I J S E T SINTA S3

INTERNATIONAL JOURNAL OF SOCIAL SCIENCE, EDUCATIONAL, ECONOMICS, AGRICULTURE RESEARCH AND TECHNOLOGY (IJSET) | ISSN (E): 2827-766X
Website: https://ijset.org/ | Volumes 5 No 4 (2026)

TEACHERS' PERSPECTIVES ON PROJECT-BASED LEARNING INTEGRATED WITH ESD-STEM IN TEACHING PHOTOSYNTHESIS TO FOSTER CRITICAL THINKING

Lusi Ayu Gustari, Ghullam Hamdu
Program Studi Pascasarjana Pendidikan Guru Sekolah Dasar, Universitas Pendidikan Indonesia Kampus Tasikmalaya, Tasikmalaya
E-mail: ghullamh2012@upi.edu

Received: 20/02/2026 | **Revised**: 02/03/2026 | **Accepted:** 20 /03/2026 | **Published**: 27/03/2026

Abstract
This study was motivated by the need for science education that can develop critical thinking skills in elementary school students through a contextual and sustainable approach. The integration of Project-Based Learning (PjBL), Education for Sustainable Development (ESD), and STEM is seen as a relevant innovative strategy, but its implementation in the field has not been fully structured. This study aims to analyze teachers' perspectives on the application of ESD-STEM integrated PjBL in photosynthesis learning and to examine its implications for the development of students' critical thinking skills. The research used a qualitative approach with an instrumental case study design conducted in three public elementary schools in Bungursari District, Tasikmalaya City. Data were obtained through in-depth interviews, learning observations, and documentation studies, then analyzed through a process of reduction, categorization, and thematic interpretation. The results showed that teachers had implemented project-based learning that encouraged active student involvement and fostered problem identification, cause-and-effect analysis, and data-based conclusion drawing skills, although the integration of ESD and STEM was still implicit and not yet fully systematic. This study concludes that the development of structured and reflective PjBL-ESD-STEM integrated teaching modules is necessary to optimize the development of students' critical thinking in sustainability-based science learning.

Keywords: Critical Thinking, Education for Sustainable Development (ESD), Project Based Learning, Science Learning, STEM.

INTRODUCTION

Science education in elementary schools plays a strategic role in building students' scientific literacy and critical thinking skills from an early age. One important topic in science is photosynthesis, because this concept is not only related to biological processes in plants, but also directly related to human survival and environmental balance. In the context of global challenges such as climate change and environmental degradation, students' understanding of photosynthesis is becoming increasingly relevant as a foundation for ecological awareness and sustainability. Unesco (2020) emphasizes that science education should be directed at shaping a generation that has scientific understanding as well as responsibility for environmental sustainability. Theoretically, 21st-century science learning requires the application of learning models that emphasize higher-order thinking skills (HOTS), particularly critical, creative, collaborative, and communicative thinking (Barbot & Kaufman, 2025; Nurhasnah et al., 2023). Project-Based Learning (PjBL) is seen as one of the effective models for developing these abilities because it actively involves students in solving real problems through the process of designing, implementing, and evaluating a project. Bell (2020) states that "project-based learning engages students in authentic inquiry processes that promote deeper understanding and critical thinking skills." These findings are reinforced by research showing that PjBL significantly improves students' critical thinking skills and learning motivation in science learning (Guo et al., 2020; Konig et al., 2022). On the other hand, the STEM (Science, Technology, Engineering, and Mathematics) approach emphasizes cross-disciplinary integration to help students understand scientific concepts in a contextual and applicable manner. Wu et al., (2024) conclude that STEM learning enables students "to connect scientific concepts with real-world problem solving through interdisciplinary learning." The integration of Education for Sustainable Development (ESD) in science learning further strengthens the value dimension by instilling awareness of sustainability, environmental responsibility, and social concern. According to (Unesco, 2020), ESD aims to equip learners with the knowledge, skills, and values to face global challenges such as climate change and environmental crises. Various theoretical studies confirm that PjBL-based learning integrated with STEM can increase learning motivation, student engagement, and critical thinking skills. Research by Kang et al. (2021) shows that students who learn with PjBL-STEM have higher levels of critical thinking than students who learn with conventional methods. Furthermore, ESD emphasizes that education should not only focus on mastering concepts, but also on shaping sustainable attitudes and behaviors (Kopnina, 2020). Thus, the integration of PjBL, STEM, and ESD is conceptually a comprehensive approach to addressing the need for meaningful, contextual, and relevant science learning that is relevant to real-life challenges. However, empirical evidence in the field shows that teaching photosynthesis in elementary schools still faces various obstacles. The results of exploratory studies and interviews with teachers indicate that photosynthesis is still considered difficult for students to understand because it is abstract, involves scientific terms, and involves processes that cannot be observed directly. International research also reports that the concept of photosynthesis is one of the most difficult biology topics for students to understand because of its microscopic nature and processes that cannot be observed directly (Husna et al., 2023).

Learning is still dominated by conceptual explanations and the use of textbooks, while practical activities and visualization of the photosynthesis process have not been carried out optimally. As a result, students tend to memorize concepts without deeply understanding the meaning of the photosynthesis process (Darwis & Rustaman, 2016; Siregar, 2024). In addition, students' critical thinking skills in science learning still vary. Some students are able to explain processes and draw conclusions, but others are still passive, unable to ask questions, and are not yet accustomed to connecting concepts with issues in their surroundings. A study by Facione (2011) confirms that critical thinking does not develop automatically but must be trained through learning strategies that require analysis, reflection, and problem solving. This condition shows that the theoretical demands of science learning oriented towards HOTS have not been fully realized in classroom learning practices.

A gap exists between the demands of educational theory and policy, which emphasize active, integrative, and critical thinking-oriented learning, and the reality of learning in the field, which is still limited to conventional methods, minimal visual media, and a lack of systematic integration with PjBL, STEM, and ESD approaches. On the one hand, academic literature emphasizes the importance of project-based learning and sustainability (Anggraeni, 2023b; Unesco, 2020); on the other hand, teachers still face limitations in practical guidance in the form of structured and applicable teaching modules (Cinderella et al., 2025; Faradita & Afiani, 2021; Farwati et al., 2021). Another problem identified is the unavailability of teaching modules that specifically integrate PjBL with ESD-STEM in photosynthesis material. Teachers stated that they need practical, easy-to-understand, and curriculum-appropriate learning guidelines to help them design learning that encourages students to think critically while understanding environmental issues contextually. National research shows that PjBL-STEM-based teaching modules can help teachers implement innovative learning systematically and improve the quality of science learning (Anggraeni, 2024; Faradita & Afiani, 2021; Turan, 2023; Zhai et al., 2020).

Logically and objectively, research on teachers' perspectives on the application of Project-Based Learning integrated with ESD-STEM in photosynthesis learning is important and strategic. From the perspective of scientific development, this research contributes to the study of integrated science learning that connects pedagogical, cognitive, and sustainability aspects (Anggraeni, 2023a; Lozano & Barreiro-Gen, 2022; Sun et al., 2022). From the perspective of the teaching profession, this research can be the basis for developing teaching modules that are in line with the real needs of teachers in the field. From a humanitarian perspective, this research is relevant for developing a generation that has critical thinking skills and awareness of the environment and sustainability of life (Unesco, 2020). Based on empirical phenomena found in the field, theoretical studies emphasizing the importance of innovative 21st-century learning, and the gap between ideal learning demands and classroom realities, the main problem in this study lies in the suboptimal teaching of photosynthesis that integrates Project-Based Learning with the ESD-STEM approach to foster critical thinking skills in elementary school students. Although conceptually the integration of PjBL, STEM, and ESD is believed to create contextual, meaningful, and sustainability-oriented learning, its implementation at the elementary school level still faces various limitations. Therefore, this study aims to examine in depth how teachers' perspectives on the application of Project-Based Learning integrated with ESD-STEM in photosynthesis learning can foster critical thinking skills in elementary school students.

LITERATURE REVIEW

21st century learning requires students to not only master conceptual knowledge, but also be able to develop higher-order thinking skills such as critical thinking, problem solving, collaboration, and creativity. One learning approach that is widely recommended to achieve these goals is Project-Based Learning (PjBL). PjBL is a learning model that places projects at the center of learning activities so that students are actively involved in the process of investigation, problem solving, and creation of meaningful products. Research shows that PjBL can increase students' cognitive engagement and intrinsic motivation because it provides space for exploration, collaboration, and reflection during the learning process (Guo et al., 2020; Hu & Chen, 2021a). Theoretically, this approach is rooted in the social constructivist perspective, which emphasizes that knowledge is constructed through direct experience and social interaction. In the contemporary constructivist perspective, meaningful learning occurs when students construct conceptual representations through contextual authentic activities (Kirschner & Hendrick, 2024).

In the context of science learning in elementary schools, the integration of the STEM (*Science, Technology, Engineering, and Mathematics*) approach is an important strategy for developing students' analytical thinking and problem-solving skills. STEM integration emphasizes the interconnection between disciplines through authentic problem solving and conceptual reflection. Recent literature confirms that effective STEM integration requires learning designs that explicitly link cross-disciplinary concepts so that students can understand the relationship between science, technology, engineering, and mathematics in real-life contexts (English, 2024; Thibaut et al., 2018a). However, some studies show that the implementation of STEM in schools is often still multidisciplinary in nature, i.e., it only combines activities from several fields without deep conceptual integration. Without clear epistemological planning, learning has the potential to fall short of the expected interdisciplinary or transdisciplinary stage.

In addition to STEM integration, the concept of *Education for Sustainable Development* (ESD) is also gaining attention in the development of modern science curricula. ESD aims to equip students with the competencies needed to face global sustainability challenges, such as climate change, environmental degradation, and social inequality. The latest UNESCO framework emphasizes that ESD not only instills ecological awareness but also encourages the development of systemic, anticipatory, and reflective thinking competencies (Unesco, 2020). Recent research also shows that integrating ESD into science learning is more effective when linked to real action and critical reflection on the environmental impact of human activities (Rieckmann, 2017). Therefore, learning that integrates PjBL, STEM, and ESD has great potential to create authentic learning experiences that are relevant to the sustainability challenges of the future.

The development of critical thinking skills is one of the main objectives of project-based science learning. Critical thinking includes the ability to interpret information, analyze cause-and-effect relationships, evaluate evidence, draw conclusions, and engage in metacognitive reflection on the thinking process. According to Facione et al., (2021), the modern critical thinking framework includes five main dimensions: interpretation, analysis, evaluation, inference, and metacognitive reflection. Research shows that project-based learning in science can improve students' analytical and causal reasoning skills because they are directly involved in the authentic investigation process (Touitou et al., 2020). However, several studies also emphasize that the development of all dimensions of critical thinking requires explicit pedagogical support, such as reflective questions, evaluative discussions, and structured authentic assessments (Larmer et al., 2015).

Although various studies show the great potential of integrating PjBL, STEM, and ESD in science learning, its implementation at the elementary school level still faces a number of challenges. One of the main obstacles is the limited learning time in the curriculum, which is often insufficient to carry out all stages of the project in depth, from planning to reflection. Research shows that curriculum pressure and time constraints often cause teachers to simplify the project stages so that the reflection and evaluation processes are not carried out optimally (OECD, 2022). In addition, the limited availability of learning modules that explicitly integrate PjBL, STEM, and ESD is also an obstacle to implementation in the field. Without structured curriculum guidance, the integration of these approaches tends to be implicit and inconsistent (Thibaut et al., 2018a; Unesco, 2020). Another contributing factor is the limited professional training available to teachers on the pedagogical integration of STEM and ESD. Research shows that teacher competence in applying learning innovations is greatly influenced by systematic continuing professional development programs (English, 2024).

Based on this literature review, it can be concluded that the integration of PjBL, STEM, and ESD has great potential to develop students' critical thinking skills through contextual science learning based on real problems. However, there is still a gap between curriculum policies that encourage innovative learning and their implementation in elementary schools. Limited learning time, a lack of integrated modules, and minimal teacher training indicate a need to examine in greater depth how the integration of these three approaches can be effectively implemented in the context of science learning in elementary schools. Therefore, this study aims to analyze the implementation of the integration of PjBL, STEM, and ESD in science learning and its implications for the development of students' critical thinking skills.

METHOD

This study uses qualitative research because it aims to deeply understand teachers' perspectives, experiences, and interpretations of the application of Project-Based Learning (PjBL) integrated with the ESD-STEM approach in photosynthesis learning to foster critical thinking skills in elementary school students. Qualitative research is understood as an approach that seeks to understand the meaning of social phenomena in their natural context and emphasizes the interpretation of the research subjects' experiences (Creswell & Poth, 2016; deMarrais et al., 2024; Tisdell et al., 2025). Thus, this research methodology is a systematic way of understanding learning phenomena through contextual, reflective, and interpretive exploration. The research steps were adjusted to the exploratory nature of the problem, the research objectives that emphasized subjective meaning, and the framework that placed teachers as the main actors in the implementation of learning innovations.

The approach used is an instrumental case study, as this research focuses on one specific case, namely the practice of PjBL-based photosynthesis learning integrated with ESD-STEM, to gain a broader understanding of the dynamics of innovative learning implementation in elementary schools. Case studies allow researchers to explore phenomena in depth in a natural setting and maintain the integrity of the social context (Stake, 2010; Yin, 2018). This approach is relevant because the focus of the research is not on measuring variables but on understanding the meanings and practices constructed by teachers in the context of everyday learning. This study was conducted in three public elementary schools in Bungursari District, Tasikmalaya City. The selection of these three schools was based on their suitability with the focus of the study and on interview instruments indicating that fourth-grade teachers in each school taught photosynthesis material and had experience in implementing project-based learning and integrating STEM elements. By involving three research locations, this study remained focused on one main case (the implementation of ESD-STEM integrated PjBL in photosynthesis material), but explored it across several school contexts to enrich the depth and diversity of the data.

The research subjects consisted of three fourth-grade teachers from each of these schools. Informants were selected using purposive sampling techniques, considering that they had experience teaching science on photosynthesis material, understood classroom learning dynamics, and were directly involved in planning and implementing learning. The involvement of three informants from three schools allowed for triangulation of sources, thereby increasing the credibility and strength of the research findings. The type of data collected was descriptive qualitative data, which included teachers' views on the concepts of PjBL, ESD, and STEM; teachers' experiences in designing and implementing photosynthesis learning; teachers' perceptions of the development of students' critical thinking skills; and implementation constraints and needs. Qualitative data is narrative and contextual, allowing researchers to understand the meaning behind pedagogical actions and decisions (Saldana, 2021). Based on its source, the data consists of primary and secondary data. Primary data was obtained through in-depth interviews, learning observations, and teaching tool documentation. Meanwhile, secondary data was obtained from curriculum documents, school policies, and relevant scientific literature.

The research method used was qualitative case study. This method was chosen because it allows for comprehensive exploration of complex and contextual phenomena (Akker, 2023). Data collection techniques were carried out through semi-structured interviews, non-participatory observation, and documentation study. Interviews were used to explore teachers' subjective meanings and reflections in depth, observations were conducted to capture learning practices directly, while documentation served to strengthen and verify field data. The combination of these techniques enabled data triangulation to increase the credibility of the findings (Mariam & Ramli, 2022). Data analysis procedures were carried out simultaneously from the data collection stage to the drawing of conclusions. The stages of analysis included unitization (data reduction), categorization through the coding process, and interpretation of meaning. The coding process was carried out in stages through open, axial, and selective coding to find the main themes (Saldana, 2021). After that, interpretation was carried out by connecting the field findings with the theoretical framework used. To ensure data validity, source and technique triangulation, member checks with informants, and audit trails were carried out to ensure the dependability and confirmability of the research (Creswell, 2020)

Methodologically, this study began with the identification of problems and the determination of the research focus, followed by the selection of informants and the preparation of instruments, then data collection through interviews, observations, and documentation at Sukalaksana Public Elementary School, Karsamenak Public Elementary School, and Manangga Public Elementary School 1. The data obtained were analyzed through reduction, categorization, and interpretation, verified through triangulation, and then concluded to answer the problem formulation regarding teachers' perspectives on the application of ESD-STEM integrated PjBL in photosynthesis learning to foster critical thinking skills in elementary school students.

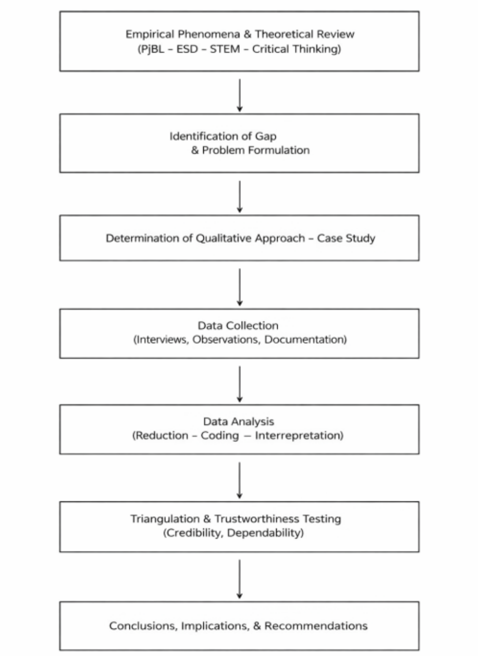

Figure 1. Qualitative Research Methodology Flowchart Case Study

.

RESULTS AND DISCUSSION

This chapter presents the results of research on teachers' perspectives on the application of Project-Based Learning (PjBL) integrated with ESD-STEM in photosynthesis learning to foster critical thinking skills in elementary school students. The description in this chapter includes: (1) research findings related to teachers' understanding and practice in integrating PjBL, ESD, and STEM; (2) analysis of the development of students' critical thinking skills; and (3) implementation constraints and needs. Each finding is presented based on the results of interviews, observations, and documentation that have been analyzed through a process of reduction, categorization, and interpretation, then discussed using relevant substantive theories.

3.1. Teachers' Perspectives on the Integration of PjBL, ESD, and STEM

This subchapter describes the findings of the study on how teachers interpret, understand, and implement the integration of Project-Based Learning (PjBL), Education for Sustainable Development (ESD), and STEM in teaching photosynthesis in fourth grade elementary school. The description is based on the results of in-depth interviews, classroom observations, and analysis of teaching materials. The data, which has been reduced and categorized, is then analyzed using the theoretical perspectives of constructivism, curriculum integration theory, and the transdisciplinary learning framework in STEM and ESD. This section also presents the research findings in the form of a conceptual model of PjBL-ESD-STEM integration based on teachers' practices in the field.

3.1.1. Teachers' Interpretation of Project-Based Learning

The interview results show that teachers understand Project-Based Learning as a learning model that "involves students in real project activities so that they learn through direct experience." This understanding emphasizes two main aspects, namely active student involvement and authentic experiences as sources of learning. Teachers stated that through projects, students become more motivated, enthusiastic, and find it easier to understand the concept of photosynthesis compared to lecture-based learning. Empirically, teachers explained that when students were asked to plant and observe plant growth, they were more active in asking questions and discussing. Observation data reinforced this finding: students were seen to be involved in the process of observation, recording plant height, and discussing factors such as light and water. These activities demonstrate the characteristics of project-based learning, which places contextual problems as the starting point for exploration. These findings are in line with recent research stating that PjBL effectively increases students' cognitive engagement and intrinsic motivation because it provides space for exploration, collaboration, and reflection (Guo et al., 2020; Hu & Chen, 2021). Theoretically, this practice is rooted in social constructivism, which places direct experience and social interaction as the foundation for knowledge formation. In the contemporary constructivist perspective, meaningful learning occurs when students construct conceptual representations through contextual authentic activities (Kirschner & Hendrick, 2024). However, even though teachers understand PjBL as experience-based learning, project planning has not been fully developed within a systematic design framework (e.g., formulation of driving questions, authentic assessment, and structured reflection). Thus, implementation is still practical-empirical and not yet fully based on integrated pedagogical design.

3.1.2. Integration of STEM Elements in Photosynthesis Learning

From the observations, STEM elements appeared in activities such as observing plant growth, measuring stem height, recording data, and discussing factors that affect photosynthesis. Science elements were evident in the understanding of the concept of photosynthesis; technology in the use of simple measuring tools; engineering in the design of planting media; and mathematics in the measurement and recording of quantitative data. However, this integration is still implicit. Teachers have not explicitly designed learning by mapping the interdisciplinary connections between STEM in a single, comprehensive conceptual framework. Integration appears more as a natural consequence of project activities rather than the result of systematic transdisciplinary planning.

Recent literature emphasizes that effective STEM integration requires learning designs that connect cross-disciplinary concepts through authentic problem solving and conceptual reflection (English, 2024; Portillo-Blanco et al., 2025). Integration that is only activity-based without clear epistemological planning has the potential to produce multidisciplinary learning, but has not yet reached the interdisciplinary or transdisciplinary stage. In this context, research findings show that teachers are at the stage of operational integration (activity-based integration), but have not yet fully reached the stage of conceptual integration (concept-based integration). This is one of the requirements for developing PjBL-ESD-STEM based teaching modules so that integration is more explicit and structured.

3.1.2. ESD Dimensions and Sustainability Awareness

The dimension of Education for Sustainable Development (ESD) emerged when teachers linked photosynthesis to the importance of protecting the environment and planting trees. Teachers emphasized that the process of photosynthesis produces oxygen that humans need, so students were encouraged to understand the importance of plants for life. The students' response to this environmental issue was positive. They demonstrated an understanding that caring for plants and the environment is part of a shared responsibility. However, the ESD approach still focuses on ecological aspects and does not yet comprehensively cover the social and economic dimensions of sustainability.

According to the latest Citaristi (2022), ESD not only instills ecological awareness but also encourages systemic, anticipatory, and reflective thinking competencies. Recent research also shows that the integration of ESD in science learning is effective when linked to concrete actions and critical reflection on environmental impacts (Feng et al., 2023). In this study, teachers have linked the material to the environmental context, but have not yet designed reflective activities that encourage students to think systemically about the relationship between photosynthesis, climate change, and broader ecosystem sustainability.

3.2. Developing Students' Critical Thinking Skills

This subsection describes the results of research on the development of students' critical thinking skills in photosynthesis learning based on Project-Based Learning (PjBL) integrated with ESD and STEM. The description is based on the results of observations of learning activities, documentation of student projects, and interviews with teachers, which were then analyzed descriptively and interpreted using a critical thinking theoretical framework in the context of Higher Order Thinking Skills (HOTS). This section not only describes empirical data but also constructs research findings in the form of patterns of development of students' critical thinking skills in the context of project-based learning. Based on the results of observations and documentation of student projects, it was found that project-based learning encourages students to be more active in observing, asking questions, and drawing simple conclusions related to the process of photosynthesis. When students carried out planting projects and recorded plant growth, they showed a higher level of curiosity compared to conventional learning. Teachers stated that through projects, students "asked more questions and tried to find out for themselves," especially when they encountered phenomena such as wilting plants or differences in growth between pots. This situation shows that project activities create a space for exploration that encourages deeper cognitive engagement by students. Analysis of student activities shows the emergence of several indicators of critical thinking, such as the ability to identify problems when students question the causes of plant wilting, the ability to analyze cause-and-effect relationships in discussing the effects of light and water on growth, and the ability to draw conclusions based on the observation data they record. The process of measuring plant height and comparing results between groups became a means for students to develop evidence-based reasoning. These findings are in line with recent research showing that project-based learning in science can improve analytical and causal reasoning skills because students are directly involved in authentic investigations (Citaristi, 2022; Shaw, 2021). Theoretically, these activities represent the dimensions of analysis and inference in the contemporary critical thinking framework.

However, the results also show that students' ability to evaluate and reflect on project results still needs to be strengthened. Students are generally able to identify factors that affect plant growth, but they are not yet fully able to evaluate the accuracy of data, consider possible observation errors, or reflect on the limitations of the experiments conducted. In the perspective of modern critical thinking theory, critical thinking skills include interpretation, analysis, evaluation, inference, and metacognitive reflection (Saiz & Rivas, 2023). In the context of this study, the dimensions of interpretation and analysis have begun to develop, while the dimensions of evaluation and metacognitive reflection have not yet emerged optimally due to the absence of a structured reflection phase in the project design. Recent research also confirms that PjBL requires explicit scaffolding in the form of reflective questions and authentic assessments so that all HOTS indicators can develop comprehensively (Loyens et al., 2023)

Thus, the findings of this study indicate that ESD-STEM integrated PjBL learning has strong potential in fostering the foundations of critical thinking in elementary school students, particularly in the aspects of problem identification, cause-and-effect analysis, and data-based conclusion drawing. However, to achieve comprehensive critical thinking development up to the evaluative and reflective levels, a more systematic and explicit learning design is needed, especially in incorporating the stages of reflection, critical discussion, and rubric-based evaluation. These findings form the conceptual basis for the development of a more structured PjBL-ESD-STEM teaching module to optimize the development of students' critical thinking skills in photosynthesis learning.

3.3. Teachers' Challenges and Needs in Implementation

This subsection describes the research findings regarding the various obstacles faced by teachers in implementing photosynthesis learning based on Project-Based Learning (PjBL) integrated with ESD-STEM, as well as the perceived need to support the optimal implementation of innovative learning. Data were obtained through in-depth interviews and analysis of teaching materials, then analyzed descriptively and interpretatively to identify patterns of structural, pedagogical, and professional obstacles that affect practice in the field. This description also constructs research findings in the form of a categorization of obstacles and needs as a basis for developing more systematic teaching modules.

The results show that one of the main obstacles is limited learning time. Teachers stated that the limited allocation of science time is often insufficient to carry out all stages of the project in depth, from planning, implementation, observation, to reflection. As a result, several important stages, such as evaluative discussions and reflection on project results, cannot be carried out optimally. This finding is in line with recent research showing that the implementation of PjBL in elementary schools is often constrained by curriculum pressures and time limitations, so that teachers tend to simplify the project stages (Bladen et al., 2022; Greenhill, 2025). In this context, time constraints are not only technical in nature but also have an impact on the quality of students' HOTS development.

The second constraint is the lack of teaching modules that explicitly integrate PjBL, ESD, and STEM. Teachers said that innovative learning has mostly depended on personal creativity and initiative, rather than systematic structured guidance. The available teaching tools are still partial and do not yet include a conceptually integrated cross-disciplinary design. This shows a gap between the curriculum policy that encourages project-based learning and the reality of learning tool support in the field. Recent studies also confirm that the success of STEM and ESD integration is greatly influenced by the availability of coherently and explicitly designed curricula and modules (Thibaut et al., 2018b; Touitou et al., 2020). Without clear support tools, integration tends to be implicit and inconsistent.

The third obstacle relates to the limited technical training on integrating STEM and ESD. Teachers acknowledge that they understand the general concept of STEM, but have not received specific training on how to integrate science, technology, engineering, and mathematics into a comprehensive learning design. Similarly, their understanding of ESD is still mostly limited to environmental awareness, rather than the development of systemic thinking and comprehensive sustainability competencies. Recent research shows that teachers' pedagogical competencies in STEM and ESD are greatly influenced by structured continuing professional development programs (English, 2024; Touitou et al., 2020). Without adequate training, teachers tend to implement innovations partially and based on personal experience.

Analytically, these findings indicate a structural gap between the demands of a curriculum that emphasizes project-based learning and the reality of classroom implementation. Teachers are in a transitional position: conceptually supporting innovative learning, but practically facing limitations in time, teaching tools, and professional support. This gap can be understood through the perspective of educational change theory, which states that curriculum innovation requires alignment between policy, teacher capacity, and institutional support in order to be implemented effectively (Lubis et al., 2022). Based on these findings, this study constructs the main needs of teachers in implementing PjBL-ESD-STEM, namely: (1) integrated teaching modules that contain systematic and explicit project stages; (2) structured critical thinking reflection and assessment guidelines; and (3) continuous professional training on the integration of STEM and ESD in elementary school science learning. Thus, this subsection not only identifies obstacles but also produces conceptual recommendations as a basis for developing research products in the form of more comprehensive and applicable PjBL-ESD-STEM teaching modules.

CONCLUSION

This study concludes that the application of Project-Based Learning (PjBL) integrated with Education for Sustainable Development (ESD) and STEM in teaching photosynthesis in elementary schools has been understood and implemented by teachers as an authentic experience-based approach that encourages active student engagement. However, its integration is still implicit and has not been systematically designed within an explicit pedagogical framework. The findings show that project-based learning is capable of fostering students' critical thinking skills in terms of problem identification, cause-and-effect analysis, and data-based conclusions, but it has not fully developed the evaluative and reflective dimensions as part of Higher Order Thinking Skills due to limitations in the design of structured reflection and assessment. In addition, this study reveals a gap between the curriculum requirements that encourage innovative learning and the reality of implementation in the field, particularly in relation to time constraints, the unavailability of integrated PjBL-ESD-STEM teaching modules, and the lack of technical training for teachers. Reflectively, this study positions itself as a conceptual and practical contribution by offering a model of PjBL-ESD-STEM integration based on teacher experience as a foundation for developing more systematic, contextual, and reflective teaching modules to optimize the development of students' critical thinking in sustainability-based science learning in elementary schools.

REFERENCES

Akker, A. van den. (2023). The use of participatory systems mapping as a research method in the context of non-communicable diseases and risk factors: A scoping review. *Health Research Policy and Systems*, *21*(1). https://doi.org/10.1186/s12961-023-01020-7

Anggraeni, I. (2023a). Implementasi Best Practice Pembelajaran Ecoliteracy melalui Pengelolaan Komposter di PAUD. *JAPRA (Jurnal Pendidikan Raudhatul Athfal)*, (Query date: 2024-11-04 11:59:36). https://journal.uinsgd.ac.id/index.php/japra/article/view/32076

Anggraeni, I. (2023b). MENINGKATKAN KERJASAMA ANAK USIA 5-6 TAHUN MELALUI PEMBELAJARAN BERBASIS PROJECT BASED LEARNING (PJBL) di SPS TAAM AT …. *Al-Marifah| Journal Pendidikan Islam Anak Usia …*, (Query date: 2024-07-12 05:39:55). https://journal.iaitasik.ac.id/index.php/Al-Marifah/article/download/237/181

Anggraeni, I. (2024). Analisis Kemampuan Sains pada Aktivitas Eco Printing di PAUD. *Al-Marifah| Journal Pendidikan Islam Anak Usia …*, (Query date: 2024-11-04 11:59:36). http://journal.iaitasik.ac.id/index.php/Al-Marifah/article/view/324

Barbot, B., & Kaufman, J. C. (2025). PISA 2022 Creative Thinking Assessment: Opportunities, Challenges, and Cautions. *The Journal of Creative Behavior*, *59*(1), e70003. https://doi.org/10.1002/jocb.70003

Bladen, C., Kennell, J., Abson, E., & Wilde, N. (2022). *Events management: An introduction*. Routledge. https://api.taylorfrancis.com/content/books/mono/download?identifierName=doi&identifierValue=10.4324/9781003102878&type=googlepdf

Cimer, A. (2012). What makes biology learning difficult and effective: Students' views. *Educational Research and Reviews*, *7*(3), 61.

Cinderella, S., Amriyah, C., & Yanti, Y. (2025). Implementation of STEM in Science Learning in Elementary Schools. *Pedagogik Journal of Islamic Elementary School*, *8*(1), 90–107. https://doi.org/10.24256/pijies.v8i1.6382

Citaristi, I. (2022). United Nations Educational, Scientific and Cultural Organization—UNESCO. In *The Europa Directory of International Organizations 2022* (24th ed.). Routledge.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications. https://books.google.com/books?hl=id&lr=&id=DLbBDQAAQBAJ&oi=fnd&pg=PP1&dq=Creswell,+J.+W.,+%26+Poth,+C.+N.+(2021).+Qualitative+inquiry+and+research+design:+Choosing+among+five+approaches+(5th+ed.).+Sage+Publications&ots=-iu18cKPOz&sig=IwVxjaG1F9va1DywuPVfvqXWHLs

Creswell, K. G. (2020). Drinking beyond the binge threshold in a clinical sample of adolescents. *Addiction*, *115*(8), 1472–1481. https://doi.org/10.1111/add.14979

Darwis, R., & Rustaman, N. (2016). The profile of middle school students in experimental planning skills through inquiry training model on heat transfer. *AIP Conference Proceedings*, (Query date: 2024-06-17 10:17:02). https://doi.org/10.1063/1.4941188/13102173/080002_1_online

deMarrais, K., Roulston, K., & Copple, J. (2024). *Qualitative Research Design and Methods: An Introduction*. Stylus Publishing, LLC.

English, L. D. (2024). STEM-based problem solving in a new era. In *Ways of Thinking in STEM-based Problem Solving* (pp. 1–14). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781003404989-1/stem-based-problem-solving-new-era-lyn-english

Facione, P. A. (2011). Critical thinking: What it is and why it counts. *Insight Assessment*, *1*(1), 1–23.

Facione, P., Facione, N., & Gittens, C. (2021). *What the Critical Thinking Data Tell Us*. 1–6.

Faradita, M. N., & Afiani, K. D. A. (2021). Elementary Teachers' Perceptions of Online Learning During Covid-19 Restrictions. *Elementary Teachers' Perceptions of Online Learning During Covid-19 Restrictions*, *8*(2), 182–187.

Farwati, R., Metafisika, K., Sari, I., Sitinjak, D. S., Solikha, D. F., & Solfarina, S. (2021). STEM Education Implementation in Indonesia: A Scoping Review. *International Journal of STEM Education for Sustainability*, *1*(1), 11–32. https://doi.org/10.53889/ijses.v1i1.2

Feng, Z., Jin, P., & Li, G. (2023). Investment Decision of Blockchain Technology in Fresh Food Supply Chains Considering Misreporting Behavior. *Sustainability*, *15*(9), 7421. https://doi.org/10.3390/su15097421

Greenhill, D. (2025). *Shifting the learning culture of a secondary school in Aotearoa New Zealand: An analysis of enacting a shared vision* [The University of Waikato]. https://hdl.handle.net/10289/17800

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*, 101586. https://doi.org/10.1016/j.ijer.2020.101586

Haslam, F., & Treagust, D. F. (1987). Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education*, *21*(3), 203–211. https://doi.org/10.1080/00219266.1987.9654897

Hu, L., & Chen, G. (2021a). A systematic review of visual representations for analyzing collaborative discourse. *Educational Research Review*, *34*, 100403. https://doi.org/10.1016/j.edurev.2021.100403

Hu, L., & Chen, G. (2021b). A systematic review of visual representations for analyzing collaborative discourse. *Educational Research Review*, *34*, 100403. https://doi.org/10.1016/j.edurev.2021.100403

Husna, H., Nerita, S., & Safitri, E. (2023). Analysis of Student Difficulties in Learning Biology. *Journal Of Biology Education Research (JBER)*, *4*(1), 1. https://doi.org/10.55215/jber.v4i1.5963

Kirschner, P. A., & Hendrick, C. (2024). *How learning happens: Seminal works in educational psychology and what they mean in practice*. Routledge. https://www.taylorfrancis.com/books/mono/10.4324/9781003395713/learning-happens-paul-kirschner-carl-hendrick

König, J., Santagata, R., Scheiner, T., Adleff, A.-K., Yang, X., & Kaiser, G. (2022). Teacher noticing: A systematic literature review of conceptualizations, research designs, and findings on learning to notice. *Educational Research Review*, *36*, 100453. https://doi.org/10.1016/j.edurev.2022.100453

Kopnina, H. (2020). Education for the future? Critical evaluation of education for sustainable development goals. *The Journal of Environmental Education*, *51*(4), 280–291. https://doi.org/10.1080/00958964.2019.1710444

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project based learning*. Ascd. https://books.google.com/books?hl=id&lr=&id=dYzgEAAAQBAJ&oi=fnd&pg=PP1&dq=Larmer,+J.,+Mergendoller,+J.+R.,+%26+Boss,+S.+(2023).+Setting+the+standard+for+project+based+learning:+A+proven+approach+to+rigorous+classroom+instruction+(2nd+ed.).+ASCD&ots=EMeOlYYG7Q&sig=NdV5wl8CicOLFcI22YG2a1Y_vbU

Leicht, A., & Heiss, J. (2018). *Issues and trends in education for sustainable development* (Vol. 5). UNESCO publishing. https://books.google.com/books?hl=id&lr=&id=V7lQDwAAQBAJ&oi=fnd&pg=PA6&dq=Leicht,+A.,+Heiss,+J.,+%26+Byun,+W.+J.+(2021).+Issues+and+trends+in+Education+for+Sustainable+Development.+UNESCO+Publishing&ots=oY2cU33DTm&sig=Cd3ammsiIYGkaIAr4pWiKqlTy00

Loyens, S. M. M., van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating Higher-Order, Critical, and Critical-Analytic Thinking in Problem- and Project-Based Learning Environments: A Systematic Review. *Educational Psychology Review*, *35*(2), 39. https://doi.org/10.1007/s10648-023-09757-x

Lozano, R., & Barreiro-Gen, M. (2022). Connections Between Sustainable Development Competences and Pedagogical Approaches. In P. Vare, N. Lausselet, & M. Rieckmann (Eds.), *Competences in Education for Sustainable Development: Critical Perspectives* (pp. 139–144). Springer International Publishing. https://doi.org/10.1007/978-3-030-91055-6_17

Lubis, M. S. A., Fatmawati, E., Pratiwi, E. Y. R., Sabtohadi, J., & Damayanto, A. (2022). Understanding Curriculum Transformation Towards Educational Innovation in The Era of All-Digital Technology. *Nazhruna: Jurnal Pendidikan Islam*, *5*(2), 526–542. https://doi.org/10.31538/nzh.v5i2.2110

Mariam, S., & Ramli, A. (2022). Pengenalan digital marketing e-katalog bagi UMKM Binaan Jakpreneur. *Jurnal Komunitas: Jurnal Pengabdian Kepada …*, (Query date: 2024-09-20 10:16:09). https://ojs.stiami.ac.id/index.php/jks/article/view/2429

Nurhasnah, N., Festiyed, F., & Yerimadesi, Y. (2023). A Review Analysis: Implementation of STEAM Project Based Learning in Natural Science Learning: Analisis Tinjauan: Penerapan Pembelajaran berbasis Proyek STEAM dalam Pembelajaran IPA. *SEJ (Science Education Journal)*, *7*(1), 1–13. https://doi.org/10.21070/sej.v7i1.1623

OECD. (2022). *OECD/INFE toolkit for measuring financial literacy and financial inclusion 2022*. OECD Publishing.

Portillo-Blanco, A., Guisasola, J., & Zuza, K. (2025). Integrated STEM education: Addressing theoretical ambiguities and practical applications. *Frontiers in Education*, *10*. https://doi.org/10.3389/feduc.2025.1568885

Rieckmann, M. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO publishing. https://books.google.com/books?hl=id&lr=&id=Fku8DgAAQBAJ&oi=fnd&pg=PP4&dq=UNESCO.+(2017).+Education+for+sustainable+development+goals:+Learning+objectives.+UNESCO+Publishing.&ots=ZOMtkC7ac9&sig=EtgiME2NEuFMWsXUeFSOWOABp3g

Saiz, C., & Rivas, S. F. (2023). Critical Thinking, Formation, and Change. *Journal of Intelligence*, *11*(12). https://doi.org/10.3390/jintelligence11120219

Saldaña, J. (2021). *The coding manual for qualitative researchers*. https://www.torrossa.com/gs/resourceProxy?an=5018667&publisher=FZ7200

Shaw, E. (2021). AMEE Consensus Statement: Planetary health and education for sustainable healthcare. *Medical Teacher*, *43*(3), 272–286. https://doi.org/10.1080/0142159X.2020.1860207

Siregar, S. A. (2024). *Pengaruh model pembelajaran problem based learning dengan pendekatan socioscientific issues terhadap literasi sains siswa pada materi pencemaran* [Undergraduate, UIN Syekh Ali Hasan Ahmad Addary Padangsidimpuan]. https://etd.uinsyahada.ac.id/11553/

Stake, R. E. (2010). *Qualitative research: Studying how things work*. https://books.google.com/books?hl=id&lr=&id=wwwVpKNFoxEC&oi=fnd&pg=PR1&dq=Stake,+R.+E.+(2020).+Qualitative+research:+Studying+how+things+work.+Guilford+Press.&ots=MekVMpluLm&sig=UgDbLiPZn3R_B8SVZiVSYxo7vmc

Sun, Y., Yan, Z., & Wu, B. (2022). How differently designed guidance influences simulation-based inquiry learning in science education: A systematic review. *Journal of Computer Assisted Learning*, *38*(4), 960–976. https://doi.org/10.1111/jcal.12667

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., & De Cock, M. (2018a). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., & De Cock, M. (2018b). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2.

Tisdell, E. J., Merriam, S. B., & Stuckey-Peyrot, H. L. (2025). *Qualitative research: A guide to design and implementation*. John Wiley & Sons. https://books.google.com/books?hl=id&lr=&id=tRpCEQAAQBAJ&oi=fnd&pg=PR7&dq=Merriam,+S.+B.,+%26+Tisdell,+E.+J.+(2022).+Qualitative+research:+A+guide+to+design+and+implementation+(5th+ed.).+Jossey-Bass.&ots=0CA0R2OVJx&sig=Td65CNp9ikSsyspAkT5FK0g3Dmk

Touitou, I., Schneider, B., & Krajcik, J. (2020). Incorporating Mathematical Thinking and Engineering Design into High School STEM Physics: A Case Study. In J. Anderson & Y. Li (Eds.), *Integrated Approaches to STEM Education: An International Perspective* (pp. 313–329). Springer International Publishing. https://doi.org/10.1007/978-3-030-52229-2_17

Turan, Z. (2023). Evaluating Whether Flipped Classrooms Improve Student Learning in Science Education: A Systematic Review and Meta-Analysis. *Scandinavian Journal of Educational Research*, *67*(1), 1–19. https://doi.org/10.1080/00313831.2021.1983868

Unesco. (2020). Education for sustainable development: A roadmap. *Transforming Our World: The 2030 Agenda for Sustainable Development A/RES/70/1, Available Online At*.

Wu, X., Yang, Y., Zhou, X., Xia, Y., & Liao, H. (2024). A meta-analysis of interdisciplinary teaching abilities among elementary and secondary school STEM teachers. *International Journal of STEM Education*, *11*(1), 38. https://doi.org/10.1186/s40594-024-00500-8

Yang, W., Wang, J., & Li, H. (2017). Achieving a Balance Between Affordability, Accessibility, Accountability, Sustainability and Social Justice: The Early Childhood Education Policies in Hong Kong. In H. Li, E. Park, & J. J. Chen (Eds.), *Early Childhood Education Policies in Asia Pacific* (Vol. 35, pp. 51–71). Springer Singapore. https://doi.org/10.1007/978-981-10-1528-1_3

Yin, R. K. (2018). *Case study research and applications* (Vol. 6). Sage Thousand Oaks, CA. https://www.academia.edu/download/106905310/Artikel_Yustinus_Calvin%20Gai_Mali.pdf

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020). Applying machine learning in science assessment: A systematic review. *Studies in Science Education*, *56*(1), 111–151. https://doi.org/10.1080/03057267.2020.1735757