PjBL-ESD as an innovation in science learning: Cultivating local wisdom values and students' critical thinking skills

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Abstract
Sustainability-oriented science education is important to improve critical thinking skills and instill local wisdom values. This study explores the implementation of Project-Based Learning based on Education for Sustainable Development (PjBL-ESD) as an innovation in science learning. This study uses a mixed method with an embedded design. Data were obtained through critical thinking tests, local wisdom value questionnaires, observations, and interviews, then analyzed using N-Gain. The results showed that students who studied with PjBL-ESD experienced a significant increase in critical thinking skills (N-Gain 0.67) in the moderate category. In addition, students better understood and appreciated local wisdom related to environmental conservation through science-based projects and traditional ecological knowledge (N gain 0.25). In conclusion, PjBL-ESD is an effective learning innovation that improves critical thinking skills and strengthens local wisdom values. This approach is recommended to support sustainability education in higher education.

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1. Introduction

Natural Science (IPA) students are not only required to understand scientific concepts. Still, they must also be able to think critically and know local wisdom because of the progress of science and technology. Critical thinking skills are essential to enable students to analyze, assess, and solve problems. Critical thinking means thinking logically and considering options about actions or beliefs (Alsaleh, 2020). On the other hand, local wisdom is essential to build a broad understanding of the environment and culture. This is in line with the principles of Education for Sustainable Development (ESD), which consist of environmental, economic, and social (Vilmala et al., 2022) . However, conventional lecture methods are often less effective in combining these two elements. Consequently, innovation in science learning is needed to meet this need.

The literature review shows that project-based learning (PjBL) is successful in improving students' critical thinking skills (Dimmitt, 2017 ; Putri & Hendawati, 2018; Ma'wa et al., 2022; Hikmah et al., 2023; Wibowo et al., 2024). PjBL emphasizes project-based learning, which engages students in the process of solving real problems. In addition, incorporating ESD into learning can help students understand cultural, social, and environmental sustainability (Vilmala et al., 2022) . Previous studies have shown that the PjBL-ESD method can improve critical thinking skills and awareness of local wisdom. For local wisdom to be significantly improved, intervention from related parties is needed (Widesma & Adnan, 2019) . However, the fact that research examining the application of PjBL-ESD in science lectures is still limited, especially in Indonesia, makes this research very important.

The importance of this article lies in its contribution to the development of innovative learning methods that not only improve critical thinking skills but also strengthen students' understanding of local wisdom (Setyowati et al., 2022). The results of this study are expected to be a reference for educators and researchers in designing curricula that are more relevant to global and local challenges. The justification for this study is based on the urgency to address the gap between theory and practice in science education, as well as the need to promote sustainable and locally context-based learning.

The purpose of this study is to develop PjBL-ESD based teaching materials and test the effectiveness of the PjBL-ESD model in improving students' critical thinking skills and local wisdom values. Thus, this study is expected to provide innovative solutions to face the challenges of science education in the era of globalization.

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2. Method

The research design used is Mixed Methods with an Embedded Experimental approach. This design combines qualitative and quantitative research procedures in one study to solve a problem. The priority of this model is quantitative, with qualitative data attached to the methodology. This study aims to develop students' critical thinking skills and local wisdom values through the use of the PjBL-ESD learning model in learning Science Around Us. The priority of this model is quantitative, with qualitative data attached to this methodology (Creswell, 2012) . This research method is shown in Figure 1. This method was chosen because the research question requires the collection of qualitative and quantitative data types to complement or explain each other. The sampling technique used was purposive sampling using one experimental class.

The mixed method in this type is considered the most appropriate for collecting data in research with interventions, where the main data is supported by other supporting data. The quantitative data that was explored was in the form of critical thinking skills and local wisdom values of students after the PjBL-ESD lecture. Qualitative data was in the form of student responses to learning carried out through lecture observations and interviews. In addition, observations were made during the intervention related to the implementation of PjBL-ESD. The qualitative and quantitative data obtained were then interpreted to obtain conclusions about the PjBL lecture program related to the ESD context in improving critical thinking skills and local wisdom values of students.

In the pre-intervention stage, a needs study is conducted. This stage is a stage of in-depth exploration of the problems being studied. Some activities carried out at this stage include: Literature study and analysis and synthesis of journals and reports and lecturers' perceptions of the Natural Sciences Around Us lectures that have been implemented, the essential principles of Natural Sciences Around Us that are linked to the ESD context, observation results related to lectures, critical thinking skills and local wisdom values. Next, the design stage is carried out, which includes the preparation of an initial product draft. At this stage, an initial draft of the product to be developed is made.

After going through the design process, the next stage is the development stage. At this stage, instruments are produced that will be implemented in the PjBL-ESD model, namely modules, critical thinking ability test questions, and student questionnaires. After the research instrument is created, it is continued with validation/assessment by experts, evaluation, and improvement.

In the initial QUAN test stage, initial information about students' critical thinking skills was explored through the evaluated test device, this part is often called the pretest. The intervention was in the form of implementing PjBL-ESD in the Science Around Us lecture while simultaneously identifying and collecting information about student activities during learning activities (qualitative during the intervention). Data was also explored: (1) the implementation of PjBL lectures that were linked to the ESD context; (2) students' learning experiences in the form of activities that train critical thinking skills and local wisdom values. This will be used as evaluation material regarding the advantages and disadvantages of implementing PjBL-ESD in the Science Around Us lecture, whether the planned activities have been achieved or not.

After the intervention stage, students' critical thinking skills and local wisdom values were re-measured in the final QUAN test, this section is often referred to as the posttest. The results of the analysis of student activity information during the intervention and the results of this final measurement became input to improve the quality of the science lectures Around Us using the PjBL-ESD model (qualitative post-intervention). To strengthen the quality of post-intervention data, a questionnaire was then distributed regarding student responses and lecturer interviews with learning conducted through questionnaires.

After the entire series of stages are completed, the next step is to carry out analysis and interpretation based on quantitative and qualitative data at the Interpretation stage based on QUAN (qual) results. The capital letter QUAN indicates dominant quantitative data/results, while the small letter QUAN indicates qualitative data/results that support and complement. The method flowchart is shown in Figure 1. The red marks on the flowchart indicate the activities that have been carried out.

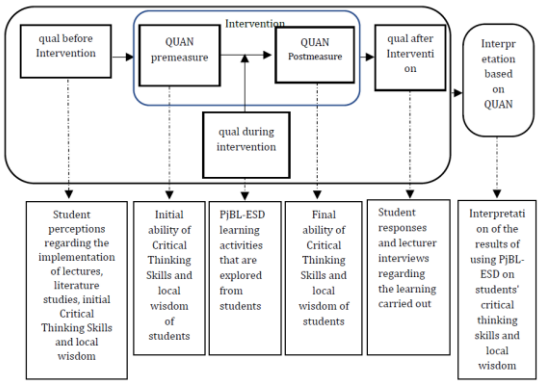

Figure 1. Design Embedded Experimental Model (adaptation from (Creswell & Plano-Clark, 2007)

3. Results and Discussion

This study aims to develop and test the effectiveness of the PjBL-ESD model in improving students' critical thinking skills and local wisdom values. The results and discussions were carried out in accordance with the methods that have been explained.

3.1. Before Intervention

Things that were done before the intervention were to see students' perceptions of the implementation of lectures, literature studies, initial Critical Thinking Skills, and their local wisdom. Based on the results of interviews with lecturers and ten students, it was obtained that the Natural Sciences lectures were taught using a lecture pattern and assignments to make papers in groups. This is certainly still not as expected. This indicates that the learning carried out has not facilitated critical thinking skills and instilling local wisdom values in students. The literature study conducted obtained that Project-Based Learning is suitable for analyzing critical thinking skills and also honing creativity (Prastyaningrum et al., 2024) but it has never been measured on science students at Muhammadiyah University of Riau.

3.2. Intervention (Design and Development of Teaching Materials Using PjBL-ESD)

Learning tools with Project Sheets for the Science Around Us lecture consist of: (1) Activity Guide and (2) Project Sheet.

3.2.1. Learning Activity Guides

Learning activity guides are very helpful in the learning process. Their main function is to provide direction and guidance to lecturers and students on the steps to be followed to achieve the objectives of the lecture. With learning activity guides, lecturers can plan and implement the learning process in a more focused, structured, and effective manner, and students have clear guidance to achieve better learning objectives. The Science Around Us Lecture Activity Guide is shown in Table 1.

Table 1. Science Lecture Activity Guide Around Us Using PjBL-ESD

Learning Stages	Lecturer and Student Activities	Skills that are trained Critical Thinking Skills	Local Wisdom Values
(Problem Identification & Project Launch) (Meeting 1)	• Lecturers provide explanations and stimuli to students about the methods that can be used to find and identify a problem • Lecturers launch projects that will be carried out by students • Students find and identify problems in their environment by conducting field studies following the problem identification project sheet and collecting supporting information that has been provided	• Focusing questions • Analyzing arguments • Asking or answering questions • Considering the credibility of sources • Observing and considering the results of observations	Cultural Social Religious Moral Economy
Building Knowledge, Understanding and Skills based on ESD concepts	• The lecturer delivers material according to the water theme and the project that the students will work on. • Students build their knowledge by answering the continuation of *the project sheet.* problem	• Defining terms and assessing definitions • Identifying assumption attributes	Economy Social

(Meeting 2)	identification and collection of supporting information as supporting information related to the knowledge, understanding and skills needed to work on the project • Students choose the best solution • Students create a project design (solution design) using the project design *sheet* based on the problems they have found.		
Developing and Revising Ideas and Products (Meeting 3)	• Students present the results of the project designs they created in front of the class. • The lecturer provides input regarding the project design presented. • Students create project creation procedures on *the project* procedure sheet. project creation • Students work on projects according to the designs and procedures that have been created. • Students conduct a trial of 1 project according to the trial and redesign *project sheet.* • Students make improvements to the project if it does not meet expectations.	• Observing and considering the results of observations • Making deductions and considering the results of deductions • Making inductions and considering the results of inductions • Making and evaluating judgments • Deciding on an action • Interact/communicate with others	Cultural Social Religious Moral Economy
Presenting Products and Answers to Guiding Questions (Meeting 4)	• Students present the projects they have worked on in front of the class. • Students answer questions related to the project they are working on	• Interact/communicate with others	Social Religious

The assessment given by 2 validators regarding the activity guide above is shown in Table 2 below.

Table 2. Results of Validation of PjBL-ESD Activity Guide by Experts

Assessment Aspects	No Item	Score obtained		Maximum Score	Percentage (%)	Criteria
		V1	V2			
Relevance and Learning Objectives	1, 2, 3, 4, 5	18	18	20	90	Very Valid
Learning Methods and Strategies	6, 7, 8, 9, 10	19	18	20	95	Very Valid
Average		18.5	18	20	91.25	Very Valid
		18.25				

Based on Table 2, it can be concluded that both validators stated that the PjBL-ESD activity guide was declared very valid by the validator. This activity guide can be used in the process of teaching science around us.

3.2.2. Project Sheet

Project Sheet is a worksheet used as a guide for students in completing their projects. The Project Sheet consists of 4, namely: (1) problem identification and collection of supporting information, (2) project design, (3) procedures *for* project creation, and (4) testing and redesign.

The assessment given by 2 validators regarding the Project Sheet above is shown in Table 3 below.

Table 3. Project Sheet Validation Results using PjBL-ESD by Experts

Assessment Aspects	No Item	Score obtained		Maximum Score	Percentage (%)	Criteria
		V1	V2			
Suitability and Relevance of Material	1, 2, 3, 4, 5	56	54	60	91.8	Very Valid
Presentation Skills and Presentation Structure	6, 7, 8, 9, 10	55	56	60	92.5	Very Valid
Creativity and Interactivity	11, 12, 13, 14, 15	58	56	60	95	Very Valid
Average		56.2	55.2	60	92.82	Very Valid
		55.7				

Based on Table 3, it can be concluded that both validators stated that *the* Project Sheet using PjBL-ESD was declared very valid by the validator. This Project Sheet can be used in the process of teaching science around us.

3.2.3. Intervention (IPA Sekitar Kita Lecture Using PjBL-ESD)

The activity guide and Project Sheet that have been declared valid by the validator are then implemented in the classroom. The first thing done at this intervention stage is to provide a pretest in the form of critical thinking skills questions and a questionnaire on local wisdom values that have been declared valid and suitable for use. After the pretest data is obtained, the Science Around Us lecture is carried out for four meetings, as made in the activity guide and project sheet. After the lecture ends, students are then given a post-test. This posttest aims to see the increase in students' critical thinking skills and local wisdom values scores in the Science Around Us lecture after being given treatment. The treatment is in the form of learning using PjBL-ESD. This score increase is analyzed using N-Gain with the formula (eq 1):

$$N\ Gain = \frac{Postest\ Score - Pretest\ Score}{Ideal\ Score - Pretest\ Score} \quad (1)$$

The increase in students' Critical Thinking Skills scores before and after Treatment can be seen in Figure 2 and Table 4.

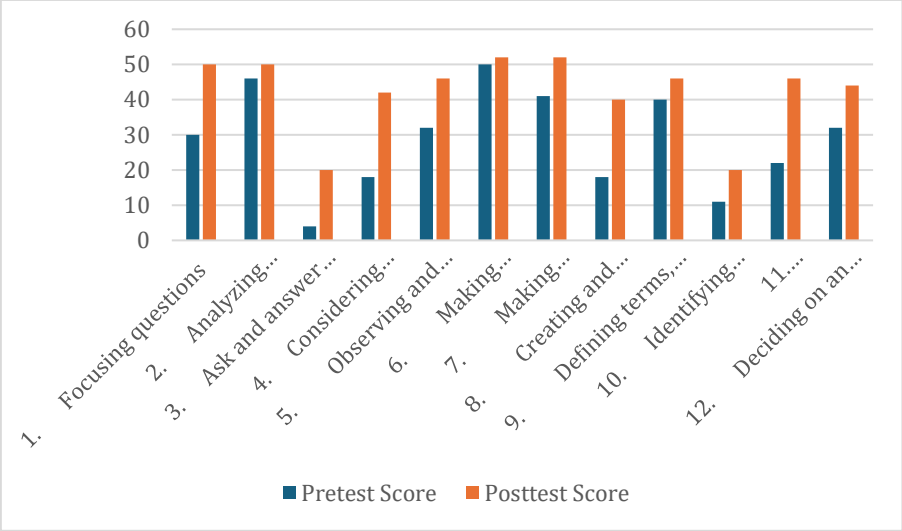

Figure 2. Pretest and Posttest Scores for Critical Thinking Skills for Each Indicator

Table 4. N-Gain Score of Students' Critical Thinking Skills

No.	Critical Thinking Skills Indicator	Pretest Score	Posttest Score	Max Score	N Gain	Criteria
1.	Focusing questions	30	50	52	0.91	High
2.	Analyzing arguments	46	50	52	0.67	Medium
3.	Ask and answer clarifying and challenging questions	4	20	52	0.33	Medium
4.	Considering credibility (criteria of a source)	18	42	52	0.71	High
5.	Observing and considering the results of observations	32	46	52	0.70	High
6.	Making deductions and considering the results of deductions	50	52	52	1.00	High
7.	Making inductions and considering inductions (material conclusions)	41	52	52	1.00	High
8.	Creating and considering important factor values	18	40	52	0.65	Medium
9.	Defining terms, Considering definitions	40	46	52	0.50	Medium
10.	Identifying assumption attributes	11	20	52	0.22	Low
11.	Interact/communicate with others	22	46	52	0.80	High
12.	Deciding on an action	32	44	52	0.60	Medium
13.	Average Score					

Various indicators show an increase in students' critical thinking skills, as shown in Table 4 of their N-Gain scores of critical thinking skills. Several indicators show very good improvement (high category) with high N-Gain (>0.70), such as Focusing questions (0.91), Considering source credibility (0.71), Observing and considering observation results (0.70), Making deductions and inductions (1.00), and Interacting/ communicating with others (0.80). Indicators that fall into the medium category (0.30–0.70) include analyzing arguments (0.67) and making and questioning arguments (0.67). Identifying assumption attributes (0.22) and asking and answering clarifying and challenging questions (0.33) are indicators with low improvement (<0.30). In general, there is variation in the level of students' critical thinking skills. Some components, such as induction, deduction, and communication, have increased significantly, but the ability to find assumptions and ask critical

questions still needs to be improved. These results are supported by research (Wulandari et al., 2024) as well as research (Ramadhani et al., 2024) which analyzed twenty articles and found that Critical thinking skills essential to science education can be improved using project-based learning instruction.

An example of a question with a medium N-gain category is question number 3. A student explained that the flood phenomenon that occurred contained several science concepts, especially fluid material. Among them, Archimedes' Law and Hydrostatic Pressure, Fluid Flow, Capillarity and Viscosity. The student concluded that fluid material only discusses liquids, such as water during a flood. This conclusion was clarified through the clarification given that liquids are the only substances that can flow according to the fluid concept. Do you agree with the student's clarification? Give your reasons! At first glance, the answer to question number 3 seems correct, but if you look again, liquid is not the only substance that can flow according to the concept of fluid; there is also gas, which is also a substance that can flow.

Likewise, with question number 8. The phenomenon of flooding due to extreme rainfall can be understood by the law of water flow (Bernoulli's Law) and the concept of forces that drive water flow, which are directly related to climate change and environmental destruction.

Some factors that affect the Bernoulli equation are:

a. Pressure (P). The fluid pressure at a certain point in the flow will affect the fluid velocity. The greater the pressure, the lower the fluid velocity at that point, according to Bernoulli's principle.

b. Speed (v). Fluid velocity is also directly related to pressure. Faster-moving fluids will produce lower pressure at that point.

c. Height (h). The height or potential energy of the fluid at a certain point affects the total energy of the flow. The higher the position of the fluid, the greater its potential energy, which affects pressure and velocity.

d. Density (ρ). The density of the fluid plays a role in determining how much kinetic energy per unit volume is contained in the fluid.

These factors interact with each other in the Bernoulli equation to explain fluid flow in pipes or channels of different sizes and conditions.

Are the factors that affect the Bernoulli equation in flood cases correct in your opinion? Explain your argument!

The most appropriate answer is according to the following equation (eq. 2):

$$P_1 + \frac{1}{2}pv_1^2 + pgh_1 = P_2 + \frac{1}{2}pv_2^2 + pgh_2 \quad (2)$$

However, there are still students who give the wrong answer.

The increase in students' Local Wisdom Value scores before and after Treatment can be seen in Figure 3 and Table 5.

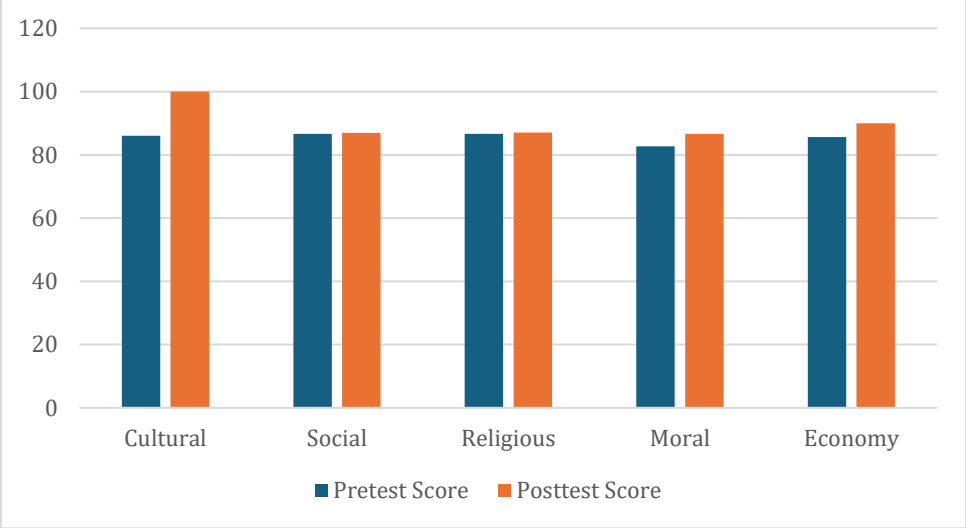

Figure 3. Pretest and Posttest Scores of Local Wisdom Values for Each Indicator

Table 5. N-Gain Score of Students' Local Wisdom Values

Local Wisdom Value Indicators	Pretest Score	Posttest Score	Max Score	N Gain	Criteria
Cultural	86.00	100.00	104	0.78	High
Social	86.68	87.00	104	0.02	Low
Religious	86.68	87.05	104	0.02	Low
Moral	82.68	86.68	104	0.19	Low
Economy	85.68	90.00	104	0.24	Low

Cultural values, which have an N-Gain of 0.78, are the only indicators that experienced a significant increase. This increase indicates that students can better understand and apply cultural values after the learning intervention. This is in line with research that states that incorporating cultural values into education can increase students' gratitude and understanding of local heritage (Dewi et al., 2024). In contrast, four additional metrics showed relatively small increases, namely social values 0.02, religious values 0.02, moral values 0.19, and economic values 0.24. Low increases in social, religious, and moral aspects may indicate that the intervention efforts made have not been effective enough in instilling these values in students. Local wisdom-based learning that is not integrated with direct experience tends to have less impact on social and moral aspects, according to research conducted by (Ecca & Kasman, 2025). The economic value increased slightly (0.24), indicating that students are beginning to understand the relationship between local wisdom and economic aspects. However, to increase awareness and skills of local cultural-based economy, a more applied approach is needed (Laia, 2024). Overall, research shows that PjBL-ESD learning has great potential to improve students' cultural values. Project-based learning based on local wisdom on Plantae material is effective for training students' scientific literacy competencies (Zahroh et al., 2022), E-modules can improve interpersonal skills, one of which is understanding students' socio-cultural phenomena. (Setiawan et al., 2023). Electronic LKS teaching materials based on Project Learning integrated with local wisdom are valid and interesting to use in helping the learning process of cultural heritage material for students (Siswoyo et al., 2024). However, additional approaches are needed to strengthen social, religious, moral, and economic elements. To achieve this goal, the curriculum can be designed in a more integrative and experience-based way.

3.3. After Intervention (Student Responses After Science Lecture Around Us Using PjBL-ESD)

Based on the results of student responses to *the* project sheet using PjBL-ESD implemented in the Science Around Us lecture, students gave positive responses to the lectures that were implemented. The responses were obtained based on the results of interviews conducted with several students. The results were that students were very interested in implementing the *IPA Sekitar Kita* lecture using PjBL-ESD assisted by the project sheet. "After taking the Science Around Us lecture with the PjBL-ESD approach, I became better at critical thinking and more aware of the importance of protecting the environment through science-based solutions and local wisdom". They also stated that the lectures became more enjoyable because they carried out field studies to find problems, design, create, and test their solutions to the problems they found. In addition, they stated that their critical thinking skills and local wisdom values were also trained.

3.4. Interpretation Based on Quantitative Data Obtained

Based on the findings in Table 4 and Table 5, it can be concluded that there was an increase in students' critical thinking skills scores with an N gain of 0.67 and local wisdom value scores with an N gain of 0.25. In line with research (Nawangsari, 2022; Prastyaningrum et al., 2024; Rogovaya et al., 2019) . This can be interpreted that the Science lectures around us using PjBL-ESD can improve students' critical thinking skills and local wisdom values. This is because in the PjBL-ESD model assisted by project sheets, indicators of each dependent variable are trained.

4. Conclusion

The conclusion of this study confirms that the implementation of the Project-Based Learning (PjBL) model based on Education for Sustainable Development (ESD) in science education contributes significantly to improving students' critical thinking skills and instilling local wisdom values. This model not only helps students understand scientific concepts more deeply but also allows them to connect science with the social and environmental realities around them. Thus, PjBL-ESD plays a role as an innovative strategy in building awareness of the importance of sustainability and preparing students to become individuals who can face global challenges without leaving their local cultural roots. The main contribution of this study is to show the effectiveness of the integration of PjBL and ESD in science education as a more contextual, applicable, and solution-oriented approach. This can be seen from the increase in the N Gain score. In addition, this study enriches the discourse on science pedagogy by proposing a more holistic learning model, which not only focuses on academic aspects but also builds their character and local wisdom values. For further research, some suggestions that can be considered are: (1) Long-term testing. Investigating the long-term impact of implementing PjBL-ESD on the development of critical thinking and environmental awareness of students at various levels of education. (2) Development of an adaptive model. Adapting PjBL-ESD to the cultural characteristics and educational contexts in various regions to ensure broader effectiveness. (3) Technology integration. Explore how digital technology can be utilized to strengthen the effectiveness of PjBL-ESD in enhancing students' learning experiences. (4) Evaluation of 21st century skills: Measuring the extent to which this approach can improve other skills such as collaboration, communication, and creativity needed in facing global challenges. By expanding the scope of research, it is hoped that the PjBL-ESD approach can continue to develop as a more inclusive, adaptive, and relevant pedagogical strategy for science education in the future.

Author Contributions

Vilmala: Conceptualization, Methodology, Writing- original draft preparation. Kisworo: Data curation, Writing—original draft preparation. Rihan: Visualization, Investigation. Syafriani: Visualization, Investigation.

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Declaration of Conflicting Interests

Regarding the research, authorship, and/or publication of this work, the author disclosed no potential conflicts of interest.

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