25 (3), 2024, 1361-1377

Jurnal Pendidikan MIPA

e-ISSN: 2685-5488 | p-ISSN: 1411-2531
http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

Implementation of PjBL-STEM Based with Online Game to Improve Critical Thinking Ability

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Abstract: This study investigates the effectiveness of project-based learning integrated with STEM (PjBL-STEM) using online games to enhance critical thinking skills among junior high school students on the topic of energy and its changes. A mixed-method approach with a sequential explanatory design was used in this study. The quantitative phase involved pretests and posttests using a standardized critical thinking skills test, while the qualitative phase included observations of student activities during learning. This study was conducted at SMP Negeri 03 Belitang Madang Raya, involving eighth-grade students divided into experimental and control groups in the odd semester of the 2024-2025 academic year. The experimental group (32 students) implemented the PjBL-STEM model using Minecraft Education, while the control group (23 students) received conventional instruction. Data analysis included Rasch modeling for pretest and posttest results, N-gain calculations to measure learning effectiveness, and thematic analysis of observation data to assess student engagement and application of STEM concepts. The findings revealed a significant improvement in the experimental group's critical thinking skills, with an N-gain score of 0.60 (effective category) compared to 0.04 (less effective category) in the control group. Projects such as wind, hydroelectric, and solar power plants, developed in Minecraft Education, highlighted students' ability to integrate scientific knowledge, engineering principles, and teamwork. Observations showed active engagement and collaboration among experimental group students during the project design and implementation phases, which were absent in the control group. This study demonstrates that integrating online games into PjBL-STEM provides an effective approach to enhancing 21st-century skills. The results underscore the potential for adapting this model to diverse educational settings and materials. However, differences in students' technological skills remain challenging, suggesting additional support and scaffolding.

Keywords: critical thinking skills, energy, minecraft education, online games, PjBL-STEM

▪ INTRODUCTION

In the rapidly evolving era of globalization, education is no longer just about mastering academic knowledge but also about preparing students with relevant skills to face the challenges of the modern world. Today, global demands in education emphasize the importance of developing 21st-century skills (Haryani et al., 2024; Xu & Zhou, 2022), including critical thinking ability (Santos, 2017). Students must apply their knowledge in a real-world context and develop critical thinking skills to solve complex problems (Halpern & Dunn, 2021).

In reality, the lack of development of critical thinking skills is a significant concern in the context of learning at the junior high school level. Students often struggle to link theoretical concepts with practical applications in everyday life (Aranguren et al., 2022). The limitation in critical thinking skills can be caused by the dominant role of the teacher in learning activities (Wan et al., 2023).

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DOI: http://dx.doi.org/10.23960/jpmipa/v25i3.pp1361-1377
Received: 05 December 2024
Accepted: 20 December 2024
Published: 23 December 2024

The education system must develop individuals with theoretical knowledge and relevant practical skills to face increasingly complex global challenges. Science education, including energy literacy (Yusup, 2021; Yusup et al., 2017), plays a key role in preparing today's youth to become responsible decision-makers, including future energy-related decisions (Namdar & Namdar, 2021).

Energy is a central concept in physics, enabling citizens to make informed decisions about critical social issues such as energy production and use and its impact on climate change. Creating renewable energy has become a highly relevant and urgent issue in addressing environmental challenges and the effects of global climate change (Ozdinc & Ceyhan, 2024). Energy and its Changes offers a unique opportunity to combine scientific concepts with practical applications. However, generating deep student engagement and holistic understanding in conventional learning is often difficult.

Making decisions and solving problems require critical thinking (Orhan, 2022). To improve students' higher-order thinking ability to meet the need for 21st-century skills, we can adopt a project-based learning (PjBL) approach in the learning process. The PjBL-STEM approach offers a holistic solution by integrating project-based learning, the use of technology, and the integration of STEM subjects. The implementation of online game-based PjBL-STEM on energy and its changes is expected to improve 21st-century skills (Baran et al., 2021; Halawa et al., 2024),

Several studies have shown that PjBL-STEM effectively improves students' concept understanding and skills (Siew & Ambo, 2020), including environmental issues (Leasa et al., 2024). One of the environmental issues today is energy and its changes. However, specific research on implementing PjBL-STEM integrated with online games on energy and its changes at the junior high school level is still limited. This research is urgent because of its potential to provide better insight into the impact of PjBL-STEM integrated online games on improving students' critical thinking skills on energy and its changes at the junior high school level, as well as contributing to the development of innovative learning models.

Based on data from the Program for International Student Assessment (PISA) in 2018, students in Indonesia can only reach level 1 and level 2 of the 6 levels of questions. So, PISA concluded that the thinking ability of students in Indonesia is very low. However, the results of the 2018 PISA study released by the OECD showed that Indonesian students' reading ability achieved an average score of 371, with an average OECD score of 487. Then the average math score reached 379, with an OECD average score of 487. Furthermore, for science, the average score of Indonesian students reached 389 with an OECD average score of 489. The 2018 PISA data above shows Indonesia is in the low performance quadrant with high equity.

According to a preliminary study on energy material in class VIII, the results of students' critical thinking skills were found to be in the insufficient category (Dewi et al., 2024). There is no research has been conducted on the implementation of online game-based PjBL-STEM at SMP Negeri 03 Belitang Madang Raya, so researchers bring energy material as research material for the implementation of online game-based PjBL-STEM at SMP Negeri 03 Belitang Madang Raya. An online game used in research is Minecraft Education, which is already available, so researchers can only use it without changing or developing the game. Minecraft Education provides a highly flexible virtual canvas for students to creatively explore STEM concepts. Features such as world customization, simulation, and simple programming allow students to build, design, and experiment with their own ideas. For example, students can build a sustainable smart city, design an efficient mining system, or even model a solar system. Through these processes, students learn about STEM concepts and develop critical thinking, problem-solving, and creativity skills that are essential in the 21st century. Minecraft Education's greatest strength is its ability to facilitate collaborative learning. Students can work in teams to complete complex projects, share ideas, and learn from each other. Features like chat, virtual whiteboards, and sharing worlds allow students to communicate and collaborate effectively. In addition, Minecraft Education can also be used to develop social skills such as negotiation, leadership, and teamwork.

This research is expected to provide a further understanding of the effectiveness and the impact of implementing online game-based PjBL-STEM in improving the critical thinking skills of junior high school students on energy and its changes.

▪ METHOD

Participants

The participants in this study were eighth-grade students from SMP Negeri 03 Belitang Madang Raya, located in East Ogan Komering Ulu Regency. The population consisted of five classes during the 2024/2025 academic year. Two classes were randomly selected as the sample: the experimental group (32 students) and the control group (23 students). The school was chosen because it has implemented the Merdeka Curriculum and is one of the pioneer schools in the district.

Research Design and Procedures

This study employed a mixed-methods approach with a sequential explanatory design, combining quantitative and qualitative data collection. The research involved pretests and posttests to measure critical thinking skills and observations to assess student engagement and activities during learning. It involved two classes: the experimental group and the control group. Students in the experimental group were taught using a PjBL-STEM model integrated with Minecraft Education, involving six meetings. The PjBL-STEM syntax followed five stages: project initiation, project design, project implementation, evaluation, and reflection. In contrast, students in the control group were taught using a guided inquiry learning model across the same six sessions. Before the intervention, a pretest was conducted to determine baseline critical thinking skills. Post-intervention, a posttest was administered to evaluate the effectiveness of the learning models.

Instruments

The instruments used in this study were the Critical Thinking Skills Test, Observation Rubric, and Product Assessment Checklist. Critical thinking skills test was used to collect quantitative data. Our team developed the Critical Thinking Skills Test, which comprises 12 multiple-choice questions aligned with critical thinking indicators to evaluate students' performance in pretests and posttests. The test was administered via Google Forms to ensure students' accessibility and familiarity. The instrument was validated to obtain validity argument and reliability. The validity test is the process of collecting relevant evidence to provide a scientific basis for score interpretation. Evidence of validity is supported by the item fit statistic. As a criterion for items fit the Rasch model if the values for mnsq outfit and mnsq infit are 0.7-1.3 logit (Bond et al., 2021), and the Zstd outfit and Zstd infit values are -2.0 to +2.0 (Boone et al., 2014). Data analysis for validity showed that all items fit the model, and the person reliability was 0.57 logit. These parameters mean that the instrument could measure students' crtitical thinking skills.

In contrast, qualitative data was obtained by observing students in the teaching and learning process. For this aim, we developed an observation rubric. A structured observation sheet was used to document students' activities, collaboration, and engagement during the learning process. The observation rubric was designed to evaluate students' engagement, collaboration, and application of STEM concepts during the learning process. It consisted of structured indicators categorized into three main phases of the PjBL-STEM implementation: project initiation, project design, and project implementation and evaluation phase.

To assess students' products, we used the products assessment checklist. This instrument evaluated the quality of the student projects based on six aspects: application of STEM concepts, critical thinking, design, technical process, collaboration, and documentation. Each indicator was scored on a 4-point Likert scale as follows:

4. (Excellent): Students consistently exhibit the behavior or skill without external prompting.
3. (Good): Students demonstrate the behavior or skill with minimal prompting.
2. (Sufficient): Students occasionally demonstrate the behavior or skill but require guidance.
1. (Poor): Students rarely or never exhibit the behavior or skill, even with guidance.

Data Analysis

Quantitative data from the pretests and posttests were analyzed using the Rasch model with Winsteps software. This analysis measured item difficulty, student ability, and test reliability. Winsteps works by estimating item and respondent ability parameters simultaneously. Item parameters include item difficulty (how difficult an item is), item discrimination power (how well an item distinguishes between high and low ability respondents), and guessing parameter (the probability of a respondent answering correctly by chance).

Qualitative data from the observation rubric were analyzed thematically to identify student engagement and collaboration patterns during the learning activities. These insights complemented the quantitative findings, providing a deeper understanding of the learning process. To ensure control of bias in the study, students were divided into two groups, control and experimental. The experimental group used Minecraft as a learning tool while the control group did not. So by comparing the results of the two groups, researchers can isolate the effect of Minecraft in learning. If significant differences occurred, it was most likely due to the learning approach, not just the play skills. The effectiveness of the learning model was analyzed using normalized gain (N-Gain) scores to compare the improvement in critical thinking skills between the experimental and control groups.

This aimed to find out how effective the implementation of PjBL-STEM based on online games on energy and its changes to improve critical thinking skills of junior high school students. N-gain analysis with B-gain uses the normalized gain equation (Hake, 1998):

$$N - gain\ (g) = \frac{S_{post} - S_{pre}}{Spretest_{max}}$$

Spre is the score obtained before treatment, Spost is the score obtained after treatment, and Smax is the maximum score that can be obtained. According to Hake (1998), the obtained N-gain score was interpreted in Table 1.

Table 1. Effectiveness category based on n-gain

N-gain Value	**Criteria**	**Effectiveness Category**
N-gain ≥ 0.7	High	Very Effective
0.7 > *N-gain* ≥ 0.3	Medium	Effective
N-gain < 0.3	Low	Less Effective

▪ **RESULT AND DISSCUSSION**

Data was collected face-to-face on 55 students in class VIII from August to September 2024 at SMPN 03 Belitang Madang Raya. The first data collection was administering pretest questions, as many as 12 multiple-choice questions representing five indicators of critical thinking skills, through a Google form on https://bit.ly/TesKemBerpikirKritis. Students provided answers directly on the Google form page using the link. After the first data collection, the researcher analyzed the pretest data.

Then, the researchers carried out learning that implemented the Online Game-Based PjBL-STEM in class VIII, an experimental class with 32 students. Learning was carried out six times a meeting, following the stages/syntax of learning in PjBL-STEM. Researchers also conducted conventional learning in class VIII, a control class with 23 students. Teaching and learning were conducted once during a meeting using the guided inquiry learning model.

Teaching and learning in the control class, at meetings 1 and 2, was the initial process stage of the PjBL-STEM syntax, where students learn the concept of energy, analyze the project theme, form groups, and identify problems related to the project. Meeting 3 is the design stage, where students design the project, discuss the division of labor, assign each task in the group, and try to operate the Minecraft Education online game. Meetings 4 and 5 are the implementation stage, where students implement the project, and the teacher monitors the implementation. The 6th meeting is the evaluation stage, where students report the results of the project work, receive project assessments from the teacher, and reflect on the implementation of the project—design follow-up plans for using renewable energy sources to be carried out in the future.

Analysis of research instruments in the form of critical thinking skills questions aims to determine the validity and reliability of research instruments and students' initial critical thinking skills level. The Item Fit statistic supports evidence of validity, as shown in Figure 1.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
9	24	55	.13	.30	1.18	1.60	1.24	1.22	A .29	.43	61.1	67.8	9
7	11	55	1.49	.36	.91	-.42	1.23	.66	B .37	.33	83.3	80.6	7
6	15	55	1.02	.33	1.13	.85	1.19	.67	C .27	.37	75.9	75.5	6
1	20	55	.51	.31	1.11	.94	1.13	.60	D .32	.41	68.5	70.2	1
12	48	55	-2.69	.47	1.09	.37	.72	-.33	E .46	.46	85.2	89.5	12
5	10	55	1.63	.38	.92	-.33	1.07	.30	F .35	.32	85.2	82.2	5
11	32	55	-.60	.31	1.07	.62	1.05	.32	f .41	.46	66.7	70.1	11
4	26	55	-.05	.30	1.04	.37	.98	-.05	e .42	.44	64.8	67.6	4
10	16	55	.91	.33	.93	-.45	.78	-.71	d .45	.38	77.8	74.3	10
2	44	55	-1.97	.39	.90	-.35	.70	-.70	c .55	.47	83.3	83.5	2
3	26	55	-.05	.30	.88	-1.18	.79	-1.16	b .53	.44	72.2	67.6	3
8	29	55	-.32	.30	.87	-1.19	.78	-1.27	a .55	.45	70.4	67.6	8
MEAN	25.1	55.0	.00	.34	1.00	.07	.97	-.04			74.5	74.7	
P.SD	11.5	.0	1.25	.05	.11	.83	.20	.76			8.1	7.2	

Figure 1. Results of item fit test analysis of critical thinking ability question instrument

Figure 1 shows the analysis result of the validity evidence of the instrument. There are no negative values of point-measure correlation. Outfit MNSQ and Infit MNSQ values are between 0.78 and 1.24. These mean that the values are in the range of criteria 0.7-1.3. Values of Zstd for outfit and infit are also in the range of the criteria of -2.0 to 2.0 (Bond & Fox, 2015). The reliability test was also carried out, and the result is shown in Figure 2. Figure 2 shows that the person reliability value is 0.51, which means that the instrument had a moderate level of reliability.

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	5.6	12.0	-.17	.72	1.00	.03	.97	.02
SEM	.3	.0	.15	.01	.04	.13	.07	.11
P.SD	2.2	.0	1.11	.10	.29	.93	.52	.79
S.SD	2.2	.0	1.12	.11	.29	.94	.53	.80
MAX.	10.0	12.0	2.02	1.14	1.77	2.57	3.28	1.90
MIN.	1.0	12.0	-3.07	.66	.57	-1.65	.18	-1.27

REAL RMSE .77 TRUE SD .79 SEPARATION 1.03 Person RELIABILITY .51
MODEL RMSE .73 TRUE SD .83 SEPARATION 1.15 Person RELIABILITY .57
S.E. OF Person MEAN = .15

MINIMUM EXTREME SCORE: 1 Person 1.8%

Figure 2. Results of reliability test analysis of critical thinking ability question instruments

Pretest

The Wright map in Figure 3 and Figure 4 shows students' critical thinking skills in the pretest. On the left side of the map is a student's ability, while the right side is items difficulty. The highest student on the map is the most able, and the lowest student is the lowest ability. The highest item on the map is the most difficult, and the lowest item is the easiest item. Figure 3 shows the results of 23 control class students; 11 students were below the M- (Less) line. The students above the M+ (More) line are 12.

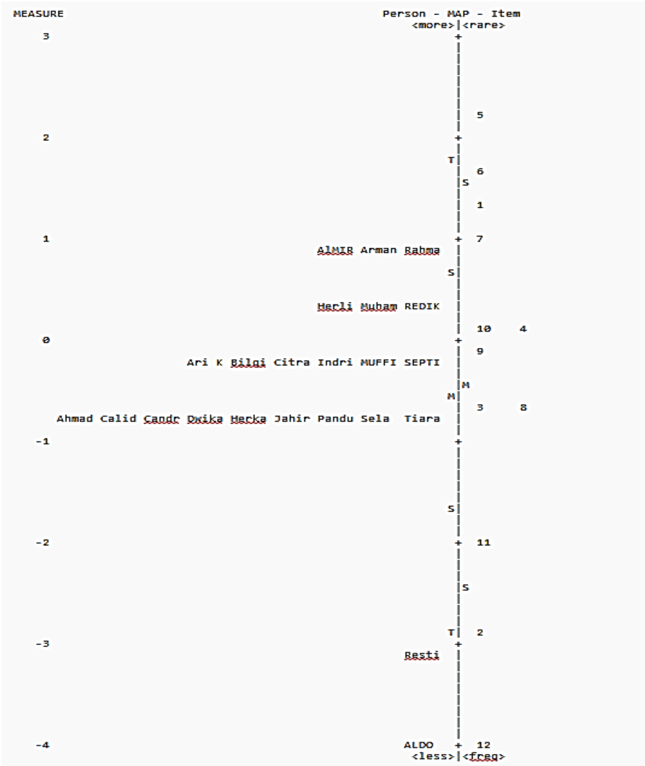

Figure 3. Results of analysis of initial critical thinking ability of control class students

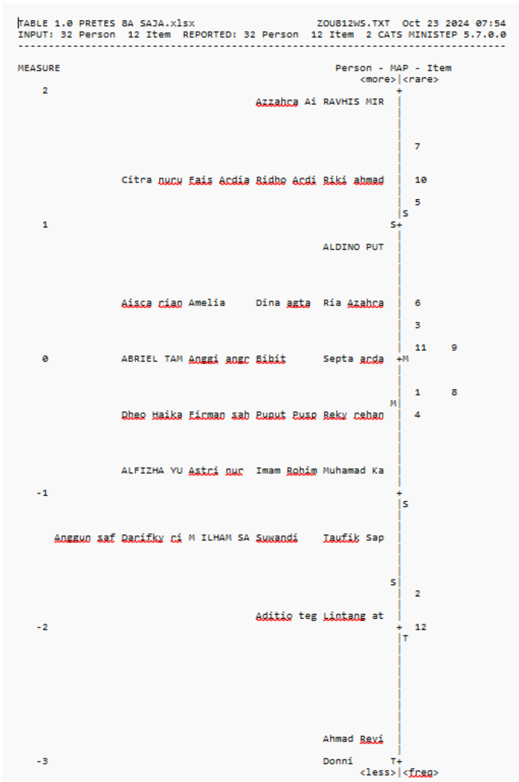

Figure 4. Results of analysis of initial critical thinking ability of experimental class students

Figure 4 shows the results of 32 experimental class students, 17 students were below the M- (Less) line. While students who are above the M + (More) line are 15 students. More than half of the students have less critical ability.

The results of the pretest of critical thinking ability of the control class are shown in Figure 4. Of 23 control class students, 12 were above the M+ (More) line, and 11 were below the M- (Less) line. No students were found to be in the excellent critical thinking ability category. There are 6 students in the good category, 6 in the sufficient category, 9 in the less category, and 2 in the very less category.

The results of the pretest of the critical thinking ability of the experimental class, as shown in Figure 5, of 32 experimental class students, 17 were below the M- (Less) line, and 15 were above the M + (More) line. There were 6 students in the category of excellent critical thinking skills, 6 in the good category, 4 in the sufficient category, 9 in the less category, and 4 in the very less category.

Of the 55 students in both classes, a total of 28 students were below the M- (Less) line or in the category of sufficient, less, and very less critical ability. This is because the learning model does not stimulate students to participate actively in learning, especially in critical thinking. Teachers are required to be able to choose a learning model that can spur students' enthusiasm to be actively involved in their learning experience.

Online Game-based PjBL-STEM Learning Outcome Product

In the project's initial phase, assessment indicators include students actively exploring the concept of energy, communicating their ideas, discussing and identifying problems, and actively looking for problem solving. Based on the data from the indicator checklist during learning activities, it was found that 11 students met 4 indicators, 17 students met 3 indicators, and 4 students met 2 indicators.

In the project design process phase, the assessment indicators include students actively trying to operate the game, designing projects according to alternative problem solving, discussing the division of labor in groups, and actively engaging in activities that stimulate critical thinking. Based on the data from the indicator checklist during learning activities in this phase, it was found that 14 students met 4 indicators, 15 students met 3 indicators, and 3 students met 2 indicators.

In the project implementation and evaluation phase, the assessment indicators include students preparing a project implementation schedule, actively collaborating during project creation, documenting each project process, and conducting evaluation and reflection. Based on the data from the indicator checklist during learning activities in this phase, it was found that 8 students met 4 indicators, and 24 students met 3 indicators.

Table 3. Product assessment of PjBL-STEM learning outcomes

Assessment Aspect	Group				
	1	**2**	**3**	**4**	**5**
Application of STEM concepts	4	4	4	4	4
Critical thinking skills	4	4	4	4	4
Product design	4	3	4	4	4
Technical process	3	4	4	4	4
Collaboration	3	4	4	4	4
Documentation	4	4	4	4	4

Total Score	23	23	24	24	24

Description: Rating Scale: Each aspect is rated on a scale of 1 to 4, where 1 is deficient, 2 is fair, 3 is good, and 4 is excellent.

The results of student learning on the implementation of Online Game-Based PjBL-STEM on energy and its changes in the experimental class are in the form of renewable energy source buildings projects they work on in the Minecraft Education Edition game. 32 students in the experimental class were divided into five groups, each of which created a project according to the design they planned.

Groups 1 and 4 worked on building a wind power plant. They built the windmill on the top of a hill. Students chose a strategic location, such as on a hill, to get maximum "wind flow" and maximize the effectiveness of the energy produced.

Game activities can help students understand STEM concepts. For example, in real life, wind turbines generate electricity delivered to homes through a transmission grid. In Minecraft, students simulate this concept with Redstone wiring that connects "wind turbines" (input) to lights (output). Students design a windmill vane that can rotate using a simple rotary block mechanism. With Redstone wiring, students build a system that allows the energy from the wind turbine to flow to the lights. Lever blocks are used as switches to regulate the on-off of electricity to the lights. The result of this group project is shown in Figure 5. Group 2 worked on a project to build a solar power plant. The project result is shown in Figure 6.

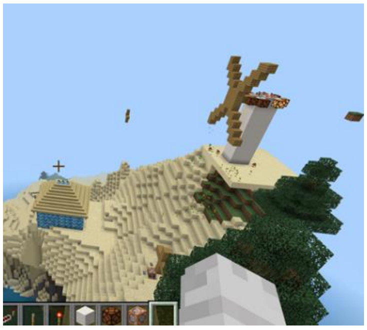

Figure 5. Wind power plant by groups 1 and group 4

Figure 6. Solar power plant (PLTS) by group 2

Group 3 worked on a project to build a hydroelectric power plant. The hydropower project had a reservoir with sluice gates to drain the water into the river. Initially, students looked for an artificial lake in Minecraft to dam up and create some floodgates. Students use Redstone to transmit energy to the lights. Lever blocks are used as switches to regulate the on-off flow of electricity to the lights. The result of the project is shown in Figure 7.

Figure 7. Hydroelectric power plant by group 3

Group 5 worked on a solar power plant construction project. There are several solar panel blocks in the project. Students choose the best spot to place the solar panels so the panels can get maximum sun exposure during the day. Students build the solar panel structure using blocks such as glass for the surface and redstone as a mechanism to channel energy to the lights. Lever blocks are used as switches to regulate the on-off flow of electricity to the lights. The result of the project is shown in Figure 8.

Figure 8. Solar power plant (PLTS) by group 5

Based on Table 3. on average, students in all groups obtained perfect scores in all aspects of product assessment. Product assessment includes applying STEM concepts, critical thinking skills, product design, technical processes, collaboration, and documentation.

STEM Aspect

Students utilized three types of renewable energy sources to make power plant construction and management projects: solar, water, and wind. In each learning outcome product, a power plant construction project using renewable energy sources, STEM concepts are applied during learning activities. The STEM aspects of each product are as follows.

Wind Power Plant

In science, students learn the concept of wind kinetic energy, which is how moving air can generate power. They also understand converting energy from the wind that drives the turbine blades into electrical energy. In Minecraft, the wind does not exist naturally.

Still, students can simulate the effect of airflow by using windmills that represent wind turbines. In the technology aspect, Redstone in Minecraft simulates electricity flow, which can be used to create distributed energy systems. Students use Redstone to distribute energy to various devices, such as lights.

In the engineering aspect, students learn to design and build wind turbines. Students act as engineers to design the structure of the wind turbine. They can create turbine blades using various Minecraft materials such as wood or stone and design a strong support structure to keep the turbine stable at high altitudes. Students also learn about the strategic placement of turbines in high places such as hills or mountains to maximize the "wind" or potential movement of the propellers in the game. In mathematics, students can calculate the ideal height to place the turbine and predict how many blades are needed to generate enough energy. Students can also calculate blocks needed to build a tall and strong structure.

Hydroelectric Power Plant

In science, students learn about the basic principle of water kinetic energy that can be converted into electrical energy. In Minecraft, students can use flowing water blocks to simulate how water flow can be utilized as an energy source. In technology, students create a mechanism for the flow of electrical energy using Redstone. With Redstone and a lever that functions as a switch, students can create a mechanism to control when electrical energy can flow to the lights.

In engineering, students learned how to build dams and sluices of the right height to achieve optimal water flow speed. Using various Minecraft blocks, they can create mechanisms to capture energy from the water flow. Students design energy distribution systems using Redstone wiring to get the "energy" needed, such as building a power grid for a house or other building. In mathematics, students can calculate how many water blocks are needed to achieve a steady flow or estimate the height required to maximize energy from water.

Solar Power Plant (PLTS)

In the science aspect, students learn about photovoltaics, the process by which sunlight is converted into electrical energy using solar cells. They also understand how weather factors and the sun's intensity affect solar panels' efficiency. In Minecraft, although there is no direct mechanism for sunlight like in the real world, students can use glass blocks to simulate how sunlight penetrates and reaches virtual solar panels and how energy can be stored and distributed. In technology, students create a mechanism for the flow of electrical energy using Redstone. Students build solar panels and connect them with Redstone to distribute energy to various devices in the game, such as turning on lights.

In engineering, students act as engineers designing and building solar panel structures in Minecraft. They can use glass blocks to simulate the surface of a solar panel and ensure that the panel is strategically located for optimal sunlight. They must make engineering decisions about the placement of the solar panel, such as placing it on the roof of a building or in an open area where there are no shadows to allow the panel to absorb maximum sunlight.

In mathematics, students can calculate how many panels are needed to power the lights for a particular time. They can also calculate the area required to place the solar panels and how many blocks should be used for optimal results.

Postest

The posttest results are intended to see the extent of the increase in students' critical thinking skills, especially in experimental. The results of the posttest data analysis are as follows. Figure 9 shows that out of 23 students in the control class, there are 12 students below the mean value, and more than half lack critical thinking ability.

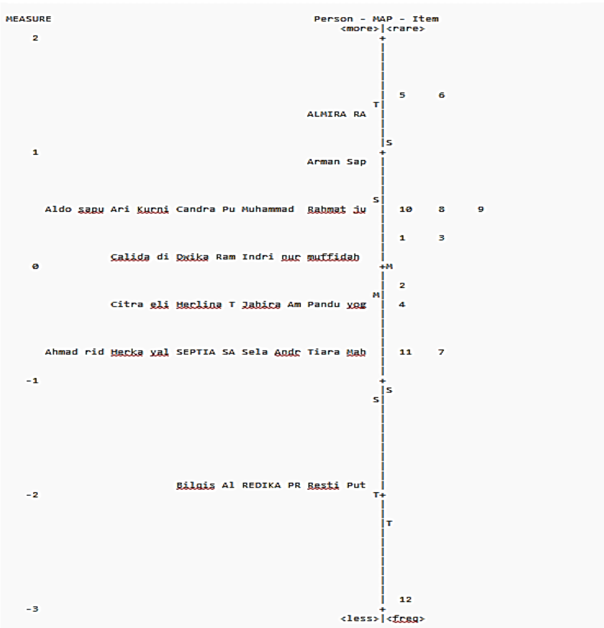

Figure 9. Results of analysis of final critical thinking ability of control class students

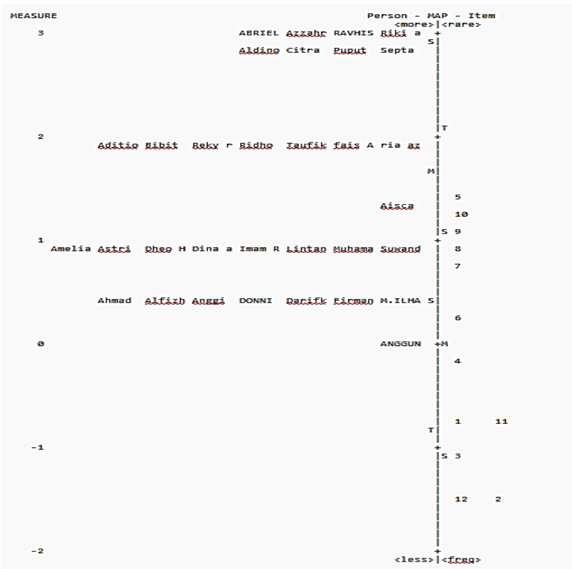

Figure 10. Results of analysis of final critical thinking ability of experimental class students

Figure 10 shows that out of 32 students, 31 are above the mean value, and 1 is on the mean. The final data taken is the posttest results in the experimental and control classes using the same questions as the pretest questions. The data collection of the posttest results was analyzed by the researcher; this is intended to see the extent of the improvement in students' critical thinking skills, especially in experimental classes that have implemented Online Game-Based PjBL-STEM learning.

The control class uses the guided inquiry learning model. In the control class, according to Figure 5, it can be seen that out of 23 control class students, there were 12 students below +M, and more than half of them lacked critical thinking ability. There was one student in the excellent critical thinking ability category, six in the good category, four in the sufficient category, nine in the deficient category, and three in the very inadequate category. This data shows no increase in students' critical thinking skills in the control class.

In the experimental class, according to Figure 6. it can be seen from 32 students, 31 students are above the +M line, and 1 student is on the +M line. There are 16 students in the excellent critical thinking ability category, 15 in the good category, 1 in the sufficient category, and no in the less and very less categories. Compared to the pretest results in the experimental class, there appears to be an increase in students' critical thinking skills. This can occur because the learning model used was in accordance with renewable energy material. So that students tend to be active in honing their critical thinking skills during learning activities.

Effectiveness of Online Game-Based PjBL-STEM Learning

The aspect assessed in this study is the improvement of students' critical thinking skills, which is influenced by the effectiveness of implementing the online game-based PjBL-STEM learning model. The effectiveness value of the learning model implementation is calculated using the effectiveness test and N-Gain analysis. The mean was used to determine the average value of students after taking the pretest and posttest.

Table 4. Pretest and postest results of experimental and control classes

Class	**Value**	**Students Count**	***Mean***
Experiment	*Pretest*	32	44.79
	Postest		76.56
Control	*Pretest*	23	46.74
	Postest		49.64

Table 5. N-Gain analysis of experimental and control classes

Class	**Average *Spost-Spre***	**Average *Smax-Spre***	***N-Gain***	**Category**
Experiment	31.77	55.21	0.60	Effective
Control	2.90	53.26	0.04	Less Effective

The effectiveness of learning using online game-based PjBL-STEM affects improving students' critical thinking skills. In the control class, with the guided inquiry learning model, the average value of students in the pretest was 46.47, while the average value of the posttest was 49.64. There was no significant increase in the average score. This shows no increase in students' critical thinking skills in the control class. The effectiveness test in the control class showed an N-gain of 0.04 and was included in the less effective category.

The experimental class's pretest and posttest data showed increased student average scores. The average value of the experimental class students' pretest was 44.79, while the average value of the posttest was 76.56. There was an increase in the average student score of 30.77. This shows increased students' critical thinking skills in the experimental class. This finding indicates that online games, like Minecraft, can be used to assess and support creativity (Rahimi et al., 2023).

From the data on the average scores of pretest and posttest students in the experimental class, N-gain was calculated to determine how effective the implementation of PjBL-STEM based on online games on energy and its changes to improve critical thinking skills of junior high school students in the experimental class. The effectiveness test in the experimental class showed an N-gain of 0.60 and was included in the effective category. So, it can be concluded that implementing PjBL-STEM based on online games effectively improves the critical thinking skills of junior high school students on energy and its changes. By implementing a project-based learning model (Sappaile et al., 2023) integrated with STEM and based on online games, students are invited to think critically about solving problems and designing solutions.

Learning Observation Results

During the learning activities in the experimental class, a learning observation assessment was carried out according to the rubric in Table 1. PjBL-STEM Learning Observation Rubric. Based on the results of learning observations, it can be seen that students actively participate in learning activities in all three learning phases, namely the initial project process, the design process, and the implementation and evaluation process. On average, each aspect of the learning observation rubric is on a scale of 3, which means good.

During the initial project process during learning activities, most students seemed to actively explore the concept of energy, communicate their ideas, discuss identifying problems, and seek problem-solving. In the project design process during learning activities, most students were active in trying to operate the game, designing projects according to alternative problem solving, discussing the division of labor in groups, and actively engaging in activities that stimulate critical thinking.

In the process of project implementation, evaluation, and reflection, during learning activities, students seem eager to develop a schedule for project implementation, actively collaborate during project development, and periodically document every process of project work. Students also follow the project evaluation process through project product presentations and questions and answers about the projects they work on nicely. In addition, students also carry out reflections at the end of each learning process and at the final stage of project work. They talk about the projects they did, their feelings during the learning, the new things encountered during the learning activities, and the future plans they think about regarding how to apply renewable energy sources in their daily lives.

Students in the experimental class actively explored solutions in Minecraft. They often discussed and tried out the Redstone configuration. Meanwhile, in the control class, students were more passive, mostly listening to the teacher's explanation without much exploration. This finding shows that online games, specifically Minecraft, can engage students more actively in collaborative problem-solving tasks (So & Gaydos, 2024) and STEM activities (Saricam & Yildirim, 2021).

▪ CONCLUSION

Based on data analysis of the research results, it is concluded that the average value of students' critical thinking skills in the experimental class, energy material, and its changes in class VIII SMP Negeri 03 Belitang Madang Raya has increased. The average value of the experimental class students' pretest was 44.79, while the average value of the posttest was 76.56. There is an increase in the average value of students by 30.77.

The results of the effectiveness test of implementing PjBL-STEM based on online games on energy and its changes in the experimental class showed an N-gain of 0.60 and were included in the effective category. So, the online game-based PjBL-STEM learning model on energy and its changes effectively improves the critical thinking skills of junior high school students.

The results of this study can be applied to various other schools that implement the Merdeka Curriculum or project-based curriculum. This method is relevant because it supports exploration-based learning, collaboration, and creativity. Exploration of the application of online game-based PjBL-STEM can also be applied to other materials, such as mechanics, ecosystems, or building structures using Minecraft or similar platforms.

Although this study showed positive results regarding the improvement of student participation, critical thinking skills, and understanding of STEM concepts, there are some weaknesses or limitations, such as students may have different levels of technological skills, students who play games more often or have a better understanding of technology may master Minecraft faster. Students with low technology skills may experience difficulties at the beginning of learning, so their participation may be limited.

▪ ACKNOWLEDGEMENT

The publication of this article was funded by "Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat (DRTPM) Penelitian Tesis Magister BIMA-Kemendikbudristek" Contract Number 090/E5/PG.02.00.PL/2024 dated 11 June 2024.

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