Development of e-LKPD Based on STEM to Enhance Students' Critical Thinking Skills on Topic of Renewable Energy

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Abstract *- The research aims to develop e-LKPD based on STEM on renewable energy material that can facilitate students in enhancing critical thinking skills. Generally, LKPD is the term in Indonesian for student worksheets. This e-LKPD was developed by using the Research and Development (R & D) method with the ADDIE development model which consists of Analysis, Design, Development, Implementation, and Evaluation stages. The feasibility of STEM-based e-LKPD is measured through validation involving 3 lecturers and 3 physics subject teachers. The enhancement of students' critical thinking skills was measured through data collection involving 35 grade X students. Students' response to the developed e-LKPD was measured by using a student response questionnaire. Based on the analysis results, it can be concluded that: 1) e-LKPD based on STEM is feasible to use when reviewed based on aspects of material/content, design, and language. 2) The enhancement of students' critical thinking skills obtained an N-Gain of 0.68 which means that learning using e-LKPD based on STEM can enhance students' critical thinking skills with a medium category. 3) STEM-based e-LKPD received positive responses from students and received scores with good qualifications.*

Keywords*: e-LKPD; STEM; Critical Thinking Skills*

INTRODUCTION

Thinking abilities that require cognitive processes and motivate trainees to approach situations critically are known as critical thinking abilities. Inductive thinking abilities including relationship recognition, open-ended problem analysis, cause and effect analysis, conclusion illustrating, and consideration of pertinent evidence are all part of critical thinking. (Saputra, 2020). Teaching and developing critical thinking skills is regarded as something very important to develop so that students are able and used to dealing with various problems around them. (Agustina, 2019).

Based on research by Wahyudi, et al., (2020) which measured critical thinking skills using five indicators expressed by Ennis, including; (1) giving simple explanations, (2) building basic skills, (3) concluding, (4) making further explanations, (5) organizing strategies and tactics, the results show that students' critical thinking skills are generally in the low category, especially in the indicators of giving simple explanations, concluding and organizing strategies and tactics. This is due to a lack of experience, or participants are not used to facing learning that stimulates critical thinking skills. Comparable study was carried out by Rosmalinda, et al., (2021) by asking students to solve PISA-type questions, The findings indicated that learners' critical thinking abilities at SMP Negeri 1 Belitang III were still low with a percentage of 58.1%. Data from the research is in accordance with field studies conducted to one of the public high schools in Cimahi. Through interviews conducted with physics teachers, it was found that the learning process was still not focused on a particular skill, including critical thinking skills.

Physics is a subject that is expected to encourage critical thinking skills because

physics learning emphasizes the provision of direct experience to develop students' competencies so that students can understand the surrounding nature more scientifically (Taufik & Doyan, 2022). This renewable energy material is one of the physics content that requires students' critical thinking skills in facing the possibility of an energy crisis in the future. A learning tool is needed to enhance students' critical thinking skills so that students can criticize how efforts are made so that the use of energy sources can fulfill current needs without sacrificing the fulfillment of future generations (Wijayanti & Siswanto, 2020).

One of the strategies to enhance critical thinking skills is by developing learning tools as a form of strategy in putting into practice instruction that can enhance learners' capacity for critical thought. Lesson plans with learning situations, assessment questions, and student worksheets make up the learning resources. (Ardiansyah, et al., 2020). The STEM-developed LKPD can enhance learners' critical thinking abilities. This is because STEM-developed LKPD contains materials and questions pertaining to mathematics, science, technology, and engineering. In the science section, LKPD can train students' science process skills, while in technology, engineering, and mathematics it can train students' critical and creative thinking skills (Santoso & Mosik, 2019; Simatupang et al., 2019). The enhancement of students' critical thinking skills after learning using e-LKPD based on STEM was proven by Rizkika, et all., (2022) who found that e-LKPD based on STEM can enhance thinking skills with moderate criteria and an N-Gain of 0.43. Similar research was conducted by Kiswanto, et all, (2024), with the aim of developing products in the form of ethnoscience-integrated STEM-loaded e-LKPD to enhance students' critical thinking skills. This research found that the average score of students on the pretest was 50.30 while the average posttest score was 89.69. The average N-gain score is 0.79. It can be concluded that the e-LKPD Effectiveness on enhancing students' critical thinking skills in the good category. As science and technology advance there is a need for LKPD that are more innovative and can be packaged in the online form or can be called Electronic Learner Worksheets (e-LKPD) Kholifahtus, et al., (2021).

In light of the above explanation, researchers are interested in developing e-LKPD based on STEM which is expected to enhance students' critical thinking skills in physics subjects, especially on renewable energy materials. As a result, research must be carried out with the title "Development of e-LKPD Based on STEM to Enhance Students' Critical Thinking Skills on Topic of Renewable Energy".

RESEARCH METHODS

Research and Development (R&D) using the ADDIE model is the methodology employed. The ADDIE development model consists of 5 main stages, namely; Analyze, Design, Develop, Implement, and Evaluate (Branch, 2009).

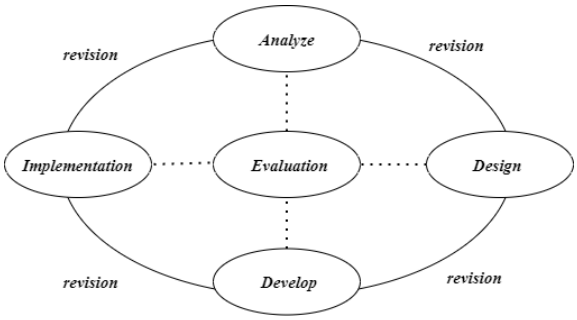

Figure 1. ADDIE Model

At the analysis stage, researchers conducted a needs analysis. This analysis was conducted to review the needs of e-LKPD development, analyze the skill profiles that need to be developed, and analyze the learning materials to be

developed. Teachers of physics were interviewed as part of the needs analysis process.

The design stage is conducted by designing the e-LKPD storyboard according to the material and learning aims that have been determined and incorporating STEM modeling in the e-LKPD.

The development stage is carried out through three steps. The first activity is making e-LKPD in accordance with the storyboard that has been designed. Next, the feasibility test of e-LKPD was carried out using the e-LKPD validation sheet. The validation sheet was assessed by 6 validators consisting of 3 physics lecturers and 3 physics subject teachers. There were 4 e-LKPD assessed by the validators which are; e-LKPD 1 (Science stage), e-LKPD 2 (Design stage), e-LKPD 3 (Construction), and e-LKPD 4 (Trial). The assessment is carried out using a Likert scale in the range of 0-3 with code information disagreeing to strongly agreeing. There are 3 aspects assessed by the validator, which are; material/content, design, and language. The e-LKPD validation sheet also provides a comment/suggestion column that can be filled in by the validator and used as a reference for improvement to perfect the e-LKPD. The last activity in the development stage is the improvement of e-LKPD according to the comments/suggestions given by the validator on the validation sheet.

The implementation stage was conducted for 3 days by applying the four e-LKPD that had been developed. At the first meeting, e-LKPD 1 (science stage) is applied, at the second meeting, e-LKPD 2 (design stage) is applied, e-LKPD 3 (construction) is used as a homework assignment that must be completed by students before meeting 3, at the time of meeting 3, e-LKPD 4 (trial stage) is applied. The implementation stage involved 35 students and was carried out to see how well e-LKPD could enhance critical thinking skills and students' responses to the developed e-LKPD. Students' critical thinking skills were assessed using a critical thinking skills question sheet instrument consisting of 10 essay questions designed in such a way based on the indicators of critical thinking skills by Ennis, (1987) which are; providing simple explanations, building basic skills, inferring, providing further explanations, and organizing strategies and tactics. Each indicator of critical thinking skills is represented by 2 questions. The critical thinking skills sheet is given to students in the form of pretests and posttests, pretests are conducted before students do a learning using e-LKPD while posttests are conducted after students do a learning using e-LKPD. Students' responses to e-LKPD were assessed using an instrument in the form of a student response questionnaire conducted through google forms.

At the evaluation stage, it is carried out based on the analysis of the enhancement of students' critical thinking skills and the results of the analysis of the students' response questionnaire. The results of the evaluation are in the form of input and suggestions that can be used for further research.

Data analysis was conducted quantitatively and qualitatively. The validation results of the six validators were analyzed using statistical calculations V Aiken, (1985). The pretest and posttest results of students were analyzed using the N-Gain statistical calculation. The values obtained were interpreted based on the following assessment criteria according to Hake, 1998.

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Table 1. N-Gain Value Criteria

N-Gain Value	Criteria
<g> < 0,3	Low
0,7 > <g> ≥ 0,3	Medium
<g> ≥ 0,7	High

The results of the student response questionnaire were analyzed in two ways, namely quantitatively using the percentage of approval. The value obtained is interpreted based on the assessment criteria according to Hadi, (1991) as follows.

Table 2. Percentage Criteria for Student Response

Percentage (%)	Criteria
< 26	Very bad
26-50	Bad
51-75	Good
76-100	Very good

Qualitative analysis was conducted on comments and suggestions given by students. Qualitative analysis was conducted by descriptive method.

RESULTS AND DISCUSSION

Results

1. Feasibility of e-LKPD

The viability of four e-LKPD 1 (science stage), e-LKPD 2 (design stage), e-LKPD 3 (construction stage), and e-LKPD 4 (trial stage) was examined. The validity of the e-LKPD produced was the basis for determining the viability of e-LKPD. Six validators carried out an e-LKPD validation test to determine the e-LKPD's viability. The analysis findings of the validator's evaluation of the four e-LKPD using the Aiken V index are shown below.

Table 3. Result of e-LKPD Analysis

e-LKPD	Aspects	V	Description
e-LKPD 1	Material/ content	0,89	Valid
	Design	0,96	Valid
	Language	0,97	Valid
e-LKPD 2	Material/ content	0,93	Valid
	Design	0,98	Valid
	Language	0,97	Valid
e-LKPD 3	Material/ content	0,92	Valid
	Design	0,94	Valid
	Language	0,97	Valid
e-LKPD 4	Material/ content	0,92	Valid
	Design	0,98	Valid
	Language	0,97	Valid

2. Enhanced Critical Thinking Skills

Ten essay questions were used to gauge the critical thinking skills of the students. Indicators of critical thinking skills used in these questions include providing simple explanations, building basic skills, inferring, providing further explanations, and strategies and tactics (Ennis, 1985). Each indicator of critical thinking skills will be represented by 2 questions.

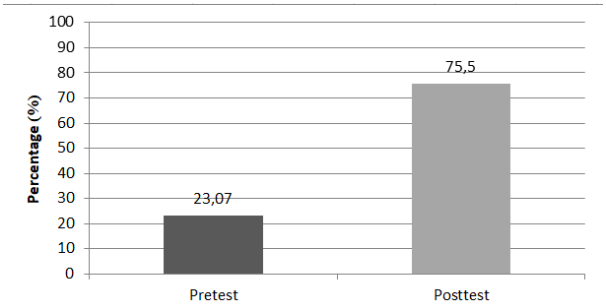


Figure 2. Average Difference in Pretest and Posttest Scores of Critical Thinking Skills

The average enhancement in students' critical thinking skills scores as a whole is presented in Table 2, while the enhancement for each indicator of critical thinking skills is presented in Table 3.

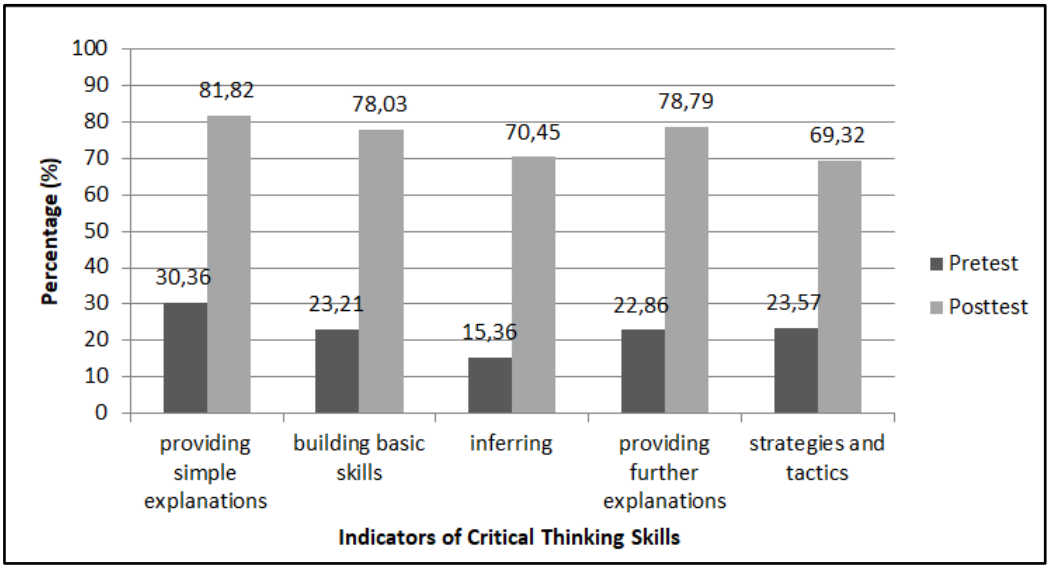


Figure 3. Pretest and Posttest Scores on Each Critical Thinking Skills Indicator

As shown in Fig 3, it can be seen that each indicator has increased significantly and each indicator also has different increases in critical thinking skills. The effectiveness of learning using e-LKPD based on STEM in an attempt to enhance students' critical thinking skills, can be seen through the N-Gain value obtained from the average pretest and posttest scores of each critical thinking skills indicator. The N-Gain results for each critical thinking skills indicator are shown in Table 4 below.

Table 2. N-Gain of Critical Thinking Skills

Indicators of Critical Thinking Skills	N-Gain	Criteria
Providing Simple Explanations	0,73	High
Building basic skills	0,72	High
Inferring	0,66	Medium
providing further explanations	0,72	High
strategies and tactics	0,60	Medium
Average N-Gain	0,68	Medium

3. Analysis of Student Response Questionnaires

The students' response questionnaire was conducted to see the students' responses to the e-LKPD based on STEM that they had used during learning. This questionnaire consists of 5 aspects, namely; use of e-LKPD, e-LKPD display, writing and language, understanding the material, and interest in e-LKPD. The analysis results of the students' response questionnaire for each aspect are shown in Table 5 below.

Table 3. Analysis of Learner Response Questionnaire

Aspects	Percentage	Description
use of e-LKPD	73%	Good
e-LKPD display	74%	Good
writing and language	75%	Very good
understanding the material	76%	Very good
interest in e-LKPD	70%	Good
Average	73,6%	Good

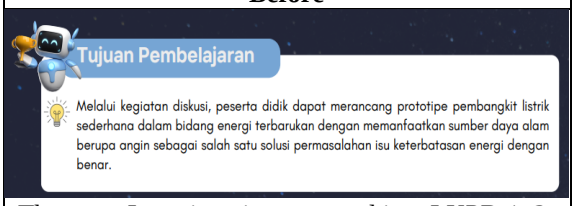
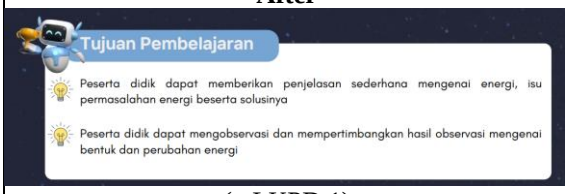
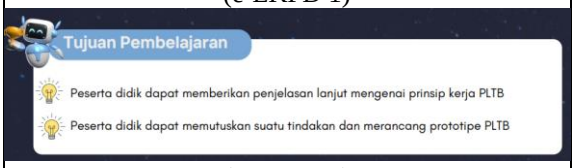
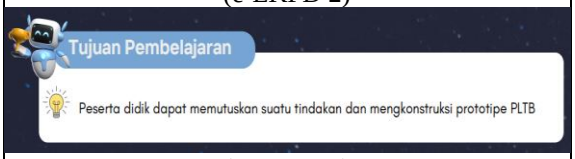
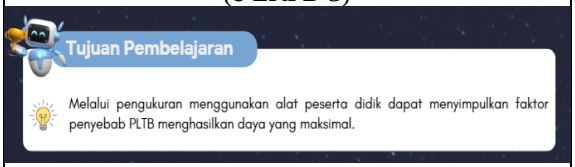
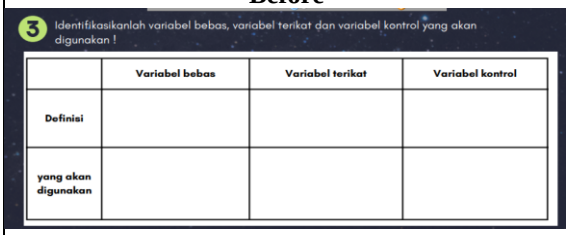
Discussion

1. Feasibility of e-LKPD

e-LKPD can be considered valid if the value obtained is higher than the V limit set. The V limit depends on the number of ratings and raters Aiken, (1985). This study used 4 ratings and involved 6 raters so the V limit that must be achieved for the e-LKPD material to be valid is 0.89. Table 3 presents that the V value of the four validated e-LKPD is higher than the V value limit set. So it concludes that e-LKPD 1, e-LKPD 2,

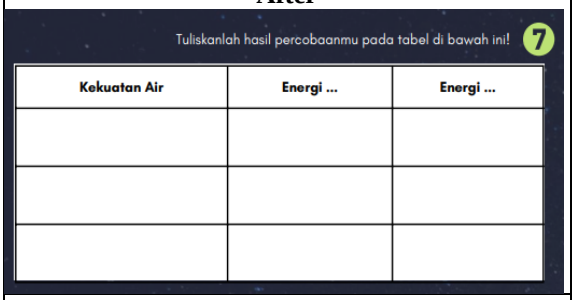
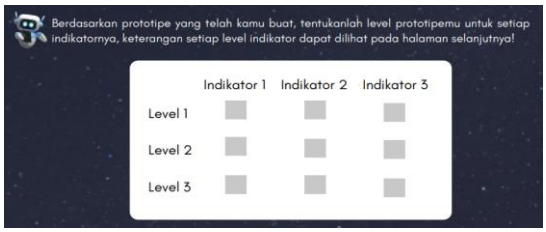
e-LKPD 3, and e-LKPD 4 are qualified to be used in learning. Besides giving an assessment, the validator also gave some comments and suggestions that should be repaired.

Table 4. Improvement of e-LKPD

Comments and suggestions
Is the learning aim for each meeting/LKPD the same? Because the result of each LKPD is different
Before

The same Learning aims are used in e-LKPD 1, 2, 3 and 4.
After

(e-LKPD 1)

(e-LKPD 2)

(e-LKPD 3)

(e-LKPD 4)
The variable table is not clear enough, it is better to separate the question between the definition of each variable and the command to mention the variable that will be used (e-LKPD 1)
Before

After

Comments and suggestions

There are no clear filling instructions in the experiment data table. It is better to put the title on each column of the table (e-LKPD 1)
Before

After

There is no specific instruction, the column should be filled with what icon, it is better to use the checklist feature on the "live worksheet" so that when the student clicks on the column, the column is immediately marked (e-LKPD 2).
Before

After


Each e-LKPD represents each discipline in the STEM approach, which is science, technology, engineering, and mathematics. The aim is to solve problems

related to energy issues, especially wind energy.

e-LKPD 1 focuses on science disciplines. Students are asked to find out the problems of energy issues in Indonesia through videos. Furthermore, students conduct exploration through PhET to gain fundamental knowledge about the process of changing energy that occurs, especially in wind power generators. This is in accordance with the opinion of Tarlokson, (2014) which clarifies that the scientific fields within STEM are studies pertaining to natural laws, in addition to the handling or application of relevant information, theories, concepts, and customs. Science is the process of creating new information through scientific inquiry as well as the body of knowledge that has been amassed over time.

e-LKPD 2 focuses on technology and engineering disciplines. At the technology stage, students are given videos and diagrams that explain the principles of the work of wind power generation, then students are asked to re-explain the principles of wind power generation in detail on each component of the tool to ensure they understand the principles of the work of wind power generation before they are requested to design a prototype of a wind power generator. Activities on e-LKPD 2 are in accordance with the opinion of Tarlokson, (2014) which defines technology as an entire system of entities, including people, organizations, information, procedures, and equipment needed to produce and use technical objects. While at the engineering stage students are asked to design a prototype of a wind power generator as an alternative solution to solve energy issues in Indonesia.

e-LKPD 3 will continue the engineering stage. Students are asked to do the construction of the design they have made. The technology stage in accordance with the opinion of Tarlokson, (2014) clarifies that the engineering stage is an accumulation of information regarding the design and development of manufactured goods and methods for problem-solving.

e-LKPD 4 focuses on the discipline of mathematics. Students are asked to measure the voltage and current generated from the wind power generation prototype produced in different wind conditions. This is in accordance with the opinion of Tarlokson, (2014) who defines the mathematical stage as the investigation of quantities, numbers, and space relationships. The improved e-LKPD can be accessed by students through the live worksheet web. According to Prabowo, (2021) liveworksheet.com is a web-based application that can convert printed worksheets in the form of .doc, .pdf, and .jpg into interactive worksheets that include text, images, animations, and videos that are more effective so that students do not get bored quickly. The four e-LKPD are compiled into a workbook to make it easier for students to access.

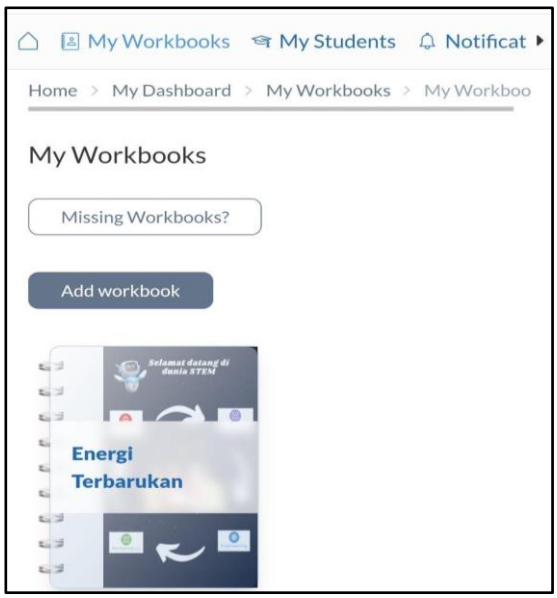


Figure 4. Workbooks External View

Figure 5. Inside View of Workbooks

2. Enhanced Critical Thinking Skills

Each critical thinking skill indicator is trained in all four e-LKPD based on STEM. The indicator of providing a simple explanation is trained in e-LKPD 1 through the question below.

Table 5. Questions on the Providing Simple Explanations Indicator

Question
Based on the video above, what problems did you and your group find?
Student's Answer
On earth, there is currently a lack of energy for power generation, coal as a fuel source for PLTU will run out shortly, and a lack of government role in technology development.
Question
According to the problems you found, give an alternative solution that can solve these problems!
Student's Answer
The alternatives that we could do; 1) Replace dependence on coal with renewable energy sources such as solar, wind, and water, 2) Encourage the government to focus on developing technology and human resources to ensure energy sustainability, 3) Increase public awareness about the importance of renewable energy sources

The activities of formulating problems and offering alternative solutions contained in the science stage e-LKPD and implemented in the classroom are considered effective in enhancing the indicator of providing simple explanations. This can be seen from the N-Gain value obtained, which is 0.73 with a high category. Building basic skills indicators is trained in e-LKPD 1 through the questions below.

Table 6. Questions on the Basic Skill Building Indicator

Question
Formulate a hypothesis that is relevant to your experiment!
Student's Answer
The hypothesis is that if the generator is functioning properly, the lights will be on and if the force of the water is greater, more energy will be produced (it will depend on the force of the flowing water).
Question
Explain the process of energy change that happens when water is replaced with wind!
Student's Answer
If in the experiment the water generator is changed to using wind, there will be a change in the energy source used to drive the turbine. Instead, the kinetic energy of the wind will be used to drive the turbine. The process will be similar, the mechanical energy from the wind will be used to move the electric generator, which will produce heat + light energy so that the lights will turn on.

The PhET experiment activities contained in the science stage e-LKPD and implemented in the classroom are considered effective in enhancing the indicators of building basic skills. This can be seen from the N-Gain value obtained which is 0.72 with a high category. The indicator of providing further explanation is trained in e-LKPD 2 through the questions below.

Table 7. Questions on the Indicator of Providing Further Explanation

Question
After watching the video and observing the diagram above, explain how the working principle of a wind power generator starts from energy transformation

until the electrical energy is distributed to the houses!

Student's Answer

Turbine- Gearbox- break system- rectifier- battery- transformer- substation- house

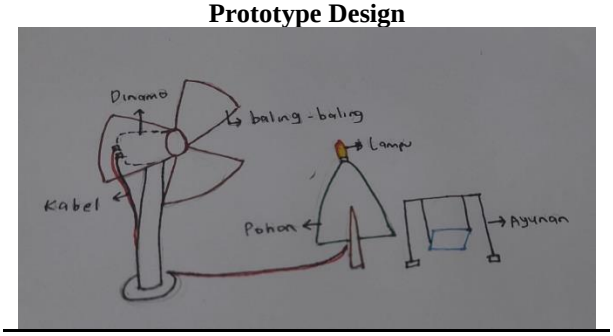
1. The turbine captures mechanical energy from the wind flow and passes it on to the generator
2. The gearbox converts the low rotation of the turbine into a high rotation
3. The break system keeps the rotation on the shaft after the gearbox works at a safe point when the wind is too strong
4. The generator converts mechanical energy into electrical energy
5. Rectifier converts AC current into DC
6. The battery stores electrical energy
7. The inverter converts DC current into AC
8. Transformers change the electrical quantities of a circuit
9. Substation as a voltage distribution point before reaching homes
10. The house receives electricity that is ready for daily use

The activity of explaining the working principle of the wind power plant is contained in the e-LKPD of the design stage and implemented in the classroom is considered effective to enhance the indicator of providing further explanation. This can be seen from the N-Gain value obtained which is 0.72 with a high category.

Indicators of strategies and techniques are trained in e-LKPD 2 and e-LKD 3 In e-LKPD 3, students are asked to design a prototype of a wind power generator with the explanation of working principles and details of materials and equipment.

Table 8. Questions on Strategy and Technique Indicators

Prototype Design



Work Principle

The working principle of the prototype that group one makes is that the kinetic energy generated by the rotation of the wheel will be converted into electricity by the generator. the electricity generated will be reflected in the indicator light. so in this design, we use components namely (wheel-dynamo-cable-and lamp).

Details of Tools and Materials

Bottle cap: for the center of the pinwheel
Thin cardboard: to make the pinwheel
12V dynamo: to convert kinetic energy into electricity
Red and black cable: to distribute the electrical energy generated from the dynamo to the lamp.
Lamp: to indicate the electrical energy that comes out of cardboard: used as the base of the pinwheel
tin: to stick the
Wires to the generator solder: as a tool for melting tin sticks
Ice cream stick: to make the swing
Pipe: the body of the pinwheel
The total cost of Rp. 17,500 (generator, cable, lamp)

In e-LKPD 3, students are asked to construct the design. e-LKPD 3 trains students to manage strategies so that the time during construction is effective and trains students to manage strategies so that the design that has been made can be realized. The activity of making the design of the wind power generation prototype contained in the design stage e-LKPD and the construction of the wind power generation prototype contained in the construction stage e-LKPD and implemented in the classroom is considered effective to enhance the indicators of strategies and techniques. This can be seen from the N-Gain value obtained, which is 0.60 with a moderate category. Inferring indicators are practiced in e-LKPD 4

Table 9. Questions on the Inferring Indicator

Question

What are the factors that make wind power generation prototypes able to produce maximum power?

Student's answer

Some of the factors that can impact a wind power generation prototype to produce maximum power include

1. Efficient Turbine Design
   An efficient turbine design can maximize the capture of energy from the wind. This includes the shape, size, and orientation of the turbine blades designed to maximize energy

	capture from the wind.
2.	Turbine Height The height of the turbine also affects the availability of more stable and stronger winds. Turbines placed at the right height can increase the efficiency of capturing wind energy though.
3.	Quality of Materials and Construction The use of quality materials and sturdy construction will ensure the reliability and optimal performance of wind power generation over a long period of time.

The activity of calculating power contained in the e-LKPD at the trial stage implemented in the classroom is considered effective in improving the conclusion indicator. This can be seen from the N-Gain value obtained, which is 0.66 with a moderate category.

While the average N-Gain obtained is 0.68 it can be concluded that learning using e-LKPD based on STEM can enhance students' critical thinking skills with a medium category according to Hake, (1989). This is in accordance with research conducted by Fithri, et al., (2021) which, After learning with STEM-based LKPD, there was an enhancement in students' critical thinking skills and obtained an N-Gain of 0.94 with a high category. This happens because learning with STEM forces students to collaborate and find answers to LKPD questions in accordance with the learning process. When learning, students absorb new material through observation, develop new concepts through understanding experiments, and answer questions based on their knowledge and skills. Students also collect data from experiments to practice their understanding of the idea. By conducting research and conducting experiments to support their theories, students can gain knowledge through the application of an integrated.

Analysis of Student's Response Questionnaire

Based on Table 5, it shows that in the aspect of using e-LKPD, the score is 73% with a good category. The excerpt of comments given by students is presented in Table 7 below.

Table 7. Comments on the Usage Aspect of e-LKPD

Comments
Sometimes to enter the web you have to log in first and cannot log in, but using the web can make the lesson easier
Good, funny and unique because I have never done Ikpd on my cellphone.

In the display aspect, the score is 74% with a good category. The excerpt of comments given by students is presented in Table 8.

Table 8. Comments on Display Aspects

Comment
Very interesting, so the enthusiasm for learning
It is appropriate but if on the cellphone it is too small and must be zoomed first

In the aspect of writing and grammar, it received a score of 75% in the good category. Extracts of comments given by students are presented in Table 9 below.

Table 9. Writing and Grammar

Comment
It's good and easy to understand
The writing is clear and not disorganized

In the aspect of understanding the material, the score is 76% with a good category. The excerpt of comments given by students is presented in Table 10.

Table 10. Understanding the material

Comment
Easy to understand, provides new insights into material that has not been studied
Reasoning is quite easy to understand even though it makes a little dizzy

In the aspect of interest in e-LKPD, it gets a score of 70% with a good category.

The excerpt of comments given by students is presented in Table 11 below.

Table 11. Interest in e-LKPD

Comment
The use of e-LKPD is one of the means not to get tired of writing material in books, then using e-LKPD is more efficient than using books.
Very exciting, cool too, and not boring

The average student response questionnaire is 73.6 with a good category. So it can be concluded that the e-LKPD based on STEM that was developed received a positive response from students. Students stated that e-LKPD can increase the enthusiasm for learning and reduce the boredom of students. This is in accordance with the opinion of Daryanto, et al., (2022) who researched increasing student learning motivation after using interactive e-LKPD. This research obtained the results that student motivation will increase by using innovative e-LKPD this is because interactive e-LKPD offer various features that can be used to display learning materials in various forms such as audio, video, animation, or other symbols that are interesting and can help increase student learning motivation.

CONCLUSION

The developed e-LKPD is feasible to use and can enhance students' critical thinking skills by 0.68 with a moderate category. The e-LKPD based on STEM developed also received a positive response from students with an average score of 73.6% and got a good category. This is in accordance with research conducted by Margaretha, et all., (2024) that e-LKPD based on STEM can make students more active and think more massively through activities designed in accordance with the STEM framework and critical thinking indicators and can enhance students' critical thinking skills by 59.8% with moderate criteria. Suggestions from this study are to develop e-LKPD using a more interactive website and develop STEM-based e-LKPD on other physics topics.

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