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The Development of Creative Problem Solving Skills Assessment on Photoelectric Effect

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***Abstract*—In order to face disruption phenomena in the era of industry 4.0, creative problem solving (CPS) skills are important to be developed and assessed through learning process. However, there is no existing instrument that can be used to assess students' CPS skills in the physics domain. This study aims to develop the CPS assessment on the concept of a photoelectric effect called the CPSPE test. The CPSPE test can be used to identify students' skills in solving problems related to the concept of photoelectric effect through the stages of exploring vision, collecting data, formulate the challenge, explore ideas, formulate solutions, and formulate a plan. Each step represents divergent thinking and convergent thinking skills. The validity of CPSPE test is obtained through expert judgment (N=3). In addition, the CPSPE test is then tried out to the students (N=32) to determine the reliability of the test items. The results of data analysis show that reliability coefficient is 0.80 with the inter-rater reliability coefficient ranging from 0.39 to 0.72 which indicating high degree of reliability. It can be concluded that the CPSPE test can be used to assess student's creative problem solving skills.**

Keywords—creative problem solving skills; assessment; photoelectric effect

I. INTRODUCTION

Creativity is a form of skill that often leads a person to achieve success in every field of work. A creative person is characterized by the ability to balance divergent thinking skills and convergent thinking in dealing with various problems. Consciously or not, basically everyone is often involved in the use of both the ability to think in solving the problems of everyday life. Thinking divergent is intended to generate many ideas and alternative choices, whereas convergent thinking focuses on evaluating activity ideas and choices to make decisions [1]. Both of these thinking skills are the basis of one's creativity [2], therefore, the kind of thinking we should continue to train and develop. One of the instructional models oriented to develop, equip, and use both skills in a balanced way is the creative problem solving (CPS) model [3].

The CPS model is a learning model focused on problem-solving skills followed by creative strengthening [4]. CPS is a process, method, or system to approach the problem in an imaginative way and produce effective action [5]. The CPS is developed on the basis of two basic assumptions that everyone is fundamentally creative, and that creative thinking skills can be learned or can be improved [4].

The CPS model is prospective to be applied in physics instruction. The many linkages of physics concepts with daily life phenomena make potential physics learning to divergent thinking and convergent thinking skills. However, instruments to measure students' CPS skills in physics are not available so far. Therefore, the development of test instruments to measure CPS students' skills in the physics domain becomes very important. In this study, the development of CPS skills test instruments on the concept of photoelectric effects was carried out, here in after referred to as CPSPE test.

The CPSPE test instrument produced in this study can be used to measure the extent to which the applied learning model can improve students' skills in creative problem solving on the concept of photoelectric effect. CPSPE test obtained can also be used as a reference in developing similar tests on other physics concepts.

II. METHOD

The development of the CPSPE test involves following stages: establishing the CPSPE capability indicator or indicator that will be used to develop the CPSPE test, constructing context-rich problems in the context of the problem, constructing and creating scoring guides, validity of test items, revision and administration items, and field tests to determine the reliability of the CPSPE test.

Validity test of CPSPE items was done through a review by 3 physics learning experts. The revised suggestions obtained will be used as input to improve the initial version of the CPSPE test to obtain the revised version of the CPSPE. Furthermore, the CPSPE 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 CPSPE test.

III. Results and Discussion

A. The Development of CPSPE Test

1) Determination of CPS skills indicator: The creative problem solving skills indicator used in the CPSPE test is adapted from the CPS indicator put forward by The Creative Education Foundation [4]. The process of presence is based on consideration of the conformity of the CPS indicators used with the conceptual characteristics of the photoelectric effect.

The CPS indicator include: (1) generate several problem statements based on the context of the problem, (2) choose problem statements that can represent the main problems encountered, (3) produce various data/facts/ information related to context of the problem, (4) choosing important data that can help in understanding the problems faced, (5) generating questions related to the problem, (6) choose problem questions that can lead to what is actually needed to solve problems, (7) generate ideas to solve problems, (8) evaluate and choose ideas that are most suitable for solving problems, (9) produce action plans that will be applied to solve the problem, and (10) choose the most appropriate action plan to apply in solving the problem.

2) Context-rich problems: Context-Rich Problem (CRP) is the context of the problem that contains the problems encountered and must be solved using the steps indicated by the 10 CPS indicators used. The context of the problem is presented in the form of a description of the problems related to the students' daily life related to the physics concept. The context of the problem acts as a starting point that will encourage students to engage directly in thinking activities to solve problems. Students will engage in the use of divergent and convergent thinking skills together to obtain solutions to the problems.

The context of the problem as outlined in the CPSPE test contains problems about physical experiment activities related to the concept of the photoelectric effect. There was a group of students who conducted experiments to analyze the characteristics of a metal element using x-ray photoelectron spectroscopy (XPS) equipment. They experimented with standardized procedures, but there were constraints on one part of the XPS device that did not have the specifications in question, thus the main objective of the experiment could not be obtained. It takes creative ideas from experiment team members to solve the problem. The team must also decide which creative ideas are considered most appropriate to solve the problem. The context of the problem used in the CPSPE test is shown in figure 1.

> You are involved in an experimental group to study the chemical state of the sodium (Na) metal element using XPS (x-ray photoelectron spectroscopy) equipment. The working principle used in XPS is the principle of photoelectric effect. The sample Na material to be analyzed is irradiated with x-rays, causing a number of electrons to be emitted from each of its orbitals. The emitted photoelectron will be detected by the XPS sensor. The electron energy level and the intensity of the photoelectron will be analyzed to determine the element's identity, chemical form, and element quantity. Therefore, the experiment to be performed must be able to produce electron emission from all its orbitals.
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> One important factor that can determine the success of the experiment is the suitability of the x-ray energy used with the amount of energy needed to produce electron emissions from the deepest orbital of the Na atoms. Based on the literature it is known that the electron energy of the Na atom in the deepest orbital is 1074.6 eV and the work function is 2.4 eV. The emission of electrons from the innermost orbitals will occur if the x-rays used have energy equivalent to the energy of electrons in these orbitals coupled with the energy of the working function of the material. Unfortunately, the x-ray frequency of 2415 x 10^{14} Hz contained in the XPS device will not be able to produce the electron emission from the deepest orbital. With such a frequency, the electrons in orbit near the atomic nucleus will not be emitted.
>
> The group leader asks you to think of possible solutions that can be applied in order to achieve the goal of the experiment, which is to produce electron emission from each of its orbitals. Answer the five questions below. The answers you provide can represent creative solutions to solve problems!

Fig. 1. Context-rich problem in CPSPE test.

3) Construct test items and scoring guides: There are three main activities carried out at the construction stage of the CPSPE test items and its scoring guide. The activities are formulating questions into test items according to the indicators of CPS skills used in relation to the given problem context, constructing test answers and benchmarking, and conducting in-depth reviews of all the test items produced.

The review process is intended to ensure that there is conformity between the questions provided with the CPS skills indicator, there is a correspondence between the test items with the answers or possible answers and predefined scoring guidelines, ensuring the clarity and completeness of the sentences used, and the suitability of the depth of information

presented to the subject or population characteristics that will be the target of the test. The product produced at the stage of construction test items and scoring guide is obtained a preliminary version of the CPSPE test.

The preliminary version of the CPSPE test is written in the Indonesian version. However, in this paper examples of test items are given in English after going through a review process of linguists. Examples of test items, answer, and scoring guide for indicator generate some problem statement based on the context of the problem and choose problem statement that can represent the main problem faced are shown in figures 2 and figure 3.

Sample item :

Here are some statements that are appropriate or not in accordance with the problems/challenges contained in the context of the problems:

(1) The x-ray energy in XPS is not equivalent to the electron energy in the K shell
(2) The x-ray energy present in XPS is less than 1074.6 eV
(3) The XPS appliance utilizes the working principle of the photoelectric effect
(4) The x-rays used are not capable of emitting electrons from the deepest orbital so that alternative treatments are required to obtain the expected data

Questions:

a. Based on the list above, which problem statements are in accordance with the problem/ challenge in the context of the above problem?
b. Make at least two new problem statements related to the problem/challenge in the context of the above problem!
c. Based on answers a and b, which problem statement do you believe is most able to represent the problem? What is the reason?

Fig. 2. Sample of test item.

Based on figure 2 it can be seen that before the question, there was a list of problem statements that could be appropriate or not in accordance with the problems contained in the context of the problem. Shiva must evaluate every statement that exists to determine whether the statement relates or is not related to the problem at hand. In addition, based on the list, students can learn how the sentence structure shows a problem statement. This understanding is needed when they have to make a new problem statement similar to that. The test pattern is used in other test items according to the CPS aspect to be measured.

Sample Answer :

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

a. The problem statement according to the context of the problem is numbers (1), (2), and (4).
b. Example new statement:
   (5) The x-ray frequency at XPS cannot produce enough energy to emit electrons from the deepest orbital.
   (6) If the deepest orbital electron is not emitted from the metal surface, the information relating to the element's identity, chemical form, and quantity of Na element cannot be obtained accurately/completely through the experiment.
c. Statements that can represent the main problems/challenges that I encounter are statements (4).
   Reason:
   The chemical state of Na element can be determined if the x-ray frequency used can supply the energy that can produce the photoelectron of all electron orbits. However, the X-ray frequencies contained in the XPS device are not possible to produce complete electron emission data according to destination. It is therefore necessary to treat certain alternatives in order for the experiment to produce data for the purpose of the experiment.

Scoring Guide :

- If student can answer item (a) correctly then given score 3.
- If the student can provide a new problem statement as in item answer (b) correctly then given score 2.
- If student can answer item (c) correctly then given score 1.
- If the student can give the correct reason to the problem (c) then given score 1.

Fig. 3. Sample of expected answers and an scoring guide for CPSPE items.

4) Testing the validity of items: The preliminary version of CPSPE test were further reviewed by three physics-learning experts using a review sheet. The criteria used in the expert review are the suitability of CPSPE items with indicators of CPS skills; the accuracy of the information presented with the concept of a photoelectric effect; suitability of the depth or breadth of information presented with the characteristics of students who are the target of the test; conformity between answers and test items; and the clarity of words, sentences, symbols, and the accuracy of the unit of physics. The results obtained at this stage are some of the revised suggestions for improving the CPSPE test.

Based on the results of the expert review it was found that overall the CPSPE test instrument had the feasibility to be used in learning. However, there are still some revision suggestions given by reviewers are some sentences that should be summarized, there are data of experimental results that can be added, and there are sentences of questions that must be adapted to the indicator of CPS to be measured.

5) Item revision and administration: The preliminary version of the CPSPE test instrument was revised in accordance with the suggestions provided by the reviewer at the items validity test stage. After being revised, the test items were prepared in the form of a CPSPE test sheet which was ready to be tested to students to determine the degree of reliability of the item.

6) Field testing: The CPSPE test instrument is tested to the students to know the degree of reliability, discrimination index and difficulty level. 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 5 main questions (contains 14 sub-questions) contained in CPSPE test.* Before students are invited to answer questions, they are given explanations of the purpose of the test, how to provide answers or responses, reminded to read the context of the problem thoroughly, and ask them to take each test question seriously. Students are also given the opportunity to ask things that have not been understood related to the execution of the exam. The time allocation for answering the CPSPE test is 90 minutes. In the implementation of the test, students submit their answers after the time allocation of the test ends. No student completes the exam for less than 90 minutes.

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 show that Crobach's Alpha coefficient (r) is 0.80 with the inter-rater reliability coefficient range is 0.39 - 0.72. It means that CPSPE test have a high degree of reliability. The reliability coefficient indicates that CPSPE 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 CPSPE test have discrimination indexes in moderate, good and excellent category, and the level of difficulty in medium and difficult category. The results of the difficulty and determination level test for each item are shown in table 1 and table 2. The discrimination and difficulty index on each test item obtained represents that the CPSPE test instrument has fulfilled the requirements as a good test instrument.

TABLE I. THE DISCRIMINATION INDEX OF CPSPE ITEMS

Item	Discrimination Index	Category
1a	.45	Good
1b	.39	Moderate
1c	.72	Excellent
2a	.42	Good
2b	.72	Excellent
2c	.47	Good
3a	.67	Good
3b	.43	Good
3c	.51	Good
4a	.63	Good
4b	.63	Good
4c	.56	Good
5a	.49	Good
5b	.44	Good

TABLE II. THE DIFFICULTY INDEX OF CPSPE ITEMS

Item	Difficulty Index	Category
1a	.46	Medium
1b	.41	Medium
1c	.28	Difficult
2a	.52	Medium
2b	.59	Medium
2c	.50	Medium
3a	.42	Medium
3b	.53	Medium
3c	.44	Medium
4a	.39	Medium
4b	.58	Medium
4c	.42	Medium
5a	.30	Difficult
5b	.13	Difficult

B. Discussion

The development of CPSPE test was conducted following a test instrument development procedure to measure the thinking and performance skills most of which had been done by researchers [6,7]. The CPSPE test was developed by adapting the general domain of CPS skills found in The Creative Education Foundation [4] into the indicator of CPS skills on photoelectric effect concept.

An important part of the CPSPE test that has been generated is the context of the problem, in addition to the open-ended questions related to the problem. The context of the problem is related to the real world problem that can be experienced by students in their lives. The context of the problem acts as a driver for students to engage directly in high-level thinking processes in solving problems. Based on various studies, higher-order thinking skills have been proven to be improved through learning that includes problem-solving activities [8,9]. Problem solving based learning is characterized by learning objectives include indicators of divergent and convergent thinking skills [10], problems given are contextual in accordance with the concept of selected learning material [11], and direct involvement of students in problem solving activities to achieve goals learning [12].

The developed CPSPE test consists of 5 main questions. Each main question contains several sub questions that represent divergent thinking skills or convergent thinking. Thus each CPSPE test item contains both of these thinking skills. For example, in question as shown in figure 2, sub questions a and b test divergent thinking skills, while sub question c tests convergent thinking skills. In sub question c, in addition to choosing a statement of the problem that is considered most representative of the main problems, the student is also asked to provide the reason why he/she chose the statement. At that stage the student must make a decision accompanied by a logical reason why he/she chose the decision among several alternative choices available.

The CPSPE 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 both studied the concept of photoelectric effect and accustomed to following learning deliberately designed to promoting CPS skills. The results of the validity and reliability test show that CPSPE test are eligible for use. Hopefully, the CPSPE test can be utilized for research or physics learning in the classroom or laboratory. The CPSPE test can be used to measure the improvement of students' CPS skills after they follow photoelectric effect learning, by comparing students' CPS skills scores before and after they follow the lesson.

IV. Conclusion

The creative problem solving skills test on the concept of photoelectric effect has been successfully developed, called the CPSPE test. The CPSPE test instruments have met valid requirements through content validity tests by experts and qualify reliably after field trials. The CPSPE test can be used for research and physics learning in class or laboratory related to photoelectric effect concept. The CPSPE test has 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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