



The Effectiveness of Project-Based Learning in Developing Sustainability Awareness and Critical Skills in High School

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Abstract: The integration of sustainability principles and critical thinking into science learning remains limited, particularly in vocational high schools, despite their importance for achieving Education for Sustainable Development (ESD). This study aimed to examine the effectiveness of Project-Based Learning (PBL) in improving students' sustainability awareness and critical thinking skills. A quasi-experimental method with a pretest-posttest control group design was employed involving 64 eleventh-grade students at SMK Negeri 1 Parigi, consisting of 32 students in the experimental group and 32 students in the control group. The experimental group received Project-Based Learning, whereas the control group was taught using conventional instruction. Data were collected using a sustainability awareness questionnaire and a critical thinking skills test. The data were analyzed through normality and homogeneity tests, independent samples t-test, and N-Gain analysis. The results revealed significant differences between the experimental and control groups ($p < 0.05$). Students taught using Project-Based Learning achieved higher learning gains in sustainability awareness (N-Gain = 0.68, medium category) and critical thinking skills (N-Gain = 0.73, high category) compared with those receiving conventional learning. The findings indicate that authentic environmental projects, collaborative learning, and reflective activities effectively enhance students' sustainability awareness while simultaneously fostering higher-order thinking skills. Therefore, Project-Based Learning is recommended as an effective instructional approach for integrating sustainability values and developing twenty-first-century competencies in vocational science education.

Keywords: Critical thinking skills; Education for sustainable development; Project-based learning; Sustainability awareness; Vocational high school

Introduction

Global sustainability issues have become one of the most significant concerns in contemporary education. Environmental challenges, including climate change, biodiversity loss, pollution, deforestation, and the depletion of natural resources, have increasingly threatened ecological balance and human well-being. These complex problems indicate that the challenges of the twenty-first century cannot be addressed solely through the acquisition of cognitive knowledge but

require individuals to develop sustainability awareness, critical thinking skills, and responsible actions toward the environment. Consequently, education plays a strategic role in preparing future generations who possess not only scientific knowledge but also the competencies, values, and attitudes necessary to contribute to sustainable development (UNESCO, 2021).

To address these global challenges, the concept of Education for Sustainable Development (ESD) has become an essential framework for educational transformation. UNESCO (2020) defines ESD as an

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educational approach that empowers learners with the knowledge, skills, values, attitudes, and behaviors required to make responsible decisions and take informed actions for environmental integrity, economic viability, and social justice for present and future generations. Unlike conventional teaching approaches that primarily emphasize knowledge acquisition, ESD encourages students to actively participate in solving authentic sustainability problems through collaborative, reflective, and action-oriented learning experiences.

From a theoretical perspective, the implementation of ESD is strongly supported by constructivist learning theory. According to Piaget (1973), learners actively construct knowledge through interactions with their physical environment and previous experiences rather than passively receiving information from teachers. Similarly, Vygotsky (1978) emphasized that meaningful learning occurs through social interaction, collaboration, and guided participation within the learner's zone of proximal development. In addition, Kolb's (1984) Experiential Learning Theory explains that meaningful knowledge is developed through concrete experience, reflective observation, abstract conceptualization, and active experimentation.

Based on these theoretical perspectives, Project-Based Learning (PjBL) is considered one of the most appropriate instructional models for implementing Education for Sustainable Development. Thomas (2021) defines PjBL as a student-centered pedagogical approach that engages learners in authentic investigations through meaningful projects. Furthermore, Konrad et al. (2021) argued that sustainability education should develop systems thinking, anticipatory thinking, normative competence, strategic competence, and interpersonal competence, all of which can be effectively fostered through authentic project-based learning.

Recent empirical studies consistently demonstrate that Project-Based Learning has considerable potential to promote sustainability competencies across different educational levels. Ásványi et al. (2025) reported significant improvements in students' sustainability consciousness, while Triyandana et al. (2024) found that environmental projects enhanced ecological awareness. Moreover, Chen et al. (2025) and Afriana et al. (2016) demonstrated that Project-Based Learning effectively improves critical thinking, scientific literacy, and problem-solving skills through inquiry, collaboration, and reflective learning.

Despite these positive findings, previous studies have also identified a persistent knowledge-action gap, where students possess environmental knowledge but fail to translate it into sustainable behavior (Kollmuss et al., 2002; Parker et al., 2018). Project-Based Learning offers an appropriate solution because students actively

investigate authentic environmental problems, collaboratively develop solutions, implement projects, and reflect on their learning experiences (Mulyadi et al., 2026; Susilawati et al., 2025). Rahmania (2024) further emphasized that sustainable behavior emerges through the interaction of environmental knowledge, psychosocial factors, reflective thinking, and meaningful participation.

Although the effectiveness of Project-Based Learning has been widely reported, several important research gaps remain. First, most previous studies examined sustainability awareness and critical thinking separately. Second, limited studies have investigated both variables simultaneously within the ESD framework. Third, empirical evidence focusing on Indonesian vocational high school students remains scarce.

Unlike previous studies, the present research simultaneously investigates sustainability awareness and critical thinking skills within the framework of Education for Sustainable Development among vocational high school students. By integrating authentic environmental projects into science learning through Project-Based Learning, this study provides empirical evidence regarding the effectiveness of this instructional model in promoting sustainability competencies and higher-order thinking skills simultaneously.

Based on these considerations, this study aims to examine the effectiveness of Project-Based Learning in improving vocational high school students' sustainability awareness and critical thinking skills. The findings are expected to enrich the implementation of Education for Sustainable Development in vocational education and provide empirical evidence supporting the integration of sustainability values into science learning through authentic project-based experiences.

Method

This study used a quasi-experimental approach with a pretest-posttest control group design, aiming to compare the learning outcomes between students taught using the PjBL model and students taught using conventional learning methods. The research population consisted of all Grade XI students at SMK Negeri 1 Parigi in the 2024/2025 academic year. The sample consisted of 64 students from two parallel classes with equivalent academic levels. Class XI TJKT-1 was the experimental group (32 students) and class XI TJKT-2 was the control group (32 students).

The overall research procedure is illustrated in Figure 1 to provide a clear overview of the stages implemented throughout this study.

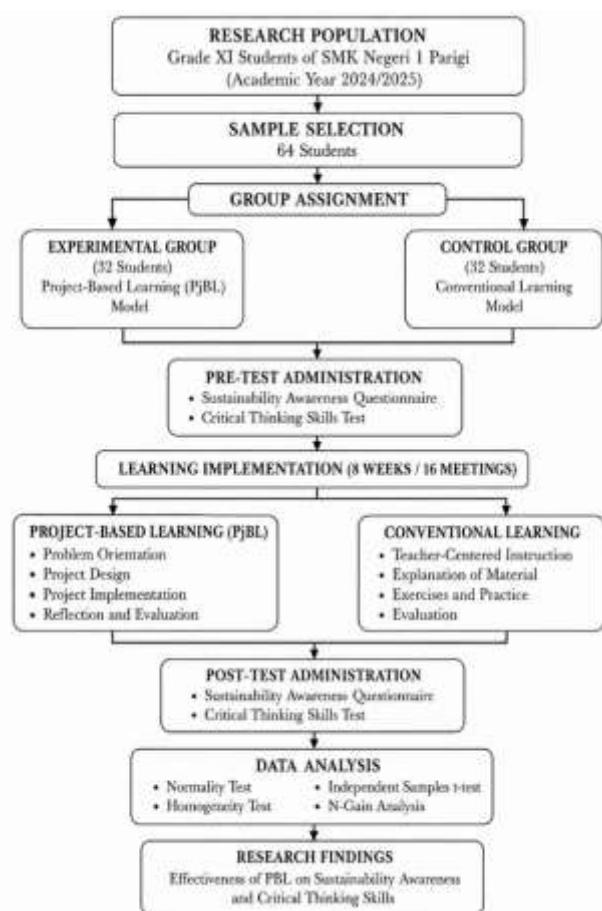


Figure 1. Research procedure flow chart

Figure 1 shows the sequence of the research procedure. The study began with the selection of participants, followed by group assignment into the experimental and control groups. Both groups completed the pre-test before receiving different learning treatments. The experimental group was taught using the Project-Based Learning model, whereas the control group received conventional instruction. After the intervention, both groups completed the post-test, and the collected data were analyzed using normality and homogeneity tests, independent samples t-test, and N-Gain analysis to determine the effectiveness of the learning model.

The research was conducted over 8 weeks (16 meetings) with the following stages: (a) Problem orientation: students identified issues of extinction in the school environment, such as energy consumption and laboratory waste management. (b) Project design: students developed action plans, such as creating a sensor-based Smart Waste Sorting System. (c) Project implementation: students developed and implemented solutions. (d) Reflection and evaluation: groups explained the project outcomes (d) and evaluated their impact on the school environment.

The research instruments used were a sustainable awareness questionnaire and a critical thinking skills test. The sustainable awareness questionnaire consisted of 30 items covering the dimensions of knowledge, attitude, and behaviour (Rahmania, 2024). Meanwhile, the critical thinking skills test consisted of 15 questions covering the indicators of analysis, evaluation, and inference. The data were analysed using normality and homogeneity tests to ensure normal data distribution and homogeneous variance. An independent test was used to test for significant differences between groups. N-Gain was used to measure the level of improvement in learning outcomes with categories of low (<0.3), medium ($0.3-0.7$) and high (>0.7). Research design and method should be clearly defined.

Result and Discussion

This study used two dependent variables, namely sustainability awareness and critical thinking skills, which were measured before and after the implementation of the Project-Based Learning (PJBL) model. The analysis was conducted on two groups, namely the experimental group (using the PJBL model) and the control group (using conventional learning).

Table 1. Descriptive Results Analysis

Variable	Group	Pre-test	Post-test	N-Gain
Sustainability Awareness	Experiment	63.15	86.80	0.68
	Control	62.92	73.40	0.32
Critical Thinking Skills	Experiment	61.45	85.10	0.73
	Control	60.95	70.45	0.29

Based on the data in Table 1, there was a significant increase in the average score in the experimental group compared to the control group. The average increase in N-Gain for sustainability awareness was 0.68 (medium-high category) and for critical thinking skills was 0.73 (high category). Meanwhile, in the control group, the increase only reached the low category (0.29-0.32).

This indicates that project-based learning provides a more meaningful learning experience and encourages students to understand sustainability issues in depth and practise their critical thinking skills in the context of real-world problem solving.

Table 2. T-test Results

Variable	t- Calculated	Sig. (2-tailed)	Description
Sustainability Awareness	6.287	0.000	Significant
Critical Thinking Skills	6.985	0.000	Significant

The significance value ($p < 0.05$) indicates that there is a significant difference between the experimental group and the control group in terms of both sustainability awareness and critical thinking skills. This means that the application of Project-Based Learning has a real effect on improving these two variables.

The results of the study indicate that the implementation of PJBL has a significant effect on increasing the sustainability awareness of vocational school students. Students in the experimental group demonstrated a deeper understanding of the concept of sustainability, which covers environmental, social, and economic aspects. This improvement was due to the direct involvement of students in projects relevant to real life. This is in line with the results of research by Ásványi et al. (2025), which shows that the implementation of project-based learning can significantly increase students' sustainability awareness, both in the short and long term. Project-based learning provides space for students to practise ecological and social reflection on the impact of their actions, thereby forming a more holistic sustainability mindset.

In addition, PJBL strengthens critical thinking skills because it requires students to analyse, compare alternative solutions, and assess the effectiveness of projects based on empirical data. This process is in line with constructivist theory (Piaget & Vygotsky), in which knowledge is constructed through exploratory and collaborative activities.

From a psychological perspective, Rahmania (2024) explains that sustainable behaviour is influenced by the interaction between environmental and psychosocial factors. PJBL is able to activate both factors through collaborative and reflective processes that encourage empathy and social responsibility in students. When students are involved in environmental projects, they experience an emotional learning process that increases their concern and sense of ownership of their surroundings (environmental ownership), as explained by Chen et al. (2025)

Increased sustainability awareness also shows that PJBL effectively bridges the knowledge-action gap, as identified by Kollmuss et al. (2002). Through active involvement in concrete projects, students not only understand sustainability issues conceptually, but also practise applying them in real actions, such as sorting waste, saving energy, and designing environmental solutions at school.

In addition to increasing sustainability awareness, the results of the study also show that the application of PJBL can significantly improve critical thinking skills. The average critical thinking skills score in the experimental group increased from 61.45 to 85.10 with an N-Gain of 0.73 (high category), while the control group only experienced a small increase (N-Gain = 0.29).

This finding is consistent with the study conducted by Anggraeni et al. (2023), which reported that the implementation of Problem-Based Learning (PjBL) has a positive effect on students' critical thinking skills. This improvement occurs because students are actively engaged in authentic problem investigation, collaborative group discussions, and shared decision-making processes. Through these learning activities, PJBL encourages students to think more deeply, analytically, and reflectively than conventional lecture-based instruction.

This improvement occurred because in PJBL, students were trained to analyse problems, evaluate various alternative solutions, and draw conclusions based on empirical evidence found during the project. This is in line with the constructivist theory proposed by Piaget and Vygotsky, that knowledge is constructed through active interaction between students and their environment. Through group discussions, field observations, and evaluative processes, students hone their analytical, inferential, and argument assessment skills, which are at the core of critical thinking.

This study supports the findings of Colombo et al. (2023), which confirm that critical thinking is a function of self-regulation and executive function that can be developed through collaborative and reflective activities such as PJBL. Thus, the environmental projects carried out by students not only hone their cognition but also develop their metacognitive and self-regulation skills.

Furthermore, Triyandana et al. (2024) emphasise that project-based learning with green curriculum integration can develop students' environmental literacy and higher-order thinking skills through exploratory and collaborative activities. Students learn to assess the consequences of actions, weigh the effectiveness of solutions, and make data-based decisions, which was also found in this study, where students were able to present their project results with scientific arguments and critical reflections (Sabrina et al., 2026; Susilawati et al., 2022).

The findings of this study provide several important implications for the world of education, particularly at the vocational secondary education level: (1) PJBL can be an implementative strategy for Education for Sustainable Development (ESD) in secondary schools, as it integrates the dimensions of knowledge, values, and sustainable actions. (2) PJBL improves the quality of critical thinking among vocational high school students, which is urgently needed to face 21st-century challenges in the fields of technology and green industry. (3) Environmental project activities such as waste management or energy monitoring can be used as interdisciplinary learning media that combine science, technology, and social values.

These results also reinforce the research by Djirong et al. (2024), which emphasises the importance of synchronisation between vocational education and environmental policy in producing a generation that is both competent and concerned about sustainability.

Conclusion

This study demonstrates that Project-Based Learning (PjBL) is effective in improving both sustainability awareness and critical thinking skills among vocational high school students. The experimental group achieved higher learning gains than the control group, with medium-to-high improvement in sustainability awareness (N-Gain = 0.68) and high improvement in critical thinking skills (N-Gain = 0.73), while the independent samples t-test confirmed significant differences between the two groups ($p < 0.05$). These findings indicate that authentic environmental projects, collaborative learning, and reflective activities enabled students to actively construct knowledge, solve real-world sustainability problems, and apply critical reasoning in meaningful contexts, consistent with the principles of constructivist learning theory and Education for Sustainable Development (ESD). Furthermore, the study confirms that Project-Based Learning helps bridge the gap between environmental knowledge and sustainable action while simultaneously fostering higher-order thinking skills. Therefore, Project-Based Learning can be recommended as an effective instructional approach for integrating sustainability values and developing twenty-first-century competencies in vocational science education.

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Conceptualization, N.G.A.P.E.S.W.; methodology, E.N.; formal analysis, E.R.I.M. and M.N.; investigation, N.G.A.P.E.S.W.; resources, E.R.I.M.; writing preparation of original draft, I.K.W.; writing reviewing and editing, N.D.N. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

No conflict interest.

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