

Discovery Learning Model-based Virtual Lab on Photoelectric Effect Material to Improve Critical Thinking Skills

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Article Info

Article history:

Received: June 20, 2023

Accepted: September 19, 2023

Published: November 29, 2023

Keywords:

Virtual learning media lab;
discovery learning;
photoelectric effect;
critical thinking skills.

ABSTRACT

This article provides an overview and explanation of a product in virtual laboratory media based on the development of discovery learning with a focus on the material of the photoelectric effect. The paper also outlines the readability and practicality aspects for both students and teachers in the virtual lab while explaining the effectiveness of the virtual lab in enhancing students' critical thinking skills. The product discussed in this article was developed using the 4D model and scheme. It has undergone expert validation and product testing. The research presented in this article was conducted at two public high schools in Yogyakarta. The study utilized questionnaires, observation sheets, expert validation sheets, readability sheets, practicality sheets, and tests. The research data was analyzed using Gregory's analysis for expert validation and Manova's analysis for field testing. The study results indicate that the virtual lab is deemed appropriate as a learning medium based on expert validation for the photoelectric effect material. From the perspectives of readability and practicality, the developed product falls into the excellent category. This study, using the Manova test, effectively illustrated a substantial enhancement in the critical thinking abilities of students, notably in the areas of analysis, elaborating on concepts, and forming conclusions. Consequently, this paper offers a detailed insight into the creation of novel educational tools and presents robust empirical data supporting their role in improving critical thinking in students, with a specific focus on the subject of the photoelectric effect.

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INTRODUCTION

In this modern era, education plays a crucial role in the progress of a nation. As we enter the second millennium, the significance of education, particularly in intellectual development, becomes increasingly evident. In the 21st century, the global focus on education is shifting towards critical thinking skills (Gunanto & Supriyadi, 2021; Wijayati et al., 2022). One manifestation of critical thinking is the ability and expertise to analyze issues in-depth (Astuti et al., 2020; Matsun et al., 2021). Critical thinking in an academic context, such as in schools, is

reflected when students provide contrasting views as a challenge to commonly accepted perspectives (Basri et al., 2019; Asyisyifa et al., 2019; Rahmadita et al., 2021). Students demonstrate critical thinking when they present different perspectives based on pre-existing knowledge. Nevertheless, theories regarding students' critical thinking must be tested against facts and field realities.

Research and field data from Indonesian institutions highlight insufficient progress in the education system, particularly concerning students' intellectual development and critical thinking skills. To address this,

How to cite

Ahmad, L. S., & Prasetyo, Z. K. (2023). Discovery learning model-based virtual lab on photoelectric effect material to improve critical thinking skills. *Jurnal ilmiah pendidikan fisika Al-Biruni*, 12(2), 153-165.

enhancing necessary thinking skills is imperative. This can be achieved through improved material understanding and comprehensive support facilities.

Students' problem-solving abilities are influenced by their perception and the learning approach (Makhrus & Hidayatullah, 2021; Miterianifa et al., 2021; Rosdiana et al., 2019). A teacher-centred system creates one-way education, making students feel like passive recipients. To address this, fostering scientific, two-way communication-oriented learning is crucial. The discovery learning model effectively integrates the learning process towards students' knowledge construction (Mulyanto et al., 2018; Mustofa & Sucianti, 2019). Here, students formulate problems, crafting research questions on physics topics using targeted concepts (Mahanal et al., 2019; Ramadhan et al., 2019; Suardana et al., 2018). They develop critical thinking skills through experiments, observations, and measurements and scientifically analyze their research questions. Emphasizing students as independent learners, the discovery learning model enhances their ability to explore, formulate, and articulate knowledge effectively during activities (Apriani et al., 2020; Changwong et al., 2018; Oktalia et al., 2018).

Integrating abstract and concrete elements in physics education is crucial at all academic levels (Fahrunisa et al., 2020; Wartono et al., 2018). However, the challenge arises in providing diverse hands-on experiences in school laboratories due to equipment and resource limitations, hindering the potential for an enriching learning experience. While face-to-face delivery of physics materials in classrooms is not always feasible, the engagement level significantly improves in a laboratory setting. Adopting digital technology-mediated laboratory activities is recommended to overcome the constraints posed by limited equipment (Clarinda et al., 2021; Gunawan et al., 2018). Digital laboratories offer flexibility and are not constrained by time, enabling students to

effectively participate and grasp complex physics concepts using visualization, animations, and other tools (Labibah et al., 2021; Rosa & Nursa'adah, 2018; Wibowo et al., 2019). These advancements enhance the learning process, providing students with a bridge to construct, reconstruct, verify, and sharpen their scientific knowledge (Husnaini & Chen, 2019; Sutarno et al., 2019; Thess, 2020), fostering imagination and understanding of physics materials.

The virtual laboratory facilitates students in conducting interactive evaluations, visualizations, and experiments in a simulated environment (Gunawan et al., 2019; Syukri et al., 2022; Tiwi et al., 2019). Developed with the interactive media concept and utilizing HTML 5, it is easily accessible through links and applications on Android and IOS platforms (Shurygin et al., 2022). It addresses challenges in understanding abstract subjects, exemplified in physics by studying phenomena like the photoelectric effect (Wahyuni & Atun, 2019).

The photoelectric effect, a complex subject exploring abstract concepts related to light photons, poses a significant challenge to comprehension due to its inherent complexity and substantial implementation costs (Lestari et al., 2023; Mandagi et al., 2021; Spagnolo et al., 2019; Sutarno et al., 2019). Students often grapple with fundamental aspects such as the electron ejection process, electron flow in a circuit, experimental setup, and predicting results, along with understanding the correlation with the model of light photons (Rahmadita et al., 2021; Sunyono & Sudjarwo, 2018). A virtual laboratory has been introduced to address these difficulties, offering a simulated experience of photoelectric effect experiments (Arista & Kuswanto, 2018). This innovative approach is expected to surmount learning obstacles and enhance students' critical thinking skills.

Students' suboptimal critical thinking skills in learning can be effectively addressed through instructional media (Wahyuni &

Atun, 2019). Numerous research studies aim to enhance learning effectiveness, such as Sutarno's successful development of the High-Order Thinking Virtual Laboratory (HOT-Vlab) model, a simulation of the photoelectric effect with high-order thinking skills (HOTS) (Sutarno et al., 2019). Khaeruddin and Bancong (2022) also explored combining the photoelectric effect with gaming elements. Additionally, Matsun et al. (2021) demonstrated the efficacy of virtual laboratories in problem-based learning for improving students' critical thinking skills in dynamic electricity materials. This research stands out for enhancing problem-solving skills and significantly improving students' critical thinking skills, setting it apart from studies that focus on combining 5E simulation with gaming for understanding and learning attitudes.

This article delves into the effectiveness of virtual lab-based discovery learning media, focusing on the photoelectric effect, as a strategic tool for improving students' critical thinking skills in physics education. The developed media encompasses clear goals, laboratory instructions, discovery learning stages, experiment result sheets, and evaluations. Distinguished by its merits, this product aims to significantly enhance students' critical thinking skills, particularly in understanding the complexities of the photoelectric effect.

METHODS

Types of Research

This research employed the R&D method (Research and Development) with a 4D scheme consisting of four phases: define, design, develop, and disseminate (Thiagarajan et al., 1974). Following the 4D research framework, the first phase is the define stage. The define stage begins by reviewing literature, including journals, references, and relevant research. Additionally, field analysis is conducted to gain a contextual understanding. The second phase is design, where the draft shape and

format of the product, a learning media, are created. Subsequently, the digital format is determined, specifically a virtual lab with a foundation in discovery learning explanations.

The third stage is development, which involves creating a product based on an application and HTML 5. Experts test the product's feasibility using a feasibility assessment sheet. Once the product receives expert approval, it is ready for testing with research subjects. The testing is divided into limited trials and field trials. The results of these trials serve as material for product improvement and, as a next step, for dissemination to users, including students and teachers. The subjects of this research were the twelfth-grade students at SMA Negeri 2 Yogyakarta and SMA Negeri 2 Sleman. Product field trials were conducted at SMA Negeri 2 Yogyakarta and SMA Negeri 2 Sleman with the control group pretest-posttest design. The increase in critical thinking skills was analyzed using the MANOVA test. The research stages used are shown in Figure 1.

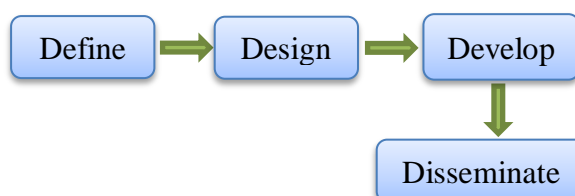


Figure 1. Research Stages
(Thiagarajan et al., 1974)

Define this stage: student analysis, concept analysis, and learning objective analysis. Stages define aims to analyze the needs of the problems experienced by students. Needs analysis is carried out to understand the learning process at school, identify problems that arise in the learning process, and determine the level of students' abilities. After that is the concept analysis stage, which aims to identify and compile a mapping of the material studied by students. Meanwhile, analysis of learning objectives describes the process and results that students will achieve.

Design: this stage is carried out after completing the needs analysis. It begins by creating the initial design of the learning media. The first step is determining the media's foundation based on the virtual lab. Subsequently, the learning model is chosen, with a preference for the discovery learning model. Discovery learning is selected because it incorporates several syntaxes that can be seamlessly integrated into digital learning, such as virtual labs. Once the initial design is complete, a thorough examination of the learning model's suitability, the virtual lab interface design, and its alignment with the topic and context is conducted. Following this, preparing the product validation sheet containing details about the media and product design is crucial.

At this stage, virtual lab-based learning media is created for discovery learning, expert validation, and learning media field trials. In a virtual lab, which an expert validator has validated, improvements are made according to suggestions and input from the validator. If the learning media that has been validated shows valid results, then it can be said to be suitable for use in testing virtual labs. The trials carried out were divided into two, namely limited trials and field trials. This was done to see how virtual lab improves students' critical thinking skills.

Meanwhile, quantitative data analysis uses pretest and posttest questions as product results assessment. The effectiveness of the virtual lab was analyzed using the MANOVA test. A questionnaire was used as reference material for teachers and students to find out the practicality of the media. The final stage of the field trial is the final revision process so that the learning media developed is ready to be distributed.

Disseminating is the final stage, namely the process after the final and overall revision of the media being developed. In this case, the virtual lab is based on learning media discovery learning. The dissemination mechanism is to several physics teacher schools in Yogyakarta and publications in national journals, which are delivered at

academic forums, such as seminars, workshops, and learning media exhibitions.

RESULTS AND DISCUSSION

Define

One of the problems in schools currently is the limited infrastructure to facilitate students to build their knowledge. Based on the results of observations at SMA Negeri 2 Yogyakarta, critical thinking skills are still not optimal, especially in abstract physics material. Class XII students also have not carried out practicums during the learning process in class XII. There are several reasons why practicums are not carried out in class. Besides that, practical activities in class require quite a lot of time. The learning media used by teachers is diktat learning media, which has been prepared by the teacher and delivered using the lecture method. Based on field studies show that students' activity abilities are still in the low category. Several studies show the same results: students' low critical thinking skills are caused by rarely being given learning materials that hone critical thinking skills. Teachers often use conventional methods such as lectures, making learning still teacher-centred. Students also only get information from the teacher, which indicates the teacher is the main learning source. Therefore, learning media is crucial to stimulate students' critical thinking skills. These low critical thinking skills can be seen from the results of students' daily assessments and mid-semester assessments (PTS). One of the physics materials considered difficult in physics subjects is the photoelectric effect. Based on these results and the view of the photoelectric effect's material difficulties, this is interesting to study. Therefore, the photoelectric effect will be interesting to study if you use digital-based learning media that can be accessed anytime.

Design

Virtual lab-based learning media was designed using syntax discovery learning:

stimulation, problem statement, data collection, data processing, verification, and conclusions. Software commonly used in this design process includes articulate storyline 3. Virtual lab-based learning media

discovery learning designed on photoelectric effect material. The design of virtual lab-based learning media discovery learning is shown in **Table 1**.

Table 1. Virtual-lab Learning Media Based on the Discovery Learning Design

No.	Learning Media	Discovery Learning	Photoelectric Effect	Instructional Virtual-Labs Learning Media Based on Discovery Learning on Photoelectric Effect Material
1.	Homepage	Discovery learning	The photoelectric effect	The homepage contains buttons start before learning media is used.
2.	Menu login	is a learning experience	is phenomenon out	The login menu contains name and class of students
3.	Main Menu	involving students in find knowledge. Syntax discovery learning that is:	electrons from something surface metal (electron emission) when it is struck and absorbed radiation	The main menu contains the learning media menu display, namely objectives and indicators, experimental instructions, materials, experiments with syntax discovery learning, evaluation, and developer profile
4.	Objectives and Indicator	a. Stimulation	electromagnetic (light) which has frequency above frequency material	Objectives and indicators contain the objectives and indicators that students will achieve
5.	Instruction Test	b. Statement		Experiment instructions contain pre-lab and lab phase instructions
6.	Materials	c. Data collection		The material contains light waves, photoelectric effects, and how barcode scanners work
7.	Experiment	d. Processing data		Experiment with syntax discovery learning includes stimulation, problem statement, problem formulation, pre-prediction, group prediction, idea determination, exploration, and conclusion
8.	Evaluation	e. Verification		The evaluation contains questions about critical thinking skills
9.	Developer profile	f. Conclusion		The developer profile contains the personal data of the developer and supervisor

The design of virtual lab-based learning media discovery learning covers the homepage, login menu, main menu, objectives and indicators, experimental instructions, materials, experiments containing stages of discovery learning, evaluation, and developer profile. Furthermore, a validation sheet was also designed to test the effectiveness of the virtual lab.

The design stage of virtual-lab learning media based on discovery learning uses discovery learning syntax, including stimulation, problem statement, data collection, data processing, verification and conclusions. The design flowchart can be seen in Figure 2.

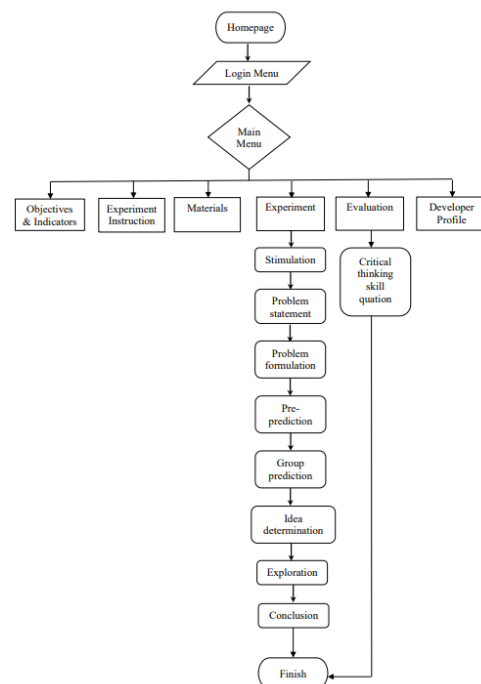


Figure 2. Design Flowchart

Develop

Virtual lab-based learning media discovery learning developed based on the design that has been created. Display of virtual lab-based learning media discovery as in Figure 3 and Figure 4 show the homepage and main menu displays on virtual lab-based learning media discovery learning.



Figure 3. The Homepage Display



Figure 4. The Main Menu Display

The menu display includes objectives, indicators, experimental instructions, materials, experiments, evaluation, and developer profile. Furthermore, the experiment display has a stimulation menu, problem statement, problem formulation, pre-prediction, group prediction, idea determination, exploration, and conclusion (Figure 5). These displays stimulate students to hone critical thinking skills. Meanwhile, the equipment stimulates students to do practicum (Figure 6). These views are shown in Figure 5 and Figure 6.

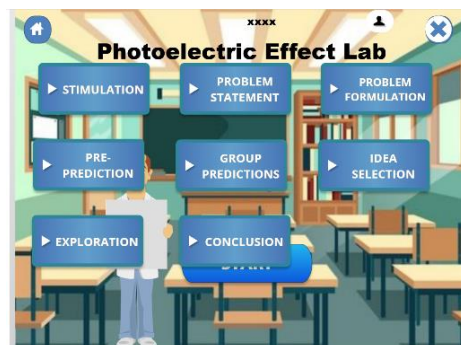


Figure 5. The Menu in the Photoelectric Effect Practicum

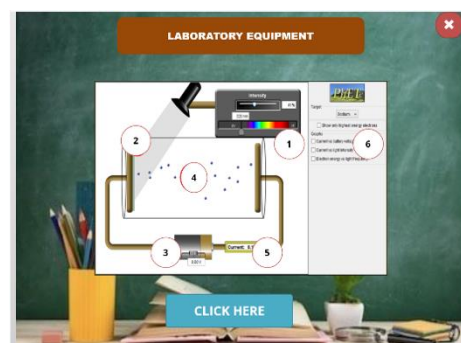


Figure 6. The Practicum Equipment Display

In problem statements, students are trained to analyze a problem. In problem formulation, students are trained to make formulations from the reading in the problem statement display. One of these displays can be seen in Figure 7.

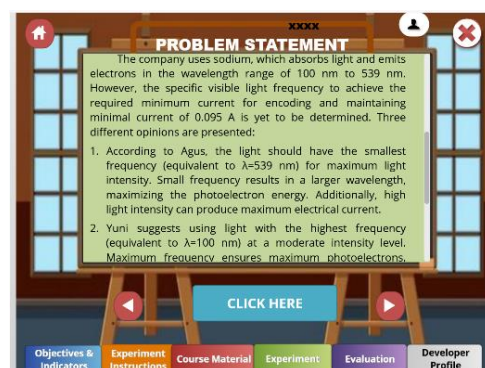


Figure 7. Problem Statement Display

In the pre-prediction stage, students are asked to make predictions that will guide them in answering the problem formulation. Students will also provide arguments and create hypotheses based on group predictions. The idea determination stage sharpens students to determine the idea chosen and why they

chosed it. In the exploration stage, students will explore and answer the problem formulation by doing a practicum. Next, the data will be processed to the conclusion stage.

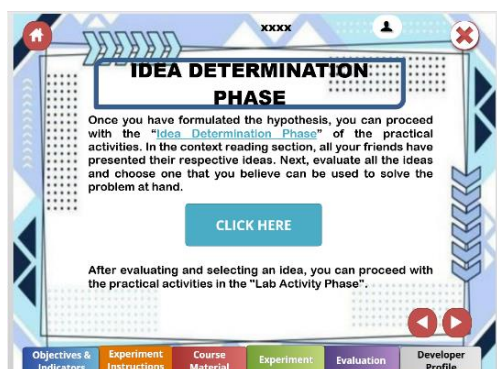


Figure 8. Idea Determination Display

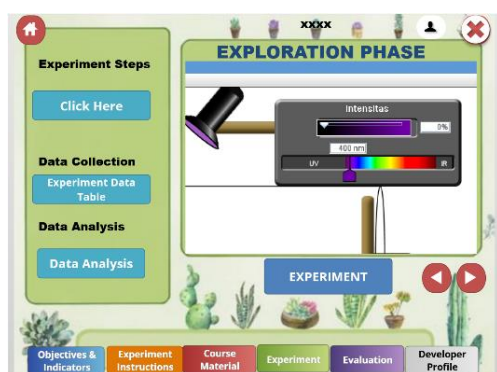


Figure 9. Eksploratory View Display

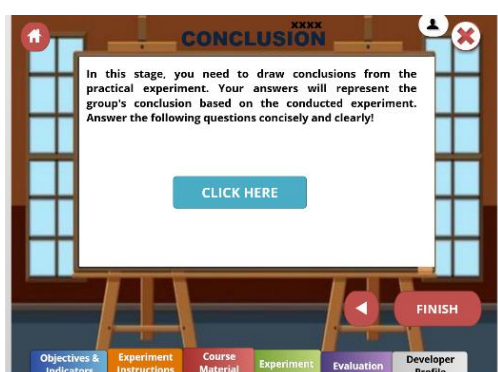


Figure 10. Conclusion Display

Virtual lab-based learning media discovery learning developed in HTML 5 form. So that learning media can only be accessed online using a laptop or smartphone. Next is the learning media validation stage, which is carried out by expert validators. The validation results assess that the learning media is suitable for

testing on students. The validation results also produce revisions to improve learning media. After the learning media has been revised, limited and field trials will be conducted. A limited trial was conducted in class XII MIPA 3 SMAN 2 Yogyakarta. Analysis of increasing critical thinking skills is carried out using the T-test. The T-test results can be seen in Table 2.

Table 2. T-test result

		Paired Samples Correlations			
		N	Correlation	Sig.	Sig.(2-tailed)
Critical thinking & skills	Pretest	35	.504	.002	.000
	Posttest				

Table 2 shows that the significance value is less than 0.05, so there is a significant difference between the data on critical thinking skills, both pretest and posttest. This shows that students' critical thinking skills have increased after being tested in a virtual lab. Furthermore, limited trials were also carried out. The readability test carried out by students was 3.80 in the excellent category. Meanwhile, the teacher's practical results were 3.66 in the excellent category. There are revisions or improvements to the virtual lab from the results of limited trials. After the learning media has been revised, the next stage is the field trial stage. The results of the students' readability test are shown in the following Table 3.

Table 3. The Results of Readability Analysis

No.	Aspect	Rating Result	Criteria
1.	Perception of ease of use	3,91	Excellent
2.	Perceived benefits	3,74	Excellent
3.	Appearance	3,83	Excellent
4.	The use of media in learning	3,64	Excellent
Rating average		3,80	Excellent

Table 3, which shows the results of students' readability of learning media virtual lab, shows an excellent category with an average of 3.80. These results indicate that virtual labs can be applied to class XII

MIPA students. Apart from the readability test by students, there is also a practicality test carried out by physics teachers. The results of the practicality test are shown in Table 4.

Table 4. Results of teacher practicality assessment of virtual-lab learning media based on discovery learning

No.	Aspect	Rating Result	Criteria
1.	Material	3,67	Excellent
2.	Presentation	3,61	Excellent
3.	Language	3,75	Excellent
4.	Appearance	3,64	Excellent
Average Rating		3,66	Excellent

The teacher's practicality test resulted in an average of 3.66 in the excellent category. Thus, virtual-lab-based discovery learning can be used as a learning medium to improve students' critical thinking skills. The field trial stage can be carried out after carrying out a practical test from the teacher and getting suggestions for improving the virtual lab.

Field trials were conducted in two schools, SMA Negeri 2 Yogyakarta and SMA Negeri 2 Sleman. Field trials were carried out to determine the effectiveness of virtual labs on students' critical thinking skills. The research subjects were divided into three: the experimental class using instructional media virtual-lab-based discovery learning, the counter-1 class using diktat learning media, and the contra-2 class using media slide PowerPoint. Pretests and posttests are used to measure critical thinking skills. The results of increasing critical thinking skills are shown in Figure 11.

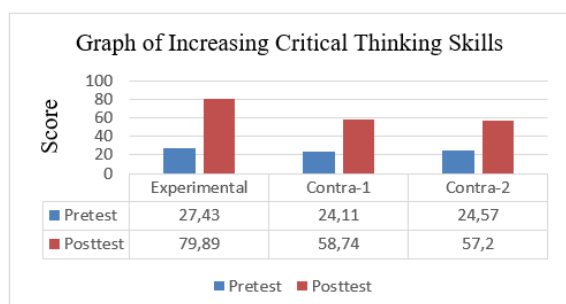


Figure 11. The Improvement of the Critical Thinking Skills

Figure 11 shows the increase in students' critical thinking skills. Figure 11 shows the critical thinking skills in each class, namely the experimental class, with an average posttest of 79.89; class contra-1, with an average posttest of 58.74; and class contra-2, with an average posttest of 57.20. Therefore, critical thinking skills between the experimental class, counter-1 class, and counter-2 class are respectively in the high, medium, and medium categories. Next, to see the effect of using learning media on critical thinking skills and scientific attitudes, a MANOVA test analysis was carried out. The MANOVA test must be carried out to meet the prerequisite tests first. The data used in the prerequisite test is normally distributed and homogeneous. After the data meets the prerequisite tests, a MANOVA test is carried out. The MANOVA test results are shown in the following Table 5.

Table 5. MANOVA Test Result

Effect (Class)	Value	Sig.
Hotelling's Trace	0,356	0,000

The MANOVA test results in Table 5 show differences in improvement between the experimental class, counter-1 class, and contra-2 class. Meanwhile, the amount of effective contribution can be seen in the column and Square, which shows a value of 0.287 (large effect size) and 0.179 (medium effect size). Based on these results, it can be said that virtual lab is learning media-based discovery learning that improves critical thinking skills with large and medium levels of effectiveness. The effect size of the test result is shown in Table 6.

Table 6. Analysis Results of Effective Contributions

No.	Variable	Eta Square	Cohen's f	Interpretation
1.	Critical thinking skills	0,287	0,339	Large effect size

Based on the MANOVA test, there was a significant increase in students' critical thinking skills. Thus, the critical thinking skills of experimental class students are better than those of the contra-1 and contra-2 classes.

Disseminate

After the virtual-lab learning media based on valid discovery learning, the final revision was then disseminated to physics teachers in several schools in Yogyakarta, namely SMAN 2 Yogyakarta, SMAN 2 Sleman, and SMAN 1 Godean.

Discussion

Instructional Media discovery learning-based virtual-lab that was developed takes the format in HTML 5. This is an important breakthrough in educational technology. This learning media product offers several advantages as a solution to educational problems. Besides that, it also has limitations with previous research in the same field. First, the main advantage of this media product lies in the application of discovery learning principles. This can be seen from combining discovery learning syntax into a virtual laboratory. In this section, students are actively involved in the learning process. Another advantage of this product is that it stimulates students' critical thinking skills. This stimulation process is achieved through a very comprehensive series of activities. This media product explains that the practicum stage starts with stimulation activities, stating a problem, generating group ideas, and then determining ideas. After this stage, the next process is problem formulation, exploration, and practical activities, followed by the data analysis stage until the final stage concludes. Then another advantage of this learning media product is that it contains discovery learning syntaxes, such as stimulation, problem formulation, and exploration in each practical part.

This model is not completely new; several studies have been carried out before,

such as by Sutarno (2019) and Safari (2022). Both studies above used virtual laboratories as research objects and critical thinking variables. However, what differentiates this research from previous research is that the product can comprehensively integrate the principles of discovery learning. Another differentiator and advantage of this research is that special indicators for critical thinking skills were created as differentiators from previous research. About the learning process, the advantage is in the material, namely the photoelectric effect, which in class has an advantage with teachers who only experiment using PowerPoint slides. This is because this research uses a Virtual Lab as a learning medium.

Then, the flexibility of this product, which is web-based and compatible with HTML 5, ensures product accessibility anytime and anywhere. As another advantage, it can be a valuable resource for teachers and students. Virtual laboratories can potentially become facilities for data collection, data analysis and scientific reasoning. In this way, it can help students develop their skills, namely critical abilities and scientific attitudes effectively. However, this product also has some limitations. However, this product shows potential in improving critical thinking skills. One of them is that the effectiveness of this product can vary according to the abilities of the user, in this case, students. The abilities in question are motivation and the context of their application. Another limitation is the carrying capacity of laboratory resources such as computer systems in schools, internet services for school computers and students' smartphones. Therefore, not all educational institutions provide adequate and universal computer and internet systems.

In conclusion, I would like to say that virtual lab learning media based on discovery learning is a valuable contribution to education, especially educational technology. The existence of advantages in integrating discovery learning syntax and

emphasis on aspects of critical thinking skills, in general, can make it a concern when compared with previous research. The ability of this product to actively engage students encourages students' sharp analysis and increases their understanding of complex subjects such as the photoelectric effect. However, it is important to consider its limitations. Including the availability of resources and varying student factors. When implementing this innovative learning media. In general, research has a significant contribution in increasing the effectiveness of virtual laboratories in improving students' critical thinking skills and scientific understanding. Fibre would be better if it was distributed in seminar forums to obtain development facilities and disseminate products.

CONCLUSION AND SUGGESTION

This research has resulted in a product in the form of a virtual lab learning media based on discovery learning on the photoelectric effect. The virtual lab learning media based on discovery learning on the photoelectric effect is declared suitable after undergoing testing phases. The results fall into the category of being highly effective in improving the critical thinking skills of students at SMA Negeri 2 Yogyakarta and SMA Negeri 2 Sleman.

Further research could explore the long-term impacts of using virtual lab learning media on students' knowledge retention and whether it enhances their problem-solving abilities and critical thinking skills. Additionally, investigating the adaptability and effectiveness of this approach in various educational settings and subjects could provide valuable insights into its broader applicability. The research identified some limitations that need consideration. Firstly, the developed media is still dependent on internet availability, making it inaccessible offline. This could pose a challenge for users in environments without stable internet access. Moreover, the media is linked to a learning-based application, limiting its

flexibility outside that platform. Therefore, future research could focus more on the adaptability and effectiveness of this approach in various educational contexts and subjects, offering a more comprehensive understanding of its potential applications.

AUTHOR CONTRIBUTIONS

LS compiled the manuscript and reviewed the literature. All authors read and approved the manuscript. ZK constructed research and reviewed manuscripts.

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