such as language proficiency or memory attention, there is a point where they can perform activities well but cannot consciously contemplate what they are doing [6]. After a successful period of activities, individuals eventually are able to reflect on what they are doing and they have learned. For Vygotsky, this activity is only considered as higher order thinking when it becomes conscious. Vygotsky explains, knowledge in terms of concepts and functions, the acquisition of knowledge is described as a process of internalizing the words and actions of teachers, parents and more on the ability of learners [7]. Cognitive processes reflect high-level thinking when they are independent, have social origins, and are accessible to their self-awareness.

Higher order thinking skills are closely related to the processes it contains [8]. There are several aspects related to higher order thinking skills, namely conceptual understanding, systematic thinking, problem solving, and critical thinking [9]. These aspects can be familiarized and trained through formal education. Education has become one of the means to practice HOTS [9]. Therefore, the process of learning is held with the support of materials, systems, and the best human resources [10]. The development of learning and learning outcomes of learners can be measured by using particular assessment format.

One common issue in relation with the teaching of Physics is the teaching of Thermodynamics. Several students show that students have been found to have low mastery in this subject matter [11]. For this subject matter, students are expected to build their own knowledge through exploration, concept recognition, and concept application [12]. In order to build this knowledge, a scaffolding approach can be employed to increase higher order thinking skills as well as self-efficacy. The study found that learning outcomes of the students for Thermodynamics in the low category so that learning media for Thermodynamics are created; the results show effective as learning aids may improve students' learning out comes of this subject matter [13]. Furthermore, the low level of learning outcomes of Physics subject is generally caused by lack of initial knowledge possessed by the students, so that it requires particular certain approach that accommodates knowledge conception to higher level of thinking [14].

Assessment techniques through HOTS tests which are designed for Thermodynamic subject matter include measurement activities [15] as it may generate numerical data as an attempt to describe the characteristics of the learners. The HOTS-oriented tests for Thermodynamic material consist of a number of questions that have types of answers that include reasoning. The test results indicate information that shows the characteristics of learners in the form of critical analysis and mastery upon Thermodynamic material.

Based on the description above, there are some issues that become concerns in relation with HOTS in the teaching of Physics which can be identified. The learning habit in Physics education has not fully solved the problems related to higher order thinking, but only Lower Order Thinking Skills (LOTS); it requires certain approach to accommodate HOTS into Physics learning.

This study focused on HOTS-oriented measurement approach for Thermodynamic subject matter, including the preparation of assessment tools and scaling system. The provision of HOTS-based assessment tools for Thermodynamic subject matter is believed to help teachers to create more assessment instrument for the learners [15].

The HOTS-oriented measurements were given to the students of 11th graders majoring on science program of senior high schools. Empirical tests and measurement were only conducted in senior state high schools with the assumption that respondent variation was homogeneous. The objectives of this study include developing eligible devices as HOTS-oriented tests for Thermodynamics subject matter, and obtaining perception of the implementation of HOTS-based tests for the Thermodynamic subject matter for the senior high school students in City of Nganjuk, East Java.

II. METHOD

The development research of the HOTS-oriented assessment instrument for the Thermodynamic subject matter was conducted the second semester of academic year 2017/2018. The senior high school sampling where the research took place was chosen purposively. The data in research were collected through written test by utilizing the produced tests. The instruments for the data collection were HOTS test batteries on the Thermodynamic subject matter. The test kits consist of two sets of questions: package A and packet B consisting 20 items of questions and reasoning for each. The test kits were prepared by considering the indicators of Higher Order Thinking Skills (HOTS) being measured in the subject matter.

The HOTS-oriented test models were developed and designed for senior high schools in particular about the Thermodynamic subject matter by using model modification according to three steps [16], including planning, testing, and measurement stages. The criteria for the preparation of test kits were limited to knowledge with HOTS indicators including the ability for analysis, evaluation, and creation.

The planning stage was indicated with setting the goals of the tests, composing the latticework, test items, and rubrics. The design of the tests was analyzed by relevant experts to obtain proof of quantity validity of content determined with Content Validity Ratio (CVR). The average score from CVR determined the amount of Content Validity Index (CVI) of the test sets. The elements that experts examined include the materials, constructions, and language aspects. The formulations to determine the amount of CVR and CVI are presented in the following equations (1) and (2).

$$CVR = \frac{N_e - \frac{N}{2}}{N-1} \quad (1)$$

$$CVI = \frac{Total\ of\ CVR}{N} \quad (2)$$

With N_e is number of the investigator who answered important and N is total number of the investigators. The next phase was to test the instruments conducted to obtain the quantitative test item parameters. The parameters in question are as follows:

The Relevant Reliability Parameters Including Model Matching with PCM

The reliability was analyzed by using Quest program. The Quest program is used to test the suitability of an item with a PCM model (the item fits if the value of INFIT MNSQ is in the range of 0.7 to 1.30) [17], determining the reliability of the test and estimating the difficulty level (the item is declared difficult if the difficulty is > +2 while very easy if the difficulty is < -2) [18], and the estimated value of the learner's abilities in logic scale.

Standard Error of Measurement (SEM) Curves

The Standard Error of Measurement (SEM) is analyzed by the using PARSCALE program. The PARSCALE program is used to describe the SEM parameter, so that the ability of the learners that should be reached through the test instrument can be observed. In addition, it is also known how much the probability of minimum ability of the learners to answer the questions in accordance with the predetermined score criteria.

Cronbach's Alpha Coefficient

Cronbach's Alpha is a measurement for reliability that has values ranging from zero to one [19]. It is analyzed by using SPSS program. Test items that meet the requirements are then assembled into test kits for the measurement. Measurement in this research aimed to estimate the students' ability parameter. The students' ability is estimated through the result, and it serves as the basis for interpretation of the learning outcomes of the students as research subjects. The results of the HOTS-oriented measurement were described quantitatively and the percentage for each HOTS indicator in each sub-material was determined by a formulation like equation (3).

$$\%HOTS = \frac{the\ number\ of\ value\ obtained}{the\ value\ of correct\ answers} \times 100\% \qquad (3)$$

With this percentage, it can be understood what the percentage of the students' ability measured by using HOTS-oriented tests that have been developed, including the ability to analyze, evaluate, and create.

III. RESULTS AND DISCUSSION

The developed HOTS-oriented tests include three indicators the ability to analyze, evaluate, and create. For the Thermodynamic subject matter, it is divided into several submissions accommodated in high school, covering the firsts, second, and third Laws of Thermodynamics and the application of the laws. The relationship matrix between HOTS materials and indicators being developed is presented in Table 1. In relation with the ability to analyze, it is divided into two sub-indicators that distinguish and give special characteristics. On evaluating, it includes sub-indicators namely check and rate. With the ability to create, the developed problems were created with the sub-indicator plan.

The components of the HOTS-oriented test items all amounted to 40 items, including 5 items as the anchor items. The number of items focusing on analysis skills was 16 items, evaluation was 16 items, and creation was 8 items. Both A and B sets of questions have the same problem grid, but different context and sequence of questions. Each package of questions has been reviewed by experts in the area of physics education. The elements reviewed included the suitability of the material, construction, and language use. Based on the expert judgments, it was stated that the test device has met valid and feasible categories with the CVI of 1.00 (Table 2).

Grain specifications were obtained through trial activities. Specification of the items in question includes model fit tests, estimated reliability, and estimated difficulty levels. The first is the model fittest, i.e. the matching of grains with the Rasch model, by looking at INFIT MNSQ and Outfit *t* value. The outputs of the Quest program showed 40 items and they have already matched the Rasch' model, having INFIT and MNSQ are between 0.77 - 1.30 and Outfit $t \leq 2$.

It was already estimated the reliability coefficients at the test stages were 0.92 and 0.97 (Table 3), respectively, so the tests are considered to have very high reliability. This reliability was seen from the output of the Quest program which presents the results of test reliability according to CTT, which was an internal consistency index. At least the reliability coefficient was 0.90 and it can be used as the basis for decisions about individuals [20]. Thus, the developed test device qualifies as a HOTS-oriented testing instrument for the Thermodynamic subject matter.

Table 1. Development of HOTS Problems for Thermodynamic Subject Matter

Sub-materials	HOTS Indicators		
	To analyze	**To evaluate**	**To create**
The Third Law of Thermodynamics	Differentiate the initial temperature and the final temperature in the isobaric process	Select relevant factors related to Thermodynamic processes	Plan the volume required to produce a desired business
	Determine businesses by gas due to pressure changes	Assess the great effort made on systems with two different processes	
1st Law of Thermodynamics	Distinguish effort by gas if temperature is different	Choose the greatest effort on the adiabatic process	Plan for negative work on the system
	Determine energy changes in	Assess the volume and final pressure of the gas to isothermal system	
2nd Law of Thermodynamics	Distinguishes the largest and smallest attempts by the system on a heat engine	Check the time it takes for freezing	Design a cooling machine with certain efficiency
	Determine the performance coefficients of the engine efficiency of the heat	Assess entropy changes in melted ice	
The application of the Law of Thermodynamics	Sort engine efficiency from the smallest to the largest	Check the high reservoir temperature if the low reservoir is known	Design the lowest temperature of a room
	Determine the temperature on the cold reservoir based on the power generated	Assess the efficiency specifications of a machine	

Table 2. CVR and CVI

The Investigators	CVR	CVI
1	1.00	
2	1.00	
3	1.00	**1.00** (valid and feasible to use)
4	1.00	
5	1.00	
6	1.00	
7	1.00	

Table 3. Estimated Parameters

Parameters	Try Out	Measurement
INFIT MNSQ	1.00±0.09	1.02±0.07
OUTFIT MNSQ	1.00±0.09	1.02±0.07
Reliability	0.92	0.97

The results of the grain analysis gave the output estimation of difficulty for 40 items in a trial of -0.88 ≤ difficulty ≤ +1.17 and the measurement result gave an -0.81 ≤ difficulty ≤ +0.92 (Table 4) estimation. Based on the requirements of difficulty values according, then the HOTS question developed meets the required criteria as it is between -2.0 ≤ difficulty ≤ +2.0.

Table 4. Difficulty Level of Items

Difficulty Levels	Try Out	Measurement
Highest	+1.17	+0.92
Lowest	-0.88	-0.81
Mean	0.00	0.00
Standard deviation	0.64	0.56

The results of students' understanding upon Thermodynamic topic tested by using HOTS-oriented tests yields the TIF and SEM curves presented in Figure 1. Figure 1 shows that the assessment tools provide comprehensive information to student's higher order thinking skills with low rates of measurement error as well as ranges of students' capabilities were -2.3 to +1.6. This means that the assessment tool is more appropriately used on the students with the ability between -2.3 to +1.6.

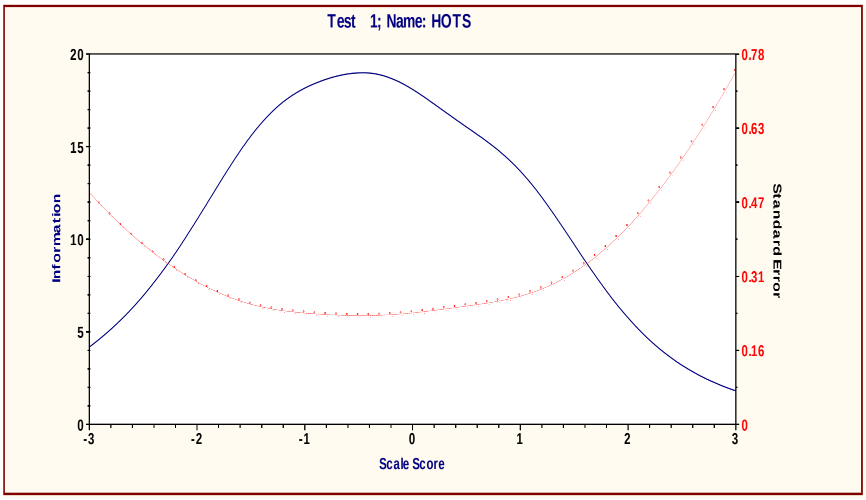

Figure 1. TIF and SEM Curves

In addition to the Total Information Function (TIF) in Figure 1 above, it can be seen as the minimum ability that the learners should be able to correctly answer each item. The rubric rating in this HOTS assessment is namely 4 if the reasoning as well as the answer are correct, 3 constitutes correct reason but wrong answer, 2 if the reasoning is wrong and the answer is correct, and 1 if both reasoning and answer are wrong. For example on item number 1 (see Figure 2). In Figure 2, it shows that to work on item number 1, learners can get a score of 1 with minimum ability of -3.0, score 2 with minimum ability of -1.5, score 3 with minimum ability of -0.5, and score 4 with minimum ability of +3.0. Each item has different abilities and probability relationship.

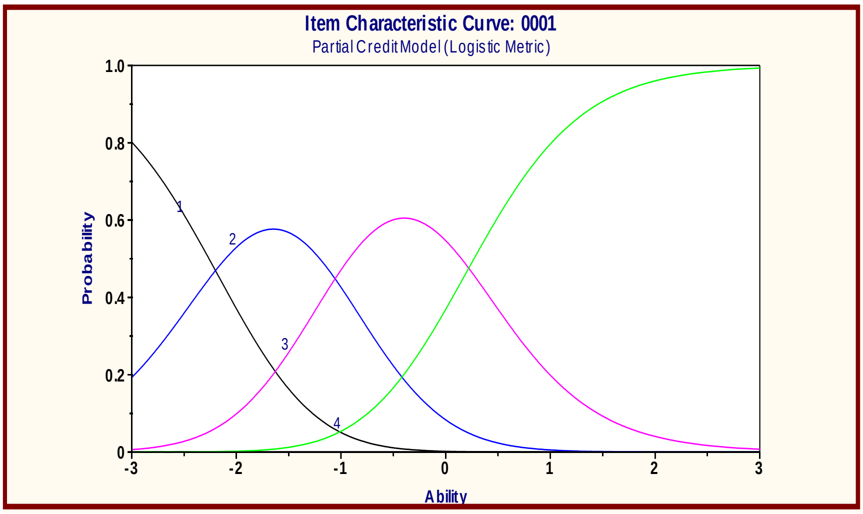

Figure 2. Item Characteristic Curve for Number 1

Problems that have been included are believed to be eligible used to measure HOTS of the learners, including the ability to analyze, evaluate, and also create. Thermodynamic subject matter itself is divided into several sub-materials, and each of the sub-material is developed according to the indicators of high order thinking. Each submitter and indicator receives different responses from the learners as presented in Table 5. The ability for analysis is shown the highest for sub-material number 2 for the Law of Thermodynamics with the percentage of 50.86 %. The ability for evaluation is the best for the first Law of Thermodynamics with the percentage of 41.02 %. The ability to create is shown the highest for the first Law of Thermodynamics with the percentage of 27.00 %. The average students' ability in sequence for the highest is the ability to analyze of 41.28 %, to evaluate of 38.70 %, and to create of 20.02 %.

Table 5. **HOTS of Students**

Sub-material	HOTS (%)		
	Analysis	**Evaluation**	**Creation**
The third Law of Thermodynamics	38.55	36.31	25.14
The first Law of Thermodynamics	31.98	41.02	27.00
The second Law of Thermodynamics	50.86	37.43	11.71
The application of the Law of Thermodynamics	43.74	40.01	16.25
Mean (%)	41.28	38.70	20.02

The application of the HOTS tests for Thermodynamics covering both content and constructs should be tested consistently in order to look at the stability. The reliability of particular product can be stable when it meets the following qualifications: measurement stability, internal consistency reliability, and inter rater reliability [21]. In order to make the Thermodynamics materials fit the needs for the higher order thinking, it should feature novelty and be supported by strong theoretical and empirical ground so it has inter-component consistency.

In terms of different level of ability of the students to analyze, evaluate, and create is caused by several things. First, the students have not been accustomed to responding to such questions in the form of multiple-choice options with a closed reason (choice of answers and reasons provided). The reasons presented in the selection contain appropriate concepts to get answers in solving the problems. Secondly, Higher Order Thinking Skills (HOTS) have not been trained and accommodated appropriately at schools. On the other hands, learners are accustomed to having Lower Order Thinking Skills (LOTS), which mainly include the ability to remember, understand, and apply the concepts. As the result, this habit may lower the learners' higher order thinking skills; if the higher cognitive domain is given, for example, the results are likely to show lower level. Several researches have elaborated some factors that directly influence on the higher order thinking skills of the students are namely psychological and intellectual characteristics, and also classroom environment [5]. For the classroom environment, teachers may be conditioned in certain context so that they may increase HOTS level of the students. This class conditioning by the teacher can be done with the appropriate learning model to increase HOTS.

Components that support HOTS would not develop automatically, unless they are well-designed and planned by the instructors [8]. Therefore, to improve the higher order thinking skills, curriculum, teaching materials, learning media, and evaluation instruments should be developed based on the principles of HOTS [22][23]. Even teachers and students should think with HOTS orientation as well as the meaning of HOTS automatically involves the ability to remember, understand, and implement (as included in the trend of LOTS) [24]. As HOTS-based learning materials are developed, the goals of LOTS are automatically also accommodated [25]. For that, teachers and learners need to get used to think with high order indicators.

In the case in Nganjuk, East Java, the average score of HOTS in Physics subject when it is associated with the results of of National Exam is 45.11 of a maximum score of 100; this is included into low category. Some certain schools in the same region, however, show better rank. This can be assumed that different high schools might implement different learning strategies, including in the teaching of Physics, despite the fact the trend of the learning activities are dominated with lecture-styled teaching activities. In addition, the teaching of Physics in senior high schools is likely to emphasize on how to solve problems in textbooks, instead of developing the conceptual understanding of the learners so that they are able to solve problems of Physics in various cognitive domains.

IV. CONCLUSION

Based on the description of results, some conclusions can be drawn as follows, namely the content validation by the experts indicate that both A and B test batteries, each of which contains 20 items with 5 anchor items, has fulfilled the required standard; the HOTS-based test kits for the Thermodynamics subject matter have obtained empirical evidence fit with the partial credit model; the difficulty level of the test batteries is in the range from -2.0 to +2.0. The difficulty level of the most difficult items in sequence aspects namely analysis, evaluation, and creation; the reliability of the test sets has fulfilled high categorical requirements, and based on the total function of information, the developed test batteries for Thermodynamics subject matter are appropriately used to measure the high order thinking skills of the learners with the ability -2.3 to +1.6; and the results of the students' responses to the ability to analyze is the highest, followed the ability to evaluate, and create.

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