Virtual Microscopic Simulation (VMS) for physics learning of the photoelectric effect in high school

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Abstract. The photoelectric effect is a physics concept that is often considered difficult by students because it contains abstract and microscopic concepts. So we need a medium that can visualize the concept of particle wave dualism on the photoelectric effect phenomenon microscopically. This study aims to produce "Virtual Microscopic Simulation (VMS)" as a medium for learning physics on the topic of the photoelectric effect in high school. The research method used is Research and Development with a 4D model (Define, Design, Development, and Disseminate). Validation of media feasibility has been carried out by several experts covering aspects of content and media with an average score of 77.2% and 75.7% with good categories. Based on the results of the expert validation test, it can be concluded that VMS can visualize the photoelectric effect process that is suitable for use as a medium for learning physics for students in high school.

1. Introduction
Physics is a fundamental science because it is the basis for the development of science and technology. Given the importance of the role of physics in human life, physics should be understood with the correct concept. The concept of physics consists of macroscopic and microscopic properties [1]. Macroscopic properties can be observed and measured easily, so it is generally well understood. On the other hand, microscopic properties cannot be understood properly because they are abstract and cannot be observed directly (unobservable) [2]. If microscopic properties can be understood, then macroscopic properties will also be easy to understand [3].

The photoelectric effect is included in the microscopic properties due to take place at the microscopic level that cannot be observed directly [4]. Students find it difficult to understand the concept of the photoelectric effect, for example, in the process of ejection of electrons and the flow of electrons in a circuit [5]. The characteristics of the abstract photoelectric effect concept make the potential for students to have an incomplete understanding. In addition, the phenomenon of the photoelectric effect is not easy to understand because of its complex nature and requires a large amount of time and money if done in the classroom [5].

The use of appropriate learning media can visualize microscopic concepts, making it easier for students to understand the concept of physics as a whole [6]. The use of instructional media in learning activities becomes an important part that should be well prepared and planned. Simulations can help students visualize aspects of science that are too big or too small to see [7]. Simulation can help the student to demonstrate physical phenomena, abstract and difficult to teach that can be delivered in a more clear and simple for students [8].

From a preliminary study that has been carried out by distributing questionnaires to one high school in Jakarta. A total of 35 students of class XII contributed in filling out the questionnaire. The
results of the analysis of student’s needs regarding learning of the photoelectric effect show that physics learning of the photoelectric effect material has not been maximized, especially in the use of learning media. As many as 65% of students are not interested in studying physics and as many as 83% of students find it difficult to understand the material of the photoelectric effect. The results of the teacher’s needs analysis of learning the photoelectric effect show the teacher’s responses through the distributed questionnaires. Aspects of limited learning media and low concept understanding results indicate that students have difficulty understanding the photoelectric effect material through the media used during learning. As many as 65% of teachers agree that the media used does not support the understanding of the photoelectric effect concept.

Several developments of abstract and microscopic photoelectric effect simulation media have been found in previous studies, including: photoelectric effect simulation combined with games [5] and photoelectric effect PhET simulation [9, 10]. However, from several photoelectric effect simulations that have been developed, there are several weaknesses, including: the simulation does not properly assess the purpose of the battery in the circuit. In addition, to determine the response to the use of PhET simulation on the topic of the photoelectric effect, a response to the use of PhET simulation media was carried out. It was found that 31% of students stated that they could not open the PhET simulation, this is because the PhET simulation has a .Jar format so that the applications run are very limited.

Therefore, the media to be developed will visualize the phenomenon of the Photoelectric Effect microscopically with virtual simulation, with additional features in the form of a voltage slider that represents the battery in the simulation with a value of -1V to +1V (smallest scale 0.1 V), and file type media in flash format (.swf) so that it is expected to make it easier for students to use the media. Based on this description, it becomes the basis for developing "Virtual Microscopic Simulation (VMS)" for physics learning that can visualize the concept of the photoelectric effect at the microscopic level in high school.

2. Method
This type of research is a R&D method (Research and Development). Developed learning media in the form of Virtual Microscopic Simulation (VMS) of the photoelectric effect created using Adobe Flash CS6 with a 4-D model of development [11]. The 4-D development model consists of four main phases, namely: Define, Design, Develop, and Disseminate. But this research was carried out until the Development stage, namely expert validation of the content and media aspects developed. Broadly speaking, the research procedures consisted of field studies, literature studies, instrument development, VMS development, and expert judgement. Validation instrument to media experts and content in the form of a questionnaire sheet is used to measure the feasibility of the resulting product

2.1 Virtual Microscopic Simulation (VMS) Media Evaluation Questionnaire for Media Experts
To measure the feasibility of the VMS media that has been developed, it is necessary to have a media research instrument that is tested by media experts. The making of the instrument is based on interactive multimedia criteria put forward by several experts and reference sources. The criteria for assessing multimedia-based learning categorized as good are as follows:

a. Ease of navigation, i.e. the developed program should be as simple as possible.

b. Media integration between aspects of language and skills to be learned.

c. The media developed must provide the learning desired by students.

d. Cognition, namely the program developed must meet the learning needs of students.

The following are the aspects used to assess VMS media, which are shown in Table 1.
Table 1. Aspects of the Media Expert Questionnaire

| No | Assessment Aspect    | Indicator Aspect Assessment                                                                 |
|----|----------------------|---------------------------------------------------------------------------------------------|
| 1  | Media design quality | • Reliable                                                                                  |
|    |                      | • Maintainable                                                                              |
| 2  | Media Interactivity  | • Communicative                                                                            |
|    |                      | • Creative (layout design, typography, color)                                                |
|    |                      | • Mobile media (animation, interactive layout, navigation icon)                              |

2.2 Virtual Microscopic Simulation (VMS) Media Evaluation Questionnaire for Content Experts

The research instrument in the form of a questionnaire was also made to obtain data on the validation of the VMS media, which was developed through examiners by material experts listed in Table 2.

Table 2. Aspects of the Questionnaire for Content Experts

| No | Assessment Aspect         | Indicator Aspect Assessment                                                                 |
|----|---------------------------|---------------------------------------------------------------------------------------------|
| 1  | Media compatibility with curriculum | • The suitability of the material with basic competencies                                      |
|    |                            | • Material depth                                                                            |
|    |                            | • Relevance of learning objectives to basic competencies                                    |
| 2  | Media content             | • Easy to understand, systematic, coherent and clear logic flow                              |
|    |                            | • The suitability of the material with the learning objectives                               |
|    |                            | • Presentation of logical and systematic material                                            |
| 3  | Language                  | • Language effectiveness and efficiency                                                     |
|    |                            | • The language used is in accordance with the rules of the Indonesian language               |

2.3 Research procedure

The research procedure is concrete and detailed steps that describe the development model used, namely the 4-D model. This research is limited only to the Develop stage. According to the 4-D model, the procedure of this study is shown in Figure 1.
Based on Figure 1, the first stage is the definition which is done to collect information from curriculum analysis. Furthermore, a needs analysis is carried out to see the actual situation in schools. Then, the material analysis is also called learning design. Learning design consists of: (1) identification of basic competencies; (2) formulating success indicators, (3) making test instrument indicators; (4) and development of learning strategies. The second step, the design of the development media is carried out with the following stages: (1) making a flowchart of the schema used as navigation; (2) collecting supporting concepts for media creation such as images, clip art, etc.; (3) create a storyboard of the developed media; (4) make an initial draft of the product of the developed media, according to the storyboard and flowchart; and (5) create an expert validation instrument to assess the media developed. The third step is evaluating VMS products which consist of validating VMS media through content experts and media experts, followed by data analysis and product revision. The last step is Desseminate, which is the stage of promoting the media to users so that it can be accepted, both individually and in groups. Before the Desseminate stage is carried out, the media must be tested on a limited scale. However, from this stage to the Desseminate stage it cannot be done due to time constraints. Therefore, the development of VMS media, according to the 4-D model only reached the development phase or the expert validation stage.

Data analysis used quantitative data analysis methods obtained from the results of questionnaires given to media experts and content experts about the assessment of the developed media. Additional media also came from interviews with physics teachers, and criticisms and suggestions from experts regarding the quality of products developed for physics learning.
3. Result and Discussion

3.1 Validation Media of Virtual Microscopic Simulation (VMS)

Products that have been created are then validated by media experts and content experts. This assessment aims to obtain suggestions, criticisms, opinions, and evaluations from the media that have been made. In this validation there are 6 validators consisting of 3 lecturers from media experts and 3 lecturers from content experts. The results of the research by media experts and content experts can be seen in the recapitulation of the validation results in Table 3 and Table 4.

| No | Assessment Aspect                                      | Media Expert Assessment Score |
|----|--------------------------------------------------------|-------------------------------|
|    |                                                        | I   | II  | III |
| 1  | Font, font size, font color and font layout of the letters used | 4   | 4   | 4   |
| 2  | Navigation buttons are easy to find and attractive     | 4   | 4   | 3   |
| 3  | Simulation clarity, layout and size                    | 4   | 3   | 4   |
| 4  | VMS media background                                   | 4   | 4   | 4   |
| 5  | The color composition used from VMS                   | 4   | 4   | 3   |
| Total |                                                   | 20  | 19  | 18  |
| Average (percentage) |                              | 19 (76%) |

Category: Good

| Media Design Quality | Media Expert Assessment Score |
|----------------------|-------------------------------|
| Font, font size, font color and font layout of the letters used | 4   | 4   | 4   |
| Navigation buttons are easy to find and attractive | 4   | 4   | 3   |
| Simulation clarity, layout and size | 4   | 3   | 4   |
| VMS media background | 4   | 4   | 4   |
| The color composition used from VMS | 4   | 4   | 3   |
| Total | 20  | 19  | 18  |
| Average (percentage) | 19 (76%) |

Category: Good

| Media Interactivity | Media Expert Assessment Score |
|---------------------|-------------------------------|
| Easy-to-use navigation buttons | 4   | 3   | 4   |
| Easy-to-use menu button | 4   | 4   | 3   |
| Use of clear and simple language | 4   | 4   | 4   |
| Total | 12  | 11  | 11  |
| Average (percentage) | 11.3 (75.6%) |

Category: Good
Table 4. VMS media validation results by Content Expert

| No | Assessment Aspect                                      | Media Expert Assessment Score |
|----|--------------------------------------------------------|-------------------------------|
|    |                                                        | I    | II  | III |
| 1  | Media compatibility with curriculum                    | 4    | 4   | 4   |
| 2  | The relationship between content and basic competencies| 4    | 3   | 4   |
| 3  | Systematic content presentation                        | 4    | 3   | 4   |
| 4  | Considering the difficulty level of the content        | 3    | 3   | 4   |
| 5  | The relevance of the content to the given simulation   | 4    | 4   | 4   |
|    | Total                                                  | 19   | 19  | 20  |
|    | Average (percentage)                                   | 19,3 | 77,3%|
|    | Category                                               | Good |

| No | Assessment Aspect                                      | Media Expert Assessment Score |
|----|--------------------------------------------------------|-------------------------------|
|    |                                                        | I    | II  | III |
| 1  | Easy to understand, systematic, coherent and clear logic flow | 4    | 4   | 4   |
| 2  | The suitability of the material with the learning objectives | 4    | 4   | 3   |
| 3  | Presentation of logical and systematic material        | 4    | 4   | 4   |
|    | Total                                                  | 12   | 12  | 11  |
|    | Average (percentage)                                   | 11,7 | 77,8%|
|    | Category                                               | Good |

| No | Assessment Aspect                                      | Media Expert Assessment Score |
|----|--------------------------------------------------------|-------------------------------|
|    |                                                        | I    | II  | III |
| 1  | Language effectiveness and efficiency                  | 4    | 4   | 4   |
| 2  | The language used is in accordance with the rules of the Indonesian language | 4    | 3   | 3   |
|    | Total                                                  | 8    | 8   | 7   |
|    | Average (percentage)                                   | 7,7  | 77,7%|
|    | Category                                               | Good |

From Table 3 and Table 4, information is obtained that the appearance and interactivity of the developed VMS media is quite good and the developed VMS media is in accordance with the photoelectric effect content. Based on the results of the VMS media validation assessment, an average of 76.45% was obtained and was declared good. The average results of the feasibility assessment of each expert on the VMS media are shown in Figure 2.

![Figure 2. Percentage of VMS validation media expert and content expert](image)

Based on the description, the media can already be used in research after the improvements made based on suggestions from experts, so it is feasible to use in physics learning, especially in the concept of the photoelectric effect.

3.2 Characteristics of Virtual Microscopic Simulation (VMS) Media

VMS media is developed using Adobe Flash CS6 which can combine text, sound, color, and animation. These advantages can be used to visualize the phenomenon of the photoelectric effect.
microscopically. The output file from adobe flash CS6 has a shockwave flash extension file (.swf) which can be animated directly if there is already a flash player plugin on the computer.

The VMS media design that has been validated and revised based on suggestions and notes from experts contains an initial display, main menu, info menu, simulation menu, graph menu, and table menu. The initial appearance of the media is shown in Figure 3. The initial display consists of the name of the media, namely “Virtual Microscopic Simulation (VMS)”. In the main menu there are four submenu buttons, which consist of: (1) The theory menu which shows a brief theory of the photoelectric effect; (2) Simulation menu that shows the simulation of the photoelectric effect phenomenon displayed by microscopic visualization; (3) The Graph menu shows the variables that affect the photoelectric effect; and (4) The exercise menu contains an understanding test of the photoelectric effect. The developed simulation menu is shown in Figure 4.

Figure 3. VMS preview

Figure 4. VMS simulation menu

Figure 3 shows the simulation menu. In the simulation menu there are several variables, such as frequency, intensity, voltage, and type of metal. The variable frequency, intensity, and battery voltage are in the form of a slider that can be moved to the right or left according to the value. The target metal type variable is a plate in a circuit that can change if the plate is clicked. In the simulation circuit there is a light source that will emit photons, the value of which depends on the frequency of the light which is indicated by the color gradation of the light particles. If the frequency of light is greater than the threshold frequency of the target metal, the electrons in the target metal will exit or move from the positive pole to the negative pole. The number of electrons that come out of the target metal is influenced by the value of the light intensity, the greater the number of electrons that come out, the more electrons will come out. In the simulation menu there is an addition, namely a voltage slider that has a value of -1v to +1v with the smallest scale of 0.1 v, to find the stopping voltage on the photoelectric effect.

Figure 5. VMS graph menu

Figure 6. VMS table menu
The novelty of VMS is a graphical menu that is displayed on a full screen shown in Figure 5 with the aim that users can see more clearly the graph that is formed. The graph menu explains the relationship "Current vs Applied Voltage" and "Max Energy vs Frequency". The target metal used consisted of 4 different metals, namely sodium, potassium, calcium, and cesium. The metal type will change when the user presses the target metal. The frequency range used is 430 THz - 710 THz from red to purple. The voltage used is within -1V to +1V with a difference of 0.01V. Figure 6 shows another novelty of VMS, namely the table menu that is used to calculate the value of energy and current in the Photoelectric Effect based on the values entered into the table.

4. Conclusion
Based on the results of research and analysis, it can be concluded that the developed Virtual Microscopic Simulation (VMS) media can be a means of learning physics for student in high school, especially on the concept of the photoelectric effect with better categories, with novelty: (1) simulation displays the correct purpose of the battery on the circuit; and (2) The VMS file type is in .swf format so that it can be run immediately without a long loading time if the computer has a flash player installed.

References
[1] H. Gould and J. Tobochnik, *Princeton University Press*, vol. 79, no. 4, pp. 431-432, 2010.
[2] F. C. Wibowo, A. Suhandi, Nahadi, A. Samsudin, D. R. Darman, Z. Suherli, A. Hasani, S. M. Leksono, A. Hendrayana, Suherman, S. Hidayat, D. Hamdani and B. Costu. *Asia-Pacific Forum on Science Learning and Teaching (APFSLT)*, vol. 18, no. 2, p. 2, 2017.
[3] F. C. Wibowo, A. Suhandi, D. Rusdiana and Y. Ruhiat. *Advanced Science Letters*, vol. 23, no. 2, pp. 839-843, 2017.
[4] S. Klassen, *Science and Education*, vol. 20, no. 7, pp. 719-731, 2011.
[5] T. Namgyel and K. Buaraphan, *Asia-Pacific Forum on Science Learning and Teaching*, vol. 18, no. 2, pp. 1-30, 2017.
[6] F. C. Wibowo, A. Setiawan, U. Alizkan, D. R. Darmawan and E. Budi, *Universal Journal of Educational Research*, vol. 7, no. 12, pp. 2867-2882, 2019.
[7] S. Khan, *Journal of Science Education and Technology*, vol. 20, no. 3, pp. 215-232, 2011.
[8] E. Bozkurt and A. Ilik, *Procedia - Social and Behavioral Sciences*, pp. 4587-4591, 2010.
[9] Supowoko, Sarwanto, Sukarmin and Suparmi, *International Journal of Science and Applied Science: Conference Series*, vol. 33, no. 1, 2017.
[10] A. Sokolowski, *Physics Education*, vol. 48, no. 1, pp. 35-41, 2013.
[11] A. F. Rahmadani, H. Hidayat and E. Syahmaidi, *International Journal of Scientific Research and Management*, vol. 6, no. 1, 2018.
[12] R. Estrígana, J. A. Medina and R. P. Barchino, *Computers & Education*, vol. 135, pp. 1-14, 2019.
[13] F. C. Wibowo, A. Suhandi, D. Rusdiana, A. Samsudin, D. R. Darman, M. N. Faizin, Wiyanto, Supriyatman and A. Permanasari, *Journal of Physics: Conference Series*, vol. 877, 2017.
[14] K. G. Nelson, A. F. McKenna, S. Brem and J. C. Hilpert, *Journal of Engineering Education*, vol. 106, no. 2, pp. 218-244, 2017.
[15] V. Potkonjak, M. Gardner, V. Callagan, P. Mattila, C. Guetl, V. M. Petrovic and K. Jovanov, *Computer & Education*, vol. 95, pp. 309-327, 2016.
[16] A. Ballu, X. Yan, A. Blachard and T. Clet, *Procedia CIRP*, vol. 43, pp. 148-153, 2016.