Received: 05 Agustus 2024; Revised: 15 September 2024; Accepted: 25 September 2024

Students' Mini-Project Activities in Problem-Based Learning (PBL): A Performance Assessment on Energy Topics

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ABSTRACT - This study aims to evaluate student performance in problem-based learning (PBL) to enhance 21st-century skills, particularly problem-solving skills related to energy. A pre-experimental design, specifically a one-shot case study, was conducted with 29 senior high school students (12 male and 17 female) in Surabaya, Indonesia. Student performance was assessed using an energy-themed project activity sheet, designed to guide students in addressing real-world problems through three stages: planning, implementation, and reporting. Student performance was evaluated using the Partial Credit Model-Rasch (PCM-Rasch) analysis based on ten aspects of performance assessment. The results indicate that students produced high-quality mini-projects aligned with the ten assessment aspects. Detailed evaluations of specific aspects are provided to guide further improvements in teaching and research. The findings from this study offer valuable insights into the student learning process within the PBL model.

Keywords: Problem-Based Learning (PBL), Performance Assessment, Energy Concept, 21st Century Skills, Problem-Solving Skills

ABSTRAK – *Penelitian ini bertujuan untuk memaparkan penilaian kinerja siswa dalam aktivitas pembelajaran berbasis masalah (PBL) untuk menunjang dan melatihkan keterampilan abad-21, terutama keterampilan pemecahan masalah pada topik energi. Penelitian pre-eksperimen ini menggunakan one-shot case study design yang diimplementasikan kepada kepada peserta didik SMA jenjang X sebanyak 29 peserta didik (12 siswa laki-laki dan 17 siswa perempuan) di Surabaya, Indonesia. Kinerja siswa dinilai menggunakan intrumen lembar aktivitas proyek bertopik energi. Instrumen tersebut dibuat untuk membiasakan siswa menyelesaikan masalah yang berkaitan dengan dunia nyata melalui 3 tahap, yaitu tahap perencanaan, tahap pelaksanaan, dan tahap laporan. Selama pelaksanaannya, kinerja siswa dinilai menggunakan analisis Partial Credit Model- Rasch* (PCM-Rasch) *berdasarkan 10 aspek penilaian kinerja siswa. Secara keseluruhan, hasil penelitian mengindikasikan bahwa secara keseluruhan kinerja siswa mengahasilkan produk karya baik sesuai 10 aspek penilain. Secara detail, penilaian beberapa aspek dipaparkan untuk perbaikan penelitian selanjutnya bagi guru dan peneliti. Temuan penelitian ini akan menawarkan wawasan berharga tentang proses pembelajaran siswa dalam model PBL.*

Kata Kunci: *Problem-Based Learning (PBL), Performance Assessment, Energy Concept, 21st Century Skills, Problem-Solving Skills*

INTRODUCTION

In the 21st century, students need to develop problem-solving skills, critical thinking, creative thinking, scientific communication, and collaboration (González-Pérez & Ramírez-Montoya, 2022; Topsakal et al., 2022; Sari et al., 2021). Therefore, physics education must help students connect the concepts they learn with real-life phenomena. Several researchers have implemented various learning approaches that focus on high-level thinking skills, problem-solving, and project-based activities. These approaches include Problem-Based Learning (PBL), Project-Based Learning (PjBL), and STEM models, as well as integrating two of these three methods within physics education (e.g., Prahani et al., 2022; Khoirulloh et al., 2024; Mufit et al., 2023; Rizki & Suprapto, 2024; Nazhifah, Wiyono, & Ismet, 2023; Berliana, Suwarma, & Novia, 2024; Muliyati, Prastiawan, & Mutoharoh, 2023; Hasanah et al., 2023; Parno et al., 2023). These learning strategies effectively develop 21st-century skills, particularly problem-solving skills.

For beginners, the PBL model serves as an alternative approach to learning and is effective in enhancing problem-solving abilities among high school students, as this learning framework focuses on complex problem-solving tasks and is grounded in the exploration, explanation, and resolution of real and significant issues (Sari, et al., 2021; Razak, et al., 2022; Overton & Randles, 2015; Marra, et al., 2014). Furthermore, students are motivated to engage in problem-solving and investigations collaboratively (Argaw, et al., 2016; Simanjutak, et al., 2021). This fosters student-centered activities in the learning process. Throughout these activities, teachers can effectively implement the PBL model with guidance. After the activity, students must present their investigative outcomes in prototypes or simple projects as solutions to the problems identified (Arends, 1991; Tan, 2021). This process equips students with skills to think critically, plan, design, create, and assess the results of their projects. Given these benefits, the researcher proposed applying the PBL model for early learners (high school students) to emphasize practicing problem-solving through planning, designing, creating, and evaluating mini-projects.

Several literature studies connect the implementation of the Problem-Based Learning (PBL) model to specific topics, as visualized in Figure 1 using VOS Viewer. This figure indicates that various researchers have concentrated on the implementation of the PBL model along with performance assessment during the period from 2014 to 2020.

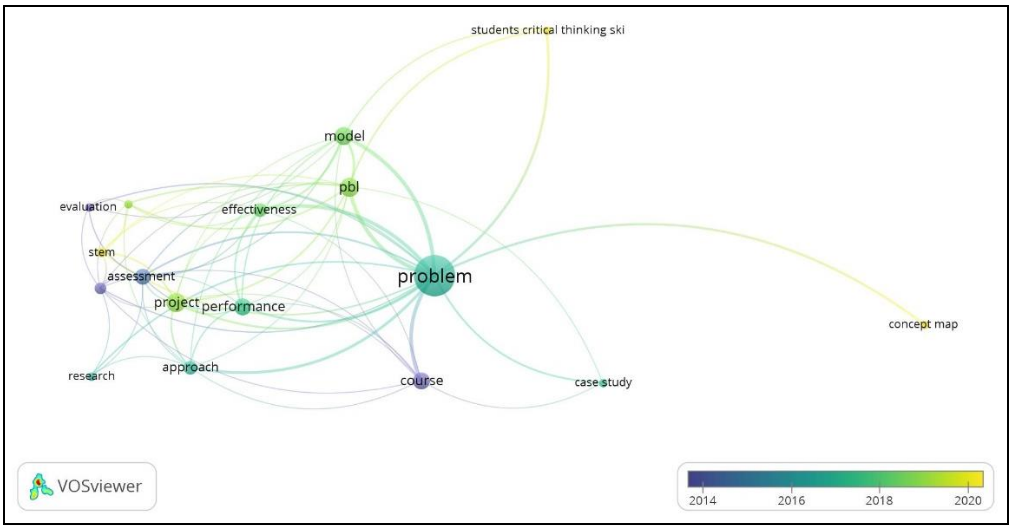


Figure 1. Visualization of Research Network using VOSviewer

For instance, research by Yew and Goh (2016) suggests that PBL-based modules can enhance problem-solving skills and improve students' academic performance. Additionally, a study by Loyens et al. (2015) found that students engaged in PBL focusing on Newton's laws achieved higher academic performance than those in a traditional learning setting. Furthermore, research by Suastra et al. (2019) indicated that students' physics problem-solving skills were superior when they experienced PBL based on authentic assessment rather than PBL with conventional assessment methods.

There is still limited research focusing on the detailed exploration of student activities. Understanding these activities during the learning process can provide a comprehensive and thorough representation of the implementation of Problem-Based Learning (PBL). This research is significant because performance assessment evaluates the learning process of students using the PBL model. Therefore, a deeper investigation into student performance assessment is needed.

In this study, the performance assessment centers around the topic of energy. According to the current Indonesian curriculum, this topic requires students to develop competencies and skills in problem-solving and project design related to energy. Additionally, the topic is relevant to everyday life, such as the application of mechanical energy. The framework for this research is illustrated in Figure 2.

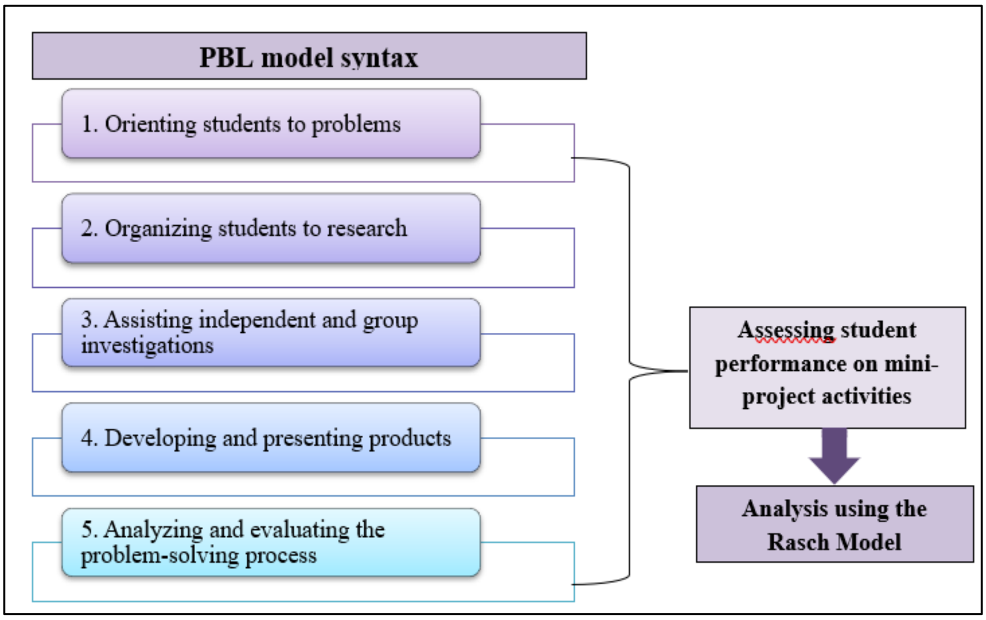


Figure 2. Research Framework for Assessing Student Performance in Implementing of PBL Model

In overview, this study aims to evaluate student performance in problem-based learning (PBL), specifically focusing on mini-project activities. These activities are designed to enhance students' 21st-century skills, particularly their problem-solving abilities. The findings of this study will offer valuable insights into the student learning process within the PBL framework. Furthermore, it is essential to provide information on performance assessment in education, highlighting its importance for students' development.

METHOD

Research Design

This pre-experimental study employed a one-shot case study design involving a single group (Fraenkel, Wallen, & Hyun, 1993). The research design is illustrated in Table 1.

Table 1. Research Design

X (Treatment)	O (Observation)
Implementation of PBL model with project activity sheet	Students’ performance in planning, designing, evaluating, and reporting mini projects.

Research Sample

The study sample consisted of 36 grade X students from a high school in Surabaya, East Java, Indonesia, which is the capital city of the province. The sampling technique used purposive sampling. Detailed demographics of the research sample are illustrated in Figure 3.

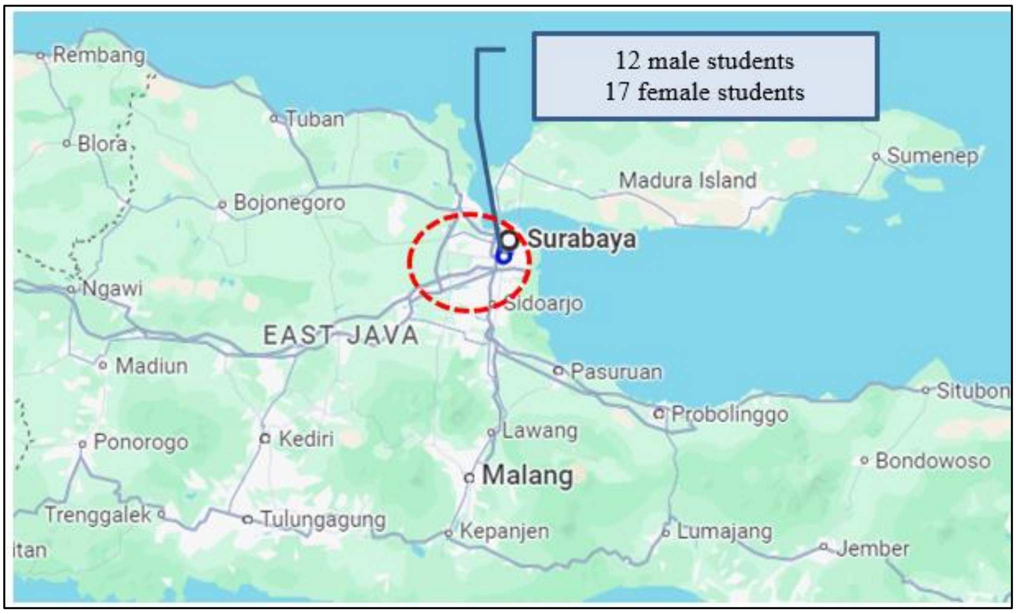


Figure 3. Demographics of the Research Sample

Research Instrument

This student worksheet is a project activity sheet designed according to the PBL syntax. An example of a student project activity sheet can be found in Table 2.

Table 2. Example of Mini-Project Activity Sheet

<u>Student Project Activity Sheet</u>
Name : Group : Class :

Problem Statement

The energy that is needed by humans today is electrical energy, for example at school, at home, in various places, if there is a power outage for just a few minutes, everyone experiences difficulties. Electrical energy can be obtained from various forms of energy in utilizing the environment around us. However, in practice, to generate electricity, many still use fossil fuels. If this continues to be done, it will cause the availability of fuel to decrease. Therefore, alternative energy is needed as a solution.
One of the alternative energies to generate electricity is using water. For example, the Ampelgading sub-district of Malang city has a waterfall, the potential energy of this water can be used to generate electricity, namely as a Hydroelectric Power Plant (PLTA).

1. Planning Stage Tasks
   a. ......
   b. ......
   c. ......

2. Design and Work Plan
   a. ......
   b. ......
   c. ......
3. Implementation Tasks
   a. ......
   b. ......
   c. ......
4. Reporting and Presentation Tasks
   a. ......
   b. ......
   c. ......

Data Analysis Techniques

Student performance assessment is conducted in three stages, with various assessment aspects detailed in Table 2. The evaluation utilizes a Likert scale ranging from 1 to 4, and descriptions for each aspect are provided in the assessment rubric in the Appendix. Additionally, the assessment results are processed using the Partial Credit Model Rasch (PCM-Rasch) with the WINSTEP software. The analysis of the assessment outcomes will also be presented using the Wright map.

Table 3. Project Activity Assessment Aspects

Stages	Rated Aspect	Item Code in Wright map
Planning	Collaboration in groups.	I1
	Ability to collect information.	I2
	Diversity of ideas for problem-solving solutions.	I3
	Design and design of product	I4
Implementation	Ability to manage the collection of work time and completeness of data.	I5
	The authenticity of work (is the result of his work) by using instructions from information obtained relevantly.	I6
	Analysis and conclusions of making work in solving problems.	I7
	Results of making work (artifacts and posters) from solving problems.	I8
Reporting	Systematics of writing reports and the appearance and use of language in reports.	I9
	Presentation of work assignment reports (posters, PowerPoint, and videos of phenomena).	I10

RESULT AND DISCUSSION

The results of this study were analyzed using the Wright map based on the Rasch Model measurement, as illustrated in Figure 4. In the Wright map, student performance scores are converted into logit values, which are then placed on a scale (Boone, 2020; Linacre, 1998, 2021). On this logit scale, higher values indicate greater student performance, while lower values suggest less effective performance. Although the assessment is conducted in groups, each student's performance is evaluated individually.

According to Figure 4, the right side displays a distribution of ten assessment aspects, coded from item 1 (I1) to item 10 (I10). Additionally, there is a distribution of students identified by their absence numbers and gender (M for male and F for female), for example, 02M, 19M, 27F, etc. Thus, it can be concluded that students with higher logit values demonstrate greater performance abilities, while those with lower logit values struggle to solve problems and complete mini-project activities centered on the topic of energy.

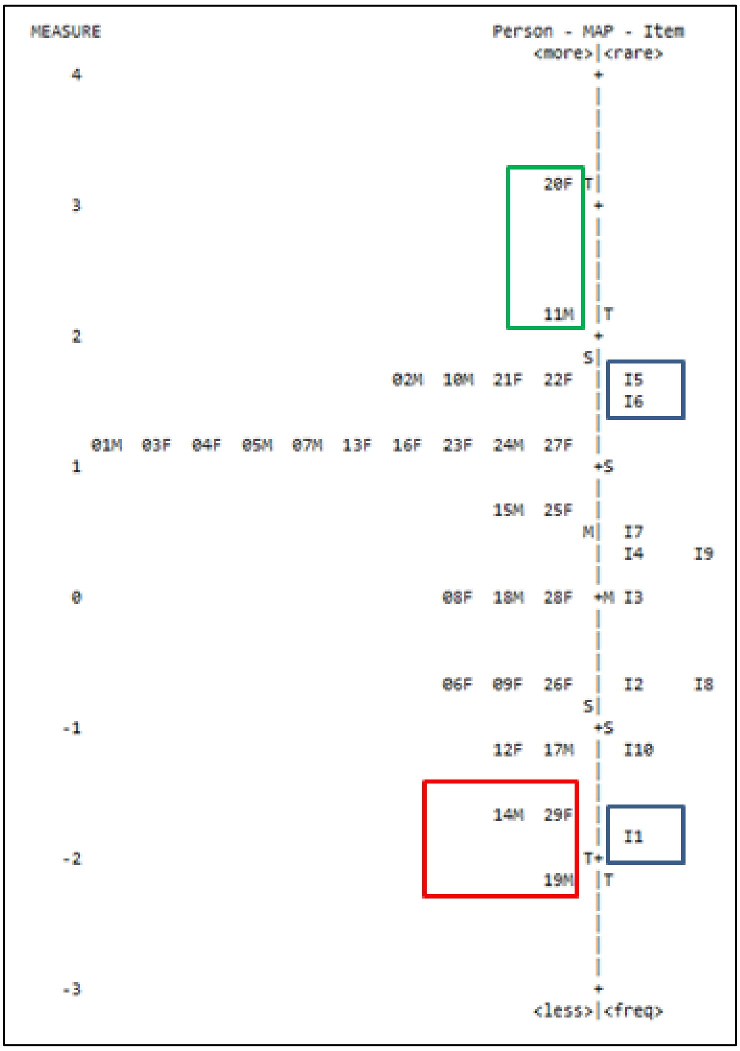


Figure 4. Results of Performance Assessment Analysis using Wright Map

Figure 4 indicates that the easiest aspect to assess is item 1 (I10), which pertains to collaboration within and between groups. This activity fosters investigation and discussion among group members. Supporting this, Santyasa et al. (2017) and Razak et al. (2022) found that Problem-Based Learning (PBL) enhances collaboration skills in problem-solving contexts. However, it is noteworthy that the student coded as 19M has not achieved this performance ability. This is primarily because he has struggled to collaborate effectively with his peers and has not been able to express his opinions openly. This finding suggests the need for tailored interventions to support such students.

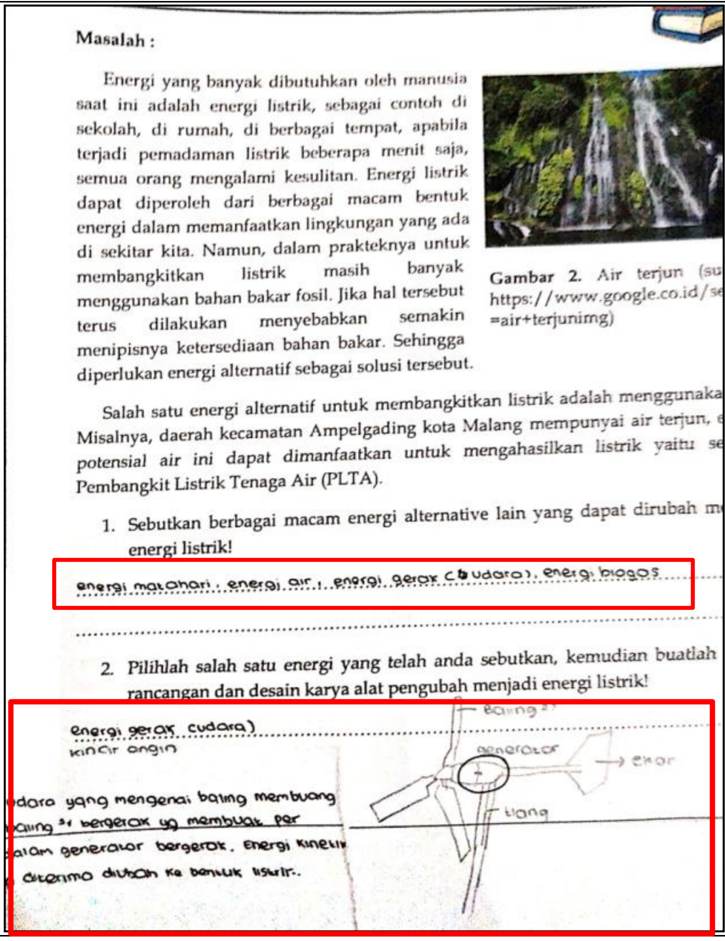
The most challenging aspects are item 5 (I5), which pertains to the ability to manage work time and data completeness, and item 6 (I6), which focuses on the authenticity of the work produced using relevant information. Both of these items are particularly difficult for students, especially I5, as many students struggle to complete the mini-project within the allocated time. Consequently, they require more time to gather and organize their project materials, leading to a mismatch between planning time and classroom conditions. This issue stems from the teacher, who as the facilitator, does not coordinate submission deadlines effectively.

Additionally, PBL (Problem-Based Learning) activities are infrequently conducted in the classroom, making it challenging for high school students, as beginners, to become accustomed to these tasks. Another observation is that students have not yet maximized their ability to generate original ideas. This is understandable, as being beginners, students typically adapt or build on others' ideas.

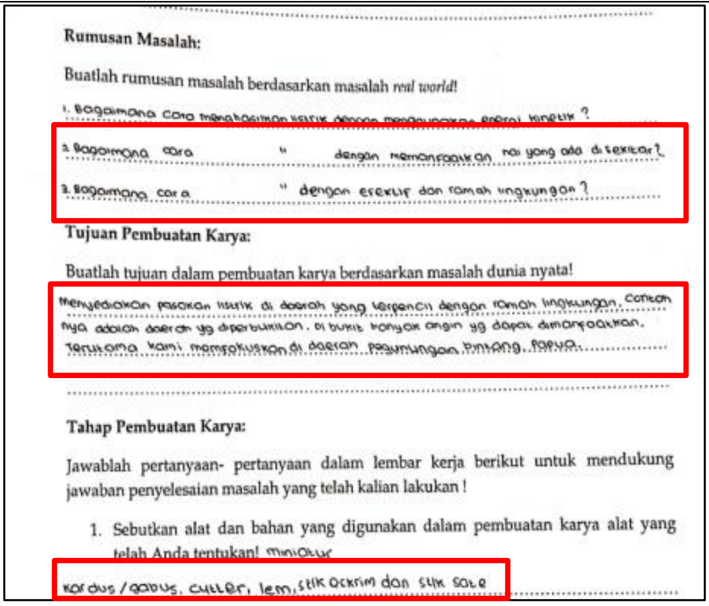
On the positive side, students are capable of linking relevant information to resolve issues related to alternative energy. Notably, two students (20F and 11M) exhibited exceptional performance, surpassing both items, indicating their near-perfect execution in mini-project activities focusing on energy topics. Detailed examples of the student's work are presented in the accompanying Table 4.

Table 4. Examples of Student Performance and Analysis of Student Performance Assessment at each stage of the PBL model

PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results
1. Orienting students to problems	Student 20F can explore ideas about different alternative energies. Additionally, these students can identify one alternative energy source to address real-world problems presented in the worksheet.

PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results
	 **Masalah :** Energi yang banyak dibutuhkan oleh manusia saat ini adalah energi listrik, sebagai contoh di sekolah, di rumah, di berbagai tempat, apabila terjadi pemadaman listrik beberapa menit saja, semua orang mengalami kesulitan. Energi listrik dapat diperoleh dari berbagai macam bentuk energi dalam memanfaatkan lingkungan yang ada di sekitar kita. Namun, dalam prakteknya untuk membangkitkan listrik masih banyak menggunakan bahan bakar fosil. Jika hal tersebut terus dilakukan menyebabkan semakin menipisnya ketersediaan bahan bakar. Sehingga diperlukan energi alternatif sebagai solusi tersebut. Gambar 2. Air terjun (su https://www.google.co.id/se =air+terjunimg) Salah satu energi alternatif untuk membangkitkan listrik adalah menggunaka Misalnya, daerah kecamatan Ampelgading kota Malang mempunyai air terjun, potensial air ini dapat dimanfaatkan untuk mengahasilkan listrik yaitu se Pembangkit Listrik Tenaga Air (PLTA). 1. Sebutkan berbagai macam energi alternative lain yang dapat dirubah m energi listrik! energi matahari, energi air, energi gerak (udara), energi biogas 2. Pilihlah salah satu energi yang telah anda sebutkan, kemudian buatlah rancangan dan desain karya alat pengubah menjadi energi listrik! energi gerak (udara) kincir angin dara yang mengenai baling membuang aling² bergerak yg membuat per alam generator bergerak. Energi kinetik diterima diubah ke bentuk listrik.
2. Organizing students to research	The student group can search for relevant information during the problem-solving process. In this phase, they can identify the purpose of their project, allowing them to focus on a single option for designing their mini-project. The process of designing the mini-project starts with analyzing information and determining the necessary tools and materials to bring the project to fruition.

PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results



Rumusan Masalah:

Buatlah rumusan masalah berdasarkan masalah *real world*!

1. Bagaimana cara menghasilkan listrik dengan menggunakan energi kinetik ?
2. Bagaimana cara " dengan memanfaatkan hal yang ada disekitar ?
3. Bagaimana cara " dengan efektif dan ramah lingkungan ?

Tujuan Pembuatan Karya:

Buatlah tujuan dalam pembuatan karya berdasarkan masalah dunia nyata!

Menyediakan pasokan listrik di daerah yang terpencil dengan ramah lingkungan. Contohnya adalah daerah yg diperbukitan. Di bukit banyak angin yg dapat dimanfaatkan. Terutama kami memfokuskan di daerah pegunungan Pintang, Papua.

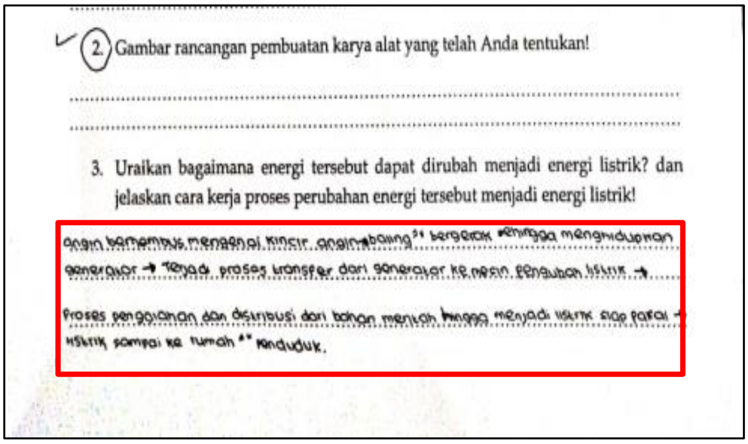
Tahap Pembuatan Karya:

Jawablah pertanyaan- pertanyaan dalam lembar kerja berikut untuk mendukung jawaban penyelesaian masalah yang telah kalian lakukan !

1. Sebutkan alat dan bahan yang digunakan dalam pembuatan karya alat yang telah Anda tentukan! miniatur

kardus / gabus, cutter, lem, stik ackrim dan stik sate

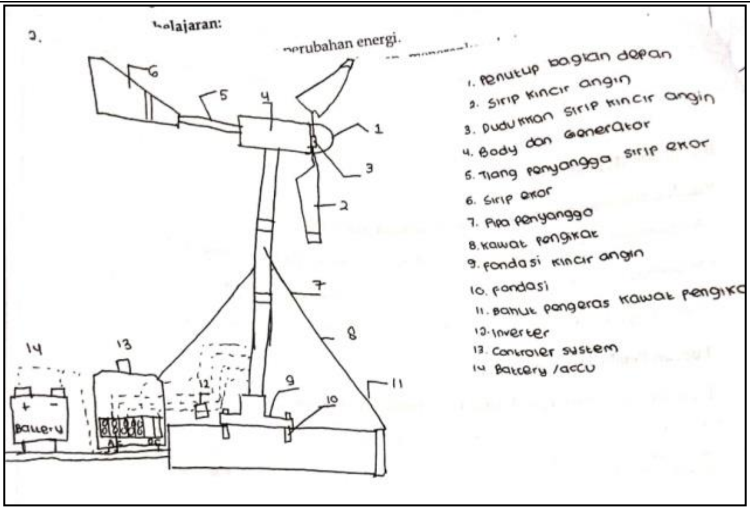
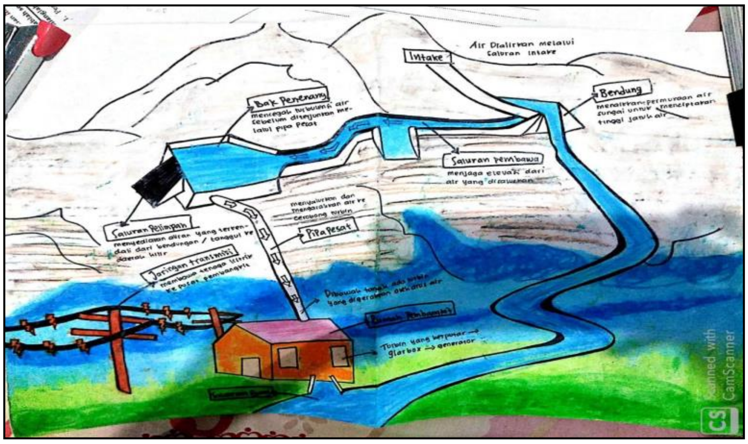
PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results
3. Assisting independent and group investigations	During a group discussion for an investigation, Student 22F successfully designed a simple prototype that aligned with the project's objectives and utilized relevant information sources. This demonstrates his ability to apply the principles of kinetic energy, potential energy, and mechanical energy.

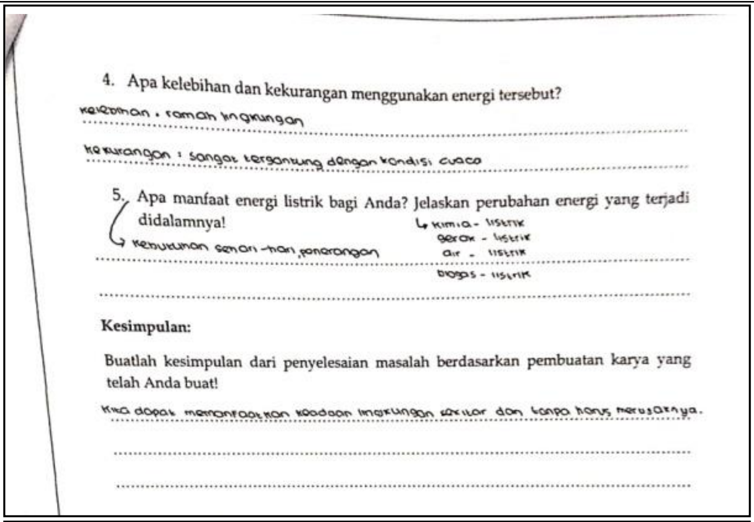


2. Gambar rancangan pembuatan karya alat yang telah Anda tentukan!

3. Uraikan bagaimana energi tersebut dapat dirubah menjadi energi listrik? dan jelaskan cara kerja proses perubahan energi tersebut menjadi energi listrik!

angin berhembus mengenai kincir angin → baling" bergerak sehingga menghidupkan generator → terjadi proses transfer dari generator ke mesin pengubah listrik → proses penggulangan dan distribusi dari bahan mentah hingga menjadi listrik siap pakai → listrik sampai ke rumah" penduduk.

PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results
	
4. Developing and presenting products	During the product development process, student 10M conducted simple experiments and showcased the initial product in class. Additionally, students and teachers collaborated to enhance the previous work, aiming for further improvement. Several groups presented their findings using PowerPoint or poster formats. 
5. Analyzing and evaluating the problem-solving process	After the improvement stage, students and their groups are able to analyze the strengths and weaknesses of their products, allowing them to evaluate their projects effectively. At this point, the teacher provides feedback and encourages reflection, enabling students to enhance their projects and make them better.

PBL Syntax	Examples of Student Performance and Analysis of Student Performance Results
	 4. Apa kelebihan dan kekurangan menggunakan energi tersebut? kelebihan : ramah lingkungan kekurangan : sangat tergantung dengan kondisi cuaca 5. Apa manfaat energi listrik bagi Anda? Jelaskan perubahan energi yang terjadi didalamnya! kebutuhan sehari-hari, penerangan kimia - listrik gerak - listrik air - listrik biogas - listrik **Kesimpulan:** Buatlah kesimpulan dari penyelesaian masalah berdasarkan pembuatan karya yang telah Anda buat! Kita dapat memanfaatkan keadaan lingkungan sekitar dan tanpa harus merusaknya.
	

Based on Table 4, it is evident that students actively participated in the learning activities. This finding aligns with the perspective of Topsakal et al. (2022) and Tan (2021), who stated that Problem-Based Learning (PBL) fosters independent learning and helps students interpret scientific concepts. Furthermore, the implementation of PBL in the classroom promotes the development of student understanding (Suwandi, Sahidu, & Gunada, 2021; Shishiigu et al., 2017; Argaw et al., 2016; Ismoyo, 2017). This suggests that students are able to apply concepts related to alternative energy, mechanical energy, and the efficiency of machine work as outlined in equations 1 and 2.

$$Em_1 = Em_2 \quad (1)$$

$$Ep_1 + Ek_1 = Ep_2 + Ek_2 \quad (2)$$

(Source: Serway, Jewett, & Peroomian, 2000)

Students not only learn mathematical equations but also explore facts and the application of energy concepts. This innovative approach to learning should continue with other relevant topics (Nurmahasih & Jumadi, 2023). However, many teachers still prioritize conventional methods that focus primarily on mathematical equations (Sahyar, Sani, & Malau, 2017). Additionally, some students have not achieved their maximum performance scores, indicating the need for action before implementing Problem-Based Learning (PBL). Therefore, we recommend providing conceptual reinforcement before implementing PBL.

CONCLUSIONS

This study concludes that the assessment of student performance in mini-project activities is generally positive. The Problem-Based Learning (PBL) model encourages students to develop problem-solving skills, collaborate effectively, conduct investigations both independently and in groups, construct energy concepts, communicate scientifically, and engage in meaningful learning experiences. However, some students did not achieve the highest scores. Therefore, we recommend that foundational conceptual learning should be introduced at the beginning as a prerequisite for PBL, especially since the research participants are beginner learners with the PBL model in the classroom.

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