The development and validation of critical thinking skills test on photoelectric effect for pre-service physics teachers

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Abstract. Critical thinking (CT) is one aspect of higher-order thinking skills that is emphasized in the 21st century learning. CT skills are important to be enhanced and assessed through learning process. Therefore, it is necessary to develop an appropriate test instrument for measuring pre-service physics teachers’ CT skills. Unfortunately, there have not been much writing which informs the results of CT test development on physics domain, especially for advanced physics concepts. This study develops CT test in photoelectric effect called CTPE test. The aspects of CT used in CTPE test are reasoning, hypothesis testing, argument analysis, likelihood and certainty analysis, and problem-solving and decision making. Each aspect is represented using two specific domains of CT on photoelectric effect concept. The validity of CTPE test is obtained through expert review (N=3). Furthermore, the CTPE test is tested on the students (N=32) to determine the reliability of the test instrument. The results of data analysis show that reliability coefficient is 0.71, this means that CTPE test have a high degree of reliability. It can be concluded that CTPE test can be used to measure students’ CT skills on the concept of photoelectric effect.

1. Introduction
Improving critical thinking (CT) skills is recognized as one of the important goals in the 21st century learning [1,2]. CT skills involve the ability to think reasonably and reflectively, to interpret and evaluate skillfully, to obtain valid conclusions, identify relationships, analyze probabilities, make logical predictions and decisions, and solve complex problems [3-5]. Initially, the trend of CT skills is taught separately with the subject matter [6]. Currently efforts to promote CT skills are done through the learning of specific subject matter [7]. The hope is that inculcating CT skills through a lesson on a specific subject matter will facilitate the acquisition of CT skills, and can be transferred to the various activities of thinking and daily life experiences [8].

The issue of CT skills assessment leads to two big ideas of CT ideas on domain generality and domain specificity. The focus of the debate lies in whether CT is a common set of skills that can be applied to an entire domain, or only applicable to particular domains [9]. The generalist view holds that CT skills
are general and applicable to domains that require CT. On the other hand, the specifist view believes that thinking is basically related to a particular domain. Different domains will involve different facts, concepts, and principles; thus, CT skills in one domain largely depend on adequate knowledge and understanding of the intended domain [10]. Specifist groups assume that CT assessment should always be made in the context of a particular subject matter. The instrument development of CT skills tests in this study is based on specifist views.

Promoting CT skills is very important for pre-service physics teachers. This skills are not only useful to him in the face of increasingly complex 21st century challenges, but also as a valuable experience about how to provide students with CT skills through physical learning. Several studies related to the development of CT skills tests in physics material have been conducted [11,12], however it is found that generally the existing CT skills test is only related to basic physics materials. The development of CT skills tests for advanced physics subject matters are still rare. In addition, there has not been a CT skills test that makes laboratory activity as the context of the problems presented. Therefore, it is important to develop a CT skills test for advanced physics subject matter that oriented to laboratory activities, both real and virtual lab. This study develops CT skills tests on the photoelectric effect (CTPE test) for pre-service physics teachers. The context of the problems used in CTPE test relates to the process and results of photoelectric effect experiment. Students are positioned as actors involved in the activities of experimental physics conducted. The characteristics of CTPE test are believed to be able to challenge and encourage students to be involved in solving problems using CT.

2. Method
The development of CTPE test involves several stages of activity: (a) identifying and selecting the appropriate framework of CT skills, (b) formulating specific domain CT skills on the concept of photoelectric effect based on the general domain of CT skills (c) creating scoring guide, (d) testing the validity of items, (e) items revision and administration, and (f) field test to determine the reliability of the CTPE test.

The validity test of CTPE items was done through expert review by 3 physics learning experts. The revised suggestions provided by the experts will be used as inputs to correct the CTPE test to obtain a revised CTPE version. Furthermore, the CTPE test is tested on the 32 pre-service physics teachers (9 men and 23 women, 21-23 years age range) at a university in Bengkulu, Indonesia, in the even semester of 2017-2018 academic year. The subjects of the test are students who have received photoelectric effect lesson. The test scores obtained by students are used to determine the reliability of the test instrument, discrimination index, and difficulty level of CTPE test.

3. Result and discussion
The stage of identifying and selecting the framework of CT skills in CTPE test development contain activities defining CT skills and selecting the domain of targeted thinking skills. At this stage identification of existing CT test instruments and CT aspects are used. Some of the test instruments that were identified are the Cornell CT Test [13], the California CT Skills Test [14], the Ennis-Weir CT Essay Test [15], the Watson-Glaser CT Appraisal [16]; and the Halpern CT Assessment [17]. Based on the results of identification and analysis it was decided that the CT framework to be used in CTPE test is the Halpern CT Assessment (HCTA). This decision is based on the consideration that the aspects and domains of CT contained in HCTA conform to the expected characteristics of CTPE test. The aspects and general domain of CT skills on HCTA can be used as a basis for developing CT skills on the concept of photoelectric effect.

Aspects of CT skills on HCTA to be used in CTPE are verbal aspects of reasoning, argument analysis, hypothesis testing, likelihood and uncertainty analysis, and problem-solving and decision-making. In CTPE test, each aspect is spelled out into two specific domains of CT on the concept of photoelectric effect so that a total of 10 specific domains will be obtained evaluate the validity of data, interpret the results of an experiment, draw valid inference from given tabular or graphical information, identify key part of an argument, infer a correct statement from a given data set, predict the probability of event,
examine the relevance of the procedures in solving problems, and recognize the features of problem and adjust solution plan accordingly.

Based on the results of the identification of some CT skills test instruments, it is shown that the test format used in the CT skills test is in the form of multiple choice, essay (open-ended or constructed-response), and combination of forced-choice and constructed-response. The test format to be used in CTPE test is constructed-response. This is based on the reason that constructed-response items have a better ability to measure certain aspects of CT skills such as identify key part of an argument, examine the relevance of procedures in solving problems, recognize the features of problem and adjust solution plan accordingly, and systematically solving problems [18,11].

There are several important activities carried out at the stage of items construction and creating items scoring guide, namely constructing items based on the concept of photoelectric effect and CT skills aspects used, creating a scoring guide for CT skills, and review all of items and scoring guide along with co-authors. This is done to re-examine the suitability the question items with the CT aspects to be measured, the clarity and completeness of the sentences used, the suitability the depth of information presented to the subject or population characteristics that will be the target of the test, as well as reviewing the suitability of criteria used to assess every part of the students’ answers. The result of activity at this stage is obtained a preliminary version of the CTPE test.

The preliminary version of CTPE test has been reviewed by three physics-learning experts. The criteria used in expert review are the suitability of CTPE items with aspects of CT skills to be measured; the accuracy of the information presented; the suitability of the depth or breadth of information presented with the subject or population characteristics being targeted to the test; conformity between expected questions and answers; and clarity of words, sentences, symbols, tables, diagrams, graphs, and other representational forms. The results obtained at this stage are some revised suggestions for improvement of CTPE test. Some of the revision suggestions given by experts are some sentences that should be summarized, there are drawings that must be clarified, there are data of experimental results should be added, there is a context of problems that must be clarified, and there are sentences of questions that must be adapted to the aspect of CT to be measured. The next step is to revise the CTPE test according to the advice given by the expert.

**Sample Item:**
Arman, Yanti and Erick conducted photoelectric experiments using computer simulations to estimate the magnitude of the working function of a metal material used as a photocathode. They use multiple light sources of different energies to illuminate the surface of the photocathode. The observed data obtained are recorded in the following table.

| Light Energy | Photoelectron Observed | Detected Electric Current |
|--------------|-------------------------|--------------------------|
| 2.28 eV      | There are no electrons emitted from the metal surface | No electric current |
| 2.46 eV      | There are few electrons emitted from the metal surface | No electric current |
| 2.85 eV      | Many electrons are emitted from the metal surface | There is an electric current |
| 3.07 eV      | More electrons emitted from metal surfaces | There is a stronger electric current |

Based on these data, Arman, Yanti and Erick drew the following statements:

**Arman:** The work function of the photocathode investigated is 2.28 eV because at this point the electrons are almost out of the metal surface.

**Yanti:** The work function of the photocathode investigated is 2.46 eV, this is the minimum energy to remove electrons from the metal surface. Photoelectrons do not have the energy needed to move toward the node.

**Erick:** The work function of the photocathode investigated was 2.85 eV. The resulting photoelectrons can produce an electric current.

Whose statements do you think is correct? Give an explanation of why the statement you think is correct and the others are wrong!

**Figure 1.** Sample of CTPE item.
Furthermore, the CTPE test is administrated and field tested. Subjects involved at this stage were 32 pre-service physics teachers who had attended photoelectric effect concept learning/experiments. Students are asked to answer the 10 questions contained in CTPE test. Before the test begins, students are given explanations regarding the purpose of the test, how to provide answers or responses, and ask students to solve the problem seriously. The time allocation given to students to answer all CTPE test is 90 minutes. In the implementation of the test, there were 25% of students who completed the test within 60 minutes and 75% of students completed within 90 minutes. An example problem in the CTPE test for the indicator infer a correct statement from a given data set and scoring guide are shown in figure 1 and figure 2.

**Sample Answer:**

The following is an ideal complete answer that we expect from a student:

*The correct statement is Yanti's statement.*

**Reason:**

*The work function of the material shows the energy of the electrons in the outermost orbits of the metal atoms. To release these electrons, it takes at least as much energy as electrons in its orbital. The Yanti’s statement is correct because it is based on data that with an energy of 2.46 eV there are some electrons out of the metal surface, but the photoelectron does not have enough energy to move to the anode pole so it has not produced an electric current. This means that the energy of 2.46 eV is the minimum energy required to release electrons from its orbital.*

*Arman’s statement is wrong because with 2.28 eV energy the electron has not been released from the metal surface. Erick’s statement is also wrong because with the energy of 2.85 eV electrons already have residual energy to move into the anode.*

**Scoring Guide:**

- Does the student answer that the correct statement is Yanti's statement? If yes award 2 point.
- Does student emphasize that 2.46 eV energy is the minimum energy required to remove electrons from metal surfaces? If yes award 1 point.
- Does the student explain that Arman's opinion is wrong because at the energy of 2.28 eV the electron has not emitted from the metal surface? If yes award 1 point.
- Does the student explain that Erick’s opinion was wrong because at 2.85 eV energy, the electron already has the extra energy to move to the anode pole and generate an electric current? If yes award 1 point.

**Figure 2.** Scoring guide sample for CTPE item.

The students’ scores are organized in representations that present the final score of each individual. It is used to determine the reliability of items through the Cronbach’s Alpha reliability test. The results of data analysis shows that Cronbach’s Alpha coefficient (r) is 0.71 with the inter-rater reliability coefficient range is 0.35 - 0.76. It means that CTPE test have a high degree of reliability. The reliability coefficient indicates that CTPE test can provide the stability of the scores obtained by the students.

In addition to the reliability test, also checked the discrimination and difficulty level of items. It has been found that CTPE test have discrimination indexes in moderate, good and excellent category, and the level of difficulty in difficult and medium category. The results of the difficulty and determination level test for each item are shown in table 1. The discrimination and difficulty index on each test item obtained represents that the CTPE test instrument has fulfilled the requirements as a good test instrument.

The development of CTPE test was conducted following a test instrument development procedure to measure the thinking and performance skills most of which had been done by researchers [19,11]. The CTPE test was developed by adapting the general domain of CT skills found in HCTA into the specific domain of CT skills on the concept of photoelectric effect. In fact, HCTA has 23 general domain CT skills (representing 5 CT aspects) that can be adapted to the specific domain of CT, but CTPE test contains only 10 specific domains for the consideration that only those domains are best suited for the concept of photoelectric effect by setting laboratory activities. These domains represent the five main aspects of CT skills as contained in HCTA.
Table 1. The discrimination and difficulty index of CTPE items.

| Item | Discrimination Index | Category | Item | Difficulty Index | Category |
|------|----------------------|----------|------|------------------|----------|
| 1    | .74                  | Excellent| 1    | .22              | Difficult|
| 2    | .36                  | Moderate | 2    | .32              | Medium   |
| 3    | .44                  | Good     | 3    | .29              | Difficult|
| 4    | .40                  | Moderate | 4    | .39              | Medium   |
| 5    | .35                  | Moderate | 5    | .29              | Difficult|
| 6    | .58                  | Good     | 6    | .21              | Difficult|
| 7    | .39                  | Moderate | 7    | .28              | Difficult|
| 8    | .52                  | Good     | 8    | .29              | Difficult|
| 9    | .70                  | Good     | 9    | .21              | Difficult|
| 10   | .76                  | Excellent| 10   | .21              | Difficult|

The CTPE test validation procedure is not done through field testing but through expert review because it is very difficult to find the appropriate students as the test target. Students who are subjected to field test must have requirements have studied the concept of photoelectric effect and are accustomed to following learning deliberately designed to promoting CT skills. The results of the validity and reliability test show that CTPE test are eligible for use. Hopefully, the CTPE test can be utilized for the improvement of students’ CT skills after they follow photoelectric effect learning, by comparing students’ CT skills scores before and after they follow the lesson.

4. Conclusion
The critical thinking skills test instrument on the concept of photoelectric effect has been successfully developed and has fulfilled the valid and reliable requirements. It shows that CTPE test is feasible to measure CT skills of pre-service physics teachers on the concept of photoelectric effect. The CTPE test can be used for research interest and physics learning in class or laboratory related to photoelectric effect concept. The CTPE test has typical characteristics such as a constructed-response test, the context of the problems used are laboratory-oriented, and students are positioned as if directly involved in the context of the problems used.

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