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Effectiveness of E-Worksheet Renewable Energy on STEM-Project Based Learning to Improve High School Students' Critical Thinking Skills and Collaboration Skills

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Abstract – *The topic of renewable energy is one of the fundamental aspects in physics education, but many students have difficulty in understanding its abstract concepts. The purpose of this study is to determine the effectiveness of Renewable Energy E-worksheet in STEM project-based learning, which is presented to students and operated through devices. The research model used was a quasi-experiment with a one group pre-test post-test design involving 50 students of class X Phase E selected through randomized cluster sampling. This study used an experimental class and a control class with different learning activities. Data was collected through tests and questionnaires before and after treatment, focusing on students' critical thinking skills and collaboration on renewable energy material. Based on the results of the analysis, it was found that there were still problems in developing students' critical thinking and collaboration skills. The results showed that through the use of Renewable Energy E-worksheet for STEM-Project-Based Learning, significant results were obtained in improving critical thinking and collaboration skills in the experimental class. Data from pre-test and post-test results were tested and proven to be normally distributed and homogeneous with a significance value above 0.05. The N-Gain value of critical thinking ability in the experimental class was 0.72 and the N-Gain value of collaboration ability was 0.75. In the control class, the N-Gain value of critical thinking skills was 0.52 and the N-Gain value of collaboration skills was 0.46. The use of Renewable Energy E-Worksheet in STEM Project-Based Learning helps improve critical thinking skills and collaboration skills.*

Keywords: *collaboration skills; critical thinking skills; e-worksheet; renewable energy; STEM-project based learning.*

I. INTRODUCTION

In the 21st century, every aspect of human life is required to keep up with the rapid development of technology and science. Science and technology are developing very rapidly and education is one aspect of life that has a very important role for human life to adapt in the midst of global development and competition(Yusuf & Widyaningsih, 2019). Education is aimed at encouraging students to develop skills that help them respond to changes that occur over time

(Asrizal et al., 2022). Success in the field of education can be achieved through the learning process of a teacher who has theoretical and practical skills (Sulaeman et al., 2022; Martínez-Borreguero et al., 2022). Both abilities will help teachers to make learning easy to understand, fun, and students are more active in the learning process (Büyükdede & Tanel, 2019). This success can be achieved if the teacher as an educator can do his job well and stimulate students to get involved in the learning process.

The learning model developed is expected to improve 4C skills. In Indonesia, such skills can be found explicitly in the project-oriented Merdeka Belajar Curriculum to strengthen the Profil Pelajar Pancasila and are developed based on certain themes that have been determined by the government (Kemendikbud, 2022). Merdeka Belajar curriculum promotes STEM skills in a comprehensive and integrative way with P5 designed to encourage students to interact with the real world and solve problems through cross-disciplinary learning (Kemendikbud, 2023). The implementation of an independent curriculum can help educators and students to learn science concepts based on development and learning outcomes.

The project-based learning model is suitable to be applied in Merdeka Belajar curriculum learning to improve 21st century skills (Suherman et al., 2020). Project-based learning allows students to face complex problems that require critical thinking to solve and encourages students to conduct research and analysis in order to understand the problem and find solutions (Putri et al., 2021). In fact, the use of the project-based learning model in the Merdeka Belajar curriculum has not been widely used by teachers for classroom learning (Purwaningsih et al., 2020). This learning model, artifacts are created at the end of the lesson, allowing teachers to monitor students' activities during the lesson (Alemneh & Gebrie, 2024). The application of project-based learning models has a significant impact on students' abilities, including improved learning outcomes and improved 4C skills (Guo et al., 2020). According to research conducted by Putri et al., (2021), the critical thinking skills of students taught using a project-based learning model was better than that of students taught using traditional learning, and the percentage of N gains in students' critical thinking skills increased by 75.40% (high category). Based on this explanation, the use of project-based learning can affect students' learning outcomes and their ability to improve 4C skills..

In addition to the use of project-based learning model, STEM (Science, Technology, Engineering, and Mathematic) approach can be applied with project-based learning model. The use of STEM approach in learning can help students to improve learning outcomes both academically and practically (Yik et al., 2022; Fitriani, 2023). Learning with the STEM-PjBL model can affect the level of ability to solve problems (Butai et al., 2021), improve higher order thinking skills and reduce students' misconceptions (Martawijaya et al., 2023). The use of a

project-based learning model with a STEM approach can be applied for better results. In addition, the application must be supported by appropriate teaching materials, such as student worksheets.

Student worksheets that can be developed to maximize the use of technology in learning are electronic student worksheets or e-worksheet. However, the use of e-worksheet as teaching materials is still rarely used by teachers in the classroom learning process (Sarah & Rani, 2020). According to the utilization of e-worksheet as a learning tool helps overcome space and time constraints (Wahyuni et al., 2021) and interactive tools to help teachers carry out classroom tasks easily so that students can also learn happily without feeling bored. The learner worksheets developed should be aligned with the character values to be built (Sarah & Rani, 2020). Development of worksheets that can involve students in carrying out environmental activities in a fun situation in a sustainable project (Amalya et al., 2021). The worksheet in question is a STEM-based e-worksheet with a project-based learning model.

Critical thinking is one of the importants 21st century skills for students. Critical thinking skills is a key goal of the Kurikulum Merdeka movement, which matches the characteristics of Pancasila students (Amalya et al., 2021). Critical thinking skills can prepare students to think about various sciences (Alemneh & Gebrie, 2024), prepare for intellectual self-actualization (Putri et al., 2021), and develop them into individuals who have the potential to survive in the 21st century (Asrizal et al., 2022). The purpose of critical thinking is to decide what to do or believe after considering a problem and reaching a conclusion (Martawijaya et al., 2023). The critical thinking skills of students in Indonesia are still in the low category (Pradana et al., 2020). The results of the interview with the physics teacher at SMA Negeri 1 Subang revealed that during the learning process, only a small number of learners actively asked questions, while most others only listened without actively participating. Learners are not used to dealing with HOTS questions and are usually negligent when working on them. Therefore, critical thinking skills in students need to be continuously improved by integrating them directly into the learning process.

In addition to critical thinking skills, the role of collaboration skills is no less important for students to have in overcoming problems related to science and technology. When learning collaboratively, students can work together in groups to complete physics projects, such as building a waterwheel or designing an experiment. Thus, collaboration allows students to share knowledge and experience in understanding physics concepts (Santoso et al., 2021). Collaboration skills are needed for students to work productively in teams to complete complex tasks and solve problems more effectively and efficiently (Safarini, 2019). In addition, students are expected to develop collaborative skills to show tolerance (Kuo et al., 2019), responsibility (Conde et al., 2019), respect (Nurtanto et al., 2020), and wisdom when facing complex problems

(Santoso et al., 2021). Therefore, it is necessary to develop teaching materials and apply an appropriate project-based learning model to improve collaboration skills in students.

Physics learning is one of the fields of education that is closely related to the development of the 21st century. Physics is one of the branches of science that explains natural phenomena and explains how these natural phenomena occur (Khoiri et al., 2023). The ability of students to understand physics concepts is one of the determinants of their learning success (Mundilarto & Ismoyo, 2017). However, physics subjects are considered difficult by many students (Yuliati et al., 2018). One of the reasons for this belief is that students believe that physics is a science that requires understanding other disciplines such as mathematical concepts, arguments, and complex concepts in physics (Aprillia & Pathoni, 2021). Renewable energy material is one of the materials that is considered difficult (Febriansari et al., 2022). Renewable energy material is important material for students to master because the material is related to global, regional, political problems, as well as the daily lives of humanity (Aprillia & Pathoni, 2021) and the first step to achieving energy security in the future (Wulanndari & Admoko, 2023). Efforts to increase students' understanding of renewable energy material are carried out by linking learning materials with events or phenomena around students (Asrizal et al., 2024).The form of linking learning materials with life around students is through project-based learning that can provide meaningful experiences for students.

Based on the description of the background, the researcher intends to develop teaching materials in the form of STEM-based electronic students worksheet with a project-based learning model that can be used to assist students in improving critical thinking skills and collaboration skills on renewable energy material. This research focuses on renewable energy in class X Phase E SMA Negeri 1 Subang in the 2024/2025 academic year. By integrating project-based learning methods with Liveworksheets technology, this research is expected to contribute to the development of students' critical thinking and collaboration skills while answering the challenges of 21st century education that demands the integration of technology and innovative approaches in the teaching and learning process.

II. METHODS

The electronic worksheets in this study can be viewed at the URL: https://www.liveworksheets.com/w/id/fisika/7740747 . The e-worksheet design was created using Canva to produce a visually appealing and up-to-date template design. The reason why Canva was chosen because it has an intuitive and easy-to-use interface, even for users who have no previous design experience. The cover design developed can be seen in Figure 1. The e-

worksheet was launched using Liveworksheet in a link format that allows students to easily access it regardless of the different operating systems on each device. In addition, by utilizing Liveworksheet, the e-worksheet developed contains the required learning videos. This makes it easier for students to understand the learning process. The development carried out complements the e-worksheet is composed of cover, preface, table of contents, instructions for using e-worksheet, identity, description of learning activities with apperception, a video explaining the working procedures for making a simple waterwheel project, and evaluation.

E-worksheet is structured using STEM-PjBL syntax, namely reflection, research, discovery, application, and communication. Learning activities in this study were carried out as many as 3 meetings. The first meeting introduced the forms of energy, energy changes and some renewable energy used in Indonesia. The second meeting began to make a simple waterwheel project as one of the renewable energy used for alternative energy sources. The third meeting each group tried to demonstrate a simple waterwheel project that was successfully made and then continued by presenting the results and concluding about the material that had been learned.

Figure 1. Display E-Worksheet Cover

This research is a quasi-experimental research with a one group pretest-posttest design and was conducted from October to November 2024 in Subang. The total sample consists of 50 students of class X phase E. The two classes will be divided into experimental and control classes to see the effectiveness of using e-worksheet renewable energy on STEM-project based learning. Sampling was carried out using randomized cluster sampling method because it was to ensure that the experimental and control groups were homogeneous and that the distribution of data did

not differ significantly. Therefore, the sample for this study was randomly selected from the population so that each cluster had an equal chance of being selected.

Table 1. One-Group Pre Test-Post Test Design

Class	Pre-Test	Treatment	Post-Test
Experiment	O_1	X_1	O_2
Control	O_2	X_2	O_2

Description:

O_1 = Data from the evaluation of critical thinking and collaboration skills before treatment

O_2 = Data from the evaluation of critical thinking and collaboration skills after treatment

X_1 = Learning using e-worksheet renewable energy on STEM-project based learning

X_2 = Learning using conventional learning models

Data collection uses test instruments that display indicators of critical thinking skills and questionnaire instruments that display indicators of collaboration skills. Before using these tools, their validity was tested to ensure their relevance to measure the learning results as planned. The validity of the test elements is assessed by the Aiken V formula, with a valid coefficient greater than 0.8, showing high validity. These steps ensure that valuable tools to measure the understanding of the equipment of the device. Test instruments and questionnaire instruments were supported by an assessment rubric specifically designed to measure critical thinking and collaboration indicators. Indicators of critical thinking skills are: (1) analyze facts based on problems, (2) formulate problems, (3) choose logical arguments based on relevant information, and (4) make conclusions. While the indicators of collaboration skills are: (1) contribute actively and effectively, (2) work together productively, (3) take responsibility, (4) respect other members, and (5) adapt to various roles.

The data is collected from the pretest and posttest were analyzed by statistical software (SPSS 27.0 version for Windows). The normality test is done using the Shapiro-Wilk test due to the small size of the sample. Based on the normality test results, the homogeneity test and the GLM test have been used to evaluate whether there is a statistical difference in student learning results before treatment. If the probability value (sig) > 0.05, the data is considered normal distribution; If the probability value (sig) < 0.05, data is considered not normal distribution.

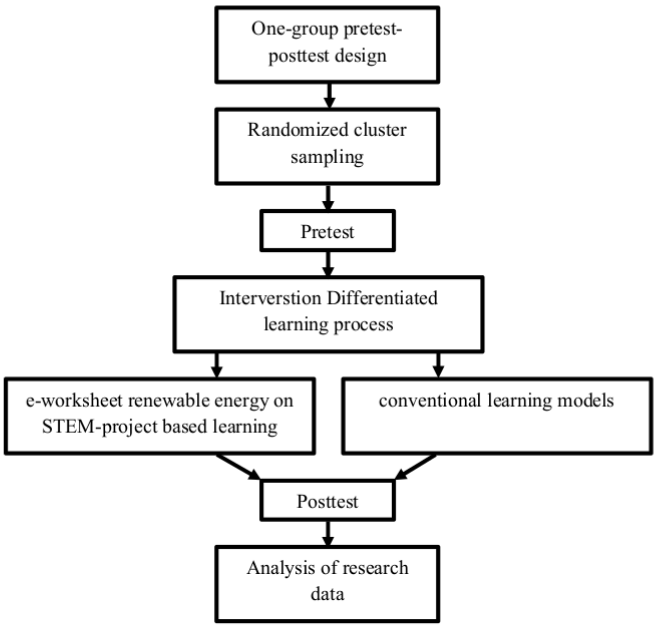

Figure 2. Research Steps

The critical thinking skills test instrument and the collaboration skills questionnaire instrument were validated by two expert validators who are physics education lecturers and two physics teachers. The assessment of the test instrument and questionnaire instrument includes content feasibility, language feasibility, and item construction or questionnaire. The experts have validated the items on the test instrument and the questionnaire items on the questionnaire instrument. The validation results based on the statements and decisions of the experts concluded that the test instruments and questionnaire instruments were suitable for measuring critical thinking skills and collaboration skills.

$$N - Gain = \frac{(S_{post} - S_{pre})}{(S_{max} - S_{pre})} \quad (1)$$

Description:

S_{post} = post-test scores for each student

S_{pre} = pre-test scores dor each student

S_{max} = maximum score

The result of the calculation of the gain score (N-Gain) can be classified according to the criteria listed in Table II.

Table 2. N-gain Classified

Interval	Category
0,70 < N-Gain	High
0,30 ≤ N-Gain ≤ 0,70	Medium
N-Gain < 0,30	Low

The N-Gain score refers to the classification of the impact of the use of renewable energy e-worksheets on critical thinking and collaboration skills in STEM project-based learning and consists of three classifications: high, medium, and low. Previously, the N-Gain test was performed using Microsoft Excel. Additionally, the effectiveness of treatment is calculated using the formula size of the Cohen effect, measuring the degree of the independent effect of the sample size. The effectiveness of intervention has been evaluated more by using the Cohen effect formula, providing a measure of the degree of treatment effect.

III. RESULTS AND DISCUSSION

The pretest and posttest responses from the students were collected and scored based on the scoring rubric. Subsequently, the total pretest and posttest scores for each student were analyzed using SPSS version 27.0 for Windows. Data analysis uses inferential analysis to determine the impact of renewable energy e-worksheet on STEM project-based learning by comparing students' pre-test and post-test scores. N-Gain test equation is used to evaluate the results. The results of this study are presented by assessing the pre-test and post-test scores using a testing tool that contains indicators of critical thinking and collaboration skills. Figure 3 shows the mean scores of pre-test and post-test for the experimental and control classes.

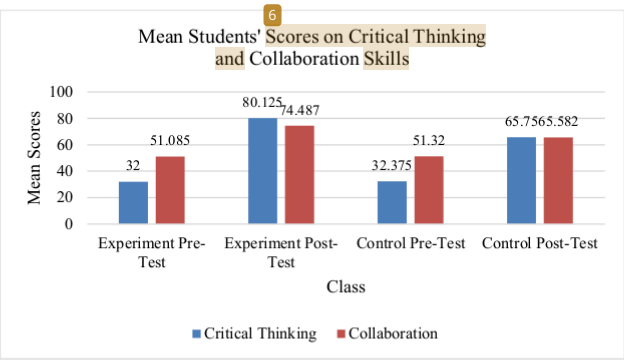

Figure 3. Mean Students' Scores on Critical Thinking and Collaboration Skills

The increase in post-test scores obtained by students can be clearly seen through the scatter diagram. The scatter diagram in Figure 3 shows that there was a significant increase in the post-test scores compared to the pre-test scores on each variable. This improvement in learning outcomes is consistent with findings from previous studies that show STEM-project based learning can improve students' critical thinking and collaboration skills. A study by Nisah et al. (2024) found that using STEM-project based learning resulted in improved students' critical thinking skills, while a study by Yanti et al. (2023) found that using STEM-project based learning motivated students to develop their collaboration skills. Then on table 3 shows the normality test based on the Shapiro-Wilk test. The Shapiro-Wilk test is used because there are less than 50 data from respondents in each class.

Table 3. Result of Pre-test and Post-Test by Shapiro-Wilk Normality Test

Variable	Test	Class	Stat.	df	Sig.
Critical Thinking Skill	Pre-Test	Experiment	0,981	25	0,905
		Control	0,971	25	0,678
	Post-Test	Experiment	0,936	25	0,118
		Control	0,977	25	0,825
Collaboration Skill	Pre-Test	Experiment	0,966	25	0,522
		Control	0,975	25	0,766
	Post-test	Experiment	0,959	25	0,403
		Control	0,952	25	0,284

Based on Table 3 which shows the data normality test according to the Shapiro-Wilk Test, all data has a significance value greater than 0.05, so it can be concluded that the pre-test and post-test data on students' critical thinking skills and collaboration skills are normally distributed. The homogeneity test was conducted to determine whether the critical thinking and collaboration skills test data in the experimental and control classes had homogeneous variances. Levene's test was used for this analysis, and the results can be seen in Table 4.

Table 4. Homogeneity Test Results Pre-Test anf Post-Test by Levene's Test

Variable	Test	Levene's Test	df1	df2	Sig.
Critical Thinking Skills	Pre-Test	0,070	1	48	0,793
	Post-Test	2,952	1	48	0,092
Collaboration Skills	Pre-Test	0,073	1	48	0,788
	Post-Test	0,007	1	48	0,936

Based on Table 4, it can be seen that the critical thinking skills and collaboration skills variables have a significance value greater than 0.05 so that it is stated that the pre-test and post-test data for the critical thinking skills and collaboration skills variables come from samples with the same population or are homogeneity. Therefore, it can be concluded that the data on the value

of critical thinking skills and collaboration skills come from the same population so they are homogeneity.

After the scores of critical thinking skills and collaboration skills were tested for normality and homogeneity, then the N-Gain test data were analyzed to determine the category of improvement and the level of effectiveness of using e-worksheet renewable energy on STEM-project based learning. e-worksheet renewable energy on STEM-project based learning is able to improve students' critical thinking skills and collaboration skills with the N-Gain category which can be seen in Table 5.

Table 5. N-Gain Result

Variable	Class	N-Gain Score	Category
Critical Thinking Skills	Experiment	0,72	High
	Control	0,52	Medium
Collaboration Skills	Experiment	0,75	High
	Control	0,46	Medium

Based on Table 5 N-Gain results, it can be stated that the use of e-worksheet renewable energy on STEM-project based learning can improve students' critical thinking skills and collaboration skills. The N-Gain value in the experimental class using the developed e-worksheet is higher than the N-Gain value in the control class using conventional learning. The effectiveness of improving students' critical thinking and collaboration skills after using e-worksheet renewable energy on STEM-project based learning was calculated using Effect Size. The resulting Effect Size value of 0.275 is included in the high category. This calculation shows that learning using E-LKPD based on STEM-Project Based Learning has a significant impact on improving students' critical thinking skills and collaboration. A significant increase in posttest scores compared to pretest scores indicates that learning using STEM-Project Based Learning-based E-LKPDs successfully optimizes the learning process, provides a deeper learning experience, and develops students' overall skills.

Learning activities on the e-worksheet support students to understand various renewable energies including the working principle of a simple waterwheel project which is one example of the use of renewable energy. In addition, learning activities are also able to build students' critical thinking and collaboration to complete a project. This improvement is supported by other research findings which state that the use of e-worksheet with STEM-project based learning can improve students' critical thinking skills (Nisah et al., 2024). The use of teaching materials that are aligned with the appropriate learning model, students are motivated to develop their collaboration skills (Yanti et al., 2023). E-worksheets can be integrated into various digital platforms such as Liveworksheets which facilitate communication between teachers and students in comprehending the learning material and support active and interesting learning for students.

IV. CONCLUSION AND SUGGESTION

The results of this study indicate that the use of e-worksheet renewable energy on STEM-project based learning has a significant and good influence on students' thinking skills and students' collaboration skills. The N-Gain scores of students' critical thinking skills and collaboration skills in the experimental class were 0.72 and 0.75, respectively, categorized as high improvement. The control class experienced a moderate improvement with N-Gain scores of students' critical thinking skills and students' collaboration skills of 0.52 and 0.46, respectively. The application of STEM-Project based learning provides opportunities for students to generate ideas collaboratively (Bulu & Tanggur, 2021) and stimulates critical thinking patterns (Rizki et al., 2024). There is a need to further improve the development and implementation of innovative instructional materials. Diverse and interactive materials build knowledge and critical thinking, and promote problem-solving through fair and collaborative decision-making. This is the answer to the demands of 21st century learning.

In addition to having a positive impact on the use of renewable energy e-worksheet on STEM-project based learning, it also has obstacles which are the limitations of this study. Internet network stability is very important in using this product so that video playback and e-worksheet filling can be accessed smoothly. For students, their experience is limited so that in making this simple waterwheel project not all groups can function properly. The teacher's expertise in using the product can also be an obstacle in creating an active class and improving critical thinking and collaboration skills. Thus, teachers need to design learning in a structured and systematic way. In future research, the type of renewable energy utilization can be developed with other projects and can be developed with various learning platforms so that it can be more interactive and able to improve students' cognitive abilities and skills.

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