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A systematic review of research on project-based learning in reducing misconceptions in Science Learning

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ABSTRACT
Misconceptions in science learning are one of the problems that hinder conceptual understanding and scientific literacy of students at various levels of education, thus becoming a challenge in supporting the achievement of Sustainable Development Goal (SDG) 4 on quality education. Project-Based Learning (PjBL) is seen as one approach that has the potential to reduce misconceptions through student engagement in authentic problem solving, investigation, collaboration, and conceptual reflection. This study aims to systematically synthesize empirical evidence regarding the effectiveness of PjBL in reducing misconceptions in science learning, identify its implementation characteristics, and map research trends and gaps that still require development. The study used the Systematic Literature Review (SLR) method based on the PRISMA 2020 guidelines, through the stages of identification, screening, feasibility assessment, and inclusion of articles published in the period 2014–2025. A total of 45 articles that met the inclusion criteria were analyzed based on the study's country of origin, educational level, scientific field of study, research design, misconception diagnostic instrument, and key findings regarding the effectiveness of PjBL. The synthesis results indicate that PjBL consistently contributes to reducing misconceptions and improving conceptual understanding, particularly in physics and chemistry learning. Most studies used quasi-experimental designs with tiered diagnostic instruments, such as two-tier and four-tier diagnostic tests. The novelty of this study lies in presenting a comprehensive synthesis that not only evaluates the effectiveness of PjBL but also identifies mechanisms of conceptual change, global research trends, and research gaps that can form the basis for developing project-based learning models in the future. These findings provide theoretical and practical contributions to the development of evidence-based science learning, while strengthening the role of PjBL as a learning strategy that supports improving the quality of science education in accordance with SDG 4.

KEYWORDS
Misconceptions; PRISMA; Project-Based Learning; Science learning; Systematic literature review.

INTRODUCTION

Human lifestyles have undergone significant changes since the beginning of the 21st century, marked by the development of the era of globalization, digital transformation, and the Industrial Revolution 4.0. These changes require students to have 21st-century skills, such as critical thinking, creativity, communication, and collaboration, to be able to adapt to developments in science and technology (Gcabashe, 2024; Levin et a., 2025; Öcal Dörterler & Akay, 2022). Therefore, the education system is required to develop a learning process that is no longer oriented towards knowledge transfer, but rather centered on students through exploration, investigation, and reflection activities (Bhagwonparsadh & Pule, 2024; Otto et al., 2024; Nisa et al., 2018). In science learning, the development of 21st-century skills is inseparable from the ability to correctly understand concepts. Conceptual understanding is the foundation for students to explain scientific phenomena, solve problems, and make decisions based on scientific evidence (Botes & Philip, 2025; Li & Lyu, 2025). However, various studies show that many students still experience misconceptions, namely understandings that do not align with scientific concepts accepted by the scientific community. Misconceptions are resistant to conventional learning because they are formed from everyday experiences, erroneous prior knowledge, or learning processes that do not provide students with opportunities to reconstruct their concepts. This condition leads to poor conceptual understanding and hinders the development of scientific thinking skills.

One approach considered to have the potential to address these issues is PjBL. Unlike information-centered learning, PjBL positions students as knowledge builders through authentic project completion, scientific investigation, collaboration, and reflection (Garcia, 2025; Indriati et al., 2024; Okwara et al., 2023; Zhang, 2022). These characteristics enable students to test their prior knowledge, compare it with empirical evidence, and then reconstruct their understanding to better align with scientific concepts. Thus, PjBL not only serves to improve 21st-century skills but also provides a learning environment that supports conceptual change, potentially reducing misconceptions.

Theoretically, the relationship between PjBL and misconception reduction can be explained through constructivism and Conceptual Change Theory. Constructivism theory views that knowledge is actively constructed through learning experiences, while Conceptual Change Theory explains that conceptual change occurs when students realize a discrepancy between their prior knowledge and scientific evidence, prompting them to revise their knowledge structure (Li & Lyu, 2025; Dahri et al., 2024; X. Zhang et al., 2025). The stages in PjBL, such as problem identification, investigation, collaboration, product development, presentation, and reflection, provide opportunities for students to experience cognitive conflict, evaluate initial ideas, and build more accurate scientific concepts. Therefore, theoretically, PjBL has a relevant mechanism in supporting misconception reduction in science learning.

However, research on the effectiveness of PjBL in reducing misconceptions still shows mixed findings. These studies are spread across various scientific fields, such as physics,

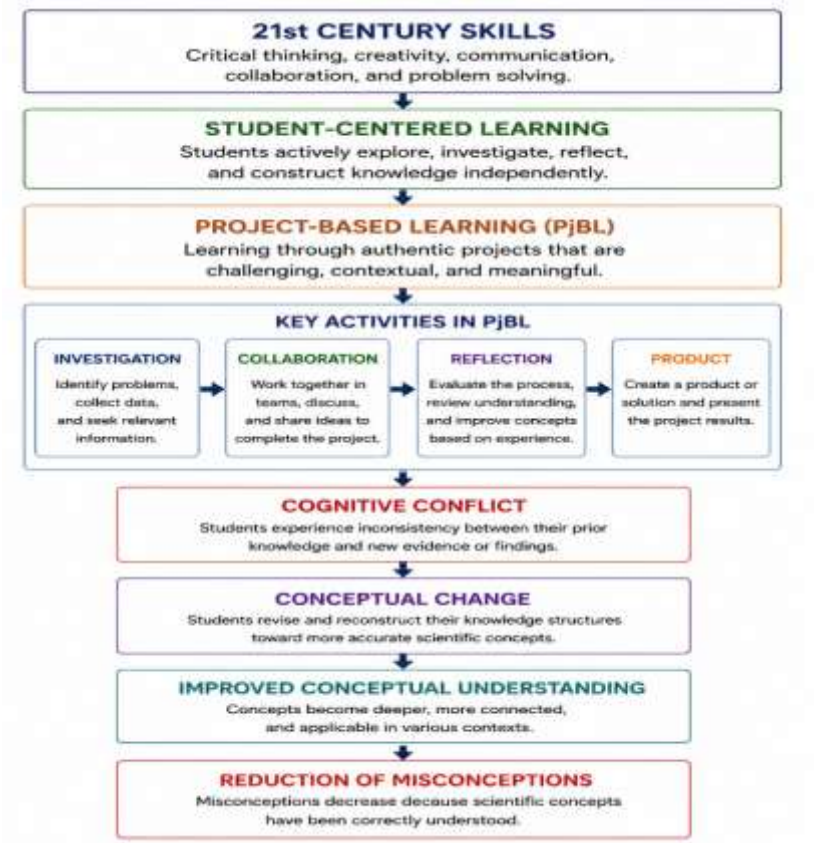
chemistry, and biology, using different educational levels, research designs, and misconception diagnostic instruments (Putica et al., 2024; Ma, Ai, et al., 2025; Ma, Liu, et al., 2025; Ma, Yang, et al., 2025). Furthermore, most studies only report the effectiveness of PjBL in specific contexts without providing a synthesis of how the characteristics of PjBL implementation influence students' conceptual change. This condition results in the lack of a comprehensive picture of research patterns, implementation mechanisms, consistency of empirical results, and research gaps that still need to be developed.

Based on these conditions, a systematic literature review is needed that can synthesize empirical evidence regarding the application of PjBL in science learning. This synthesis is essential for identifying research trends, implementation characteristics, the effectiveness of PjBL in improving conceptual understanding and reducing misconceptions, and directions for further research. Therefore, the results of this study are expected to provide a scientific basis for developing more effective and evidence-based science learning.

The objectives of this study are: (1) to map research trends regarding the application of Project-Based Learning in science learning in the period 2014–2025; (2) to identify the characteristics of PjBL implementation based on educational level, science field, research design, and instruments used; (3) to analyze empirical evidence regarding the role of PjBL in improving conceptual understanding and reducing misconceptions; and (4) to identify research gaps and provide recommendations for further research directions.

Figure 1.

Theoretical framework



METHODS

Research Design

This study uses a Systematic Literature Review (SLR) approach with reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, systematicity, and traceability from the identification process to the synthesis of articles (Malesu & Syrovátka, 2025; Ronsivalle et al., 2025; Yolcu et al., 2025), Unlike systematic reviews that only describe the results of previous research, this study integrates thematic analysis, comparative descriptive analysis, and conceptual synthesis to gain a more comprehensive understanding of the role of PjBL in improving conceptual understanding and reducing misconceptions in science learning. The integration of these analytical approaches allows this study not only to map publication trends but also to identify PjBL implementation patterns, mechanisms of conceptual change, factors influencing implementation success, and research gaps that still require development.

Search Strategy

A systematic literature search was conducted using the Scopus database and SINTA 1–2 accredited national journals for scientific articles published during the period 2014–2025. This time period was chosen to illustrate the development of research on the implementation of Project-Based Learning in science learning over the past decade. The search strategy was based on three main concepts: Project-Based Learning as an intervention, misconceptions as an outcome variable, and science learning as the research context. The search process used Boolean operators (AND and OR) with the following search string:

("Project-Based Learning" OR "Project Based Learning" OR PjBL) AND ("Misconception" OR "Scientific Misconception" OR "Alternative Conception" OR "Misunderstanding")AND("Science Learning" OR "Science Education" OR "Science Teaching")

All search results were then exported into a Microsoft Excel spreadsheet for the process of article identification, duplication removal, initial screening, and documentation of the selection process according to PRISMA guidelines.

Inclusion and Exclusion Criteria

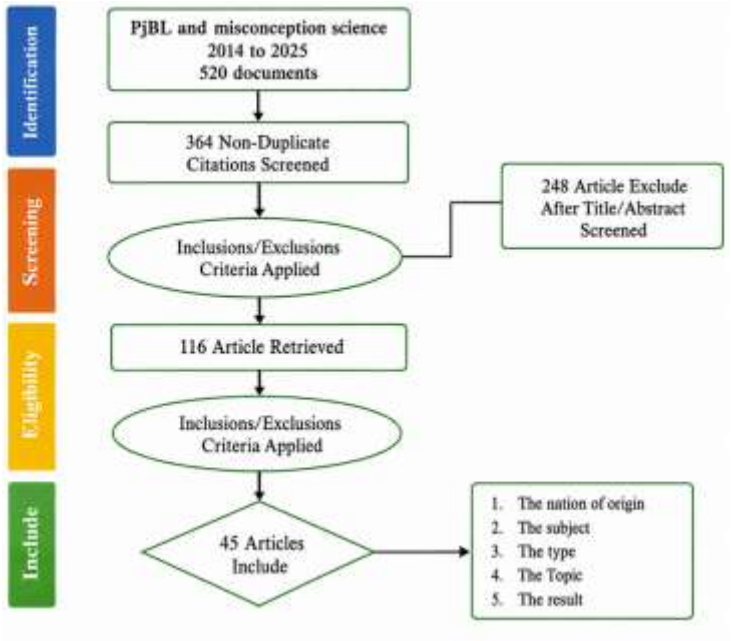
The articles analyzed were selected based on inclusion criteria established prior to the literature search to minimize potential selection bias. The inclusion criteria included: (1) empirical research articles published in the 2014–2025 period; (2) published in peer-reviewed journals indexed by Scopus or SINTA 1–2; (3) focused on the implementation of Project-Based Learning in science learning; (4) reporting research findings on conceptual understanding, conceptual change, or misconception reduction; and (5) available in full-text English. Conversely, articles in the form of proceedings, books, book chapters, editorials, conceptual articles, or literature reviews were excluded from the analysis process. Journal selection was based on the topic suitability and methodological quality of the research, not solely on the publisher's reputation.

Article Selection Process

The article selection process follows the four stages of PRISMA 2020: identification, screening, eligibility assessment, and inclusion. In the identification stage, all articles obtained from the search results are collected and checked to eliminate duplication. Next, screening is carried out based on the title and abstract using predetermined inclusion and exclusion criteria. Articles that meet the initial requirements are then thoroughly analyzed through full-text review to ensure their suitability for the research objectives. Articles that pass the eligibility stage are then entered into the inclusion stage and analyzed further. The entire selection process is visualized through a PRISMA flowchart, as shown in Figure 1, so that each stage can be traced transparently.

Figure 2.

PRISMA flowchart of the study selection process.



Data Extraction

Data from each article that met the inclusion criteria were systematically extracted using a data extraction spreadsheet prepared in Microsoft Excel. Information collected included the country of origin of the study, educational level, scientific field of study, sample size, research design, research instruments, characteristics of Project-Based Learning implementation, indicators of conceptual understanding, forms of misconceptions studied, and the main findings of the study. In addition to descriptive data, each article was also coded based on the learning mechanisms used, such as investigation, collaboration, reflection, project completion, cognitive conflict, and concept reconstruction, allowing for more in-depth cross-study analysis.

Thematic Analysis

Thematic analysis was used to identify key patterns and themes that emerged consistently across all articles analyzed. The analysis process followed three stages: open coding, axial coding, and selective coding. In the open coding stage, each article was thoroughly read to

identify important information related to PjBL implementation and misconception reduction. The axial coding stage was carried out by grouping related codes into several main categories, such as PjBL implementation characteristics, conceptual change mechanisms, learning outcomes, and supporting and inhibiting factors. Next, in the selective coding stage, all categories were integrated into main themes that explain the relationship between PjBL implementation characteristics and students' conceptual change. This analysis allows for a synthesis that is not only descriptive but also interpretive.

Comparative Descriptive Analysis

In addition to thematic analysis, this study employed comparative descriptive analysis to compare the characteristics of the studies based on country of origin, educational level, scientific field, research design, misconception diagnostic instruments, and the results of Project-Based Learning implementation. The analysis was conducted by identifying trends, similarities, and differences between the studies to obtain a picture of the consistency of the effectiveness of Project-Based Learning (PjBL) in various science learning contexts. This approach was also used to identify the relationship between the characteristics of PjBL implementation and the success of misconception reduction and improvement of conceptual understanding.

Quality Assessment

To ensure the quality of the synthesized scientific evidence, each article was evaluated using quality indicators that included: (1) clarity of research objectives; (2) appropriateness of research design; (3) validity and reliability of instruments; (4) clarity of Project-Based Learning implementation procedures; (5) accuracy of data analysis; and (6) relevance of findings to research objectives. The quality assessment process was carried out systematically on all articles before being included in the final synthesis, so that only studies with adequate methodological quality were used as a basis for drawing conclusions.

Validity and Reliability

Research validity was maintained through the application of the PRISMA 2020 guidelines, the use of inclusion and exclusion criteria established prior to the search process, and the selection of articles that had undergone peer review. Research reliability was ensured through the use of a uniform data extraction format, consistent coding procedures, and cross-checking of all extracted data. Each coding result was compared with the source article to ensure accurate interpretation and reduce potential bias during the synthesis process.

Conceptual Synthesis

The final stage of the research was a conceptual synthesis that integrated the results of the thematic analysis and comparative descriptive analysis to build a more comprehensive understanding of the mechanisms of Project-Based Learning in reducing misconceptions in science learning. This synthesis resulted in a conceptual framework that explains the relationship between the characteristics of PjBL implementation, the process of conceptual change, increased conceptual understanding, and misconception reduction. Furthermore, the

conceptual synthesis was used to identify research gaps, formulate theoretical and practical implications, and develop recommendations for further research, thus making a broader contribution to the development of evidence-based science learning.

RESULTS

Project-Based Learning Research Trends in Science Learning

Based on an analysis of 45 articles that met the inclusion criteria, research on the application of PjBL in science learning that focuses on improving conceptual understanding and reducing misconceptions shows a diverse distribution between countries. Indonesia is the largest contributor with 18 articles (Amini, 2019; Anazifa, 2017; Dewi et al., 2021; Elvianasti, et al, 2024; Hariyono, 2023; Haryono et al., 2024; Hasyim & Sujiono, 2023; Kaniawati, 2021; Mufit, 2023; Negoro et al., 2023; Rustaman, 2020; Samsudin et al., 2024; Santyasa, et al 2020; Sarwanto, 2021; Solihah et al., 2024; Umar, 2022; Wahono et al., 2021; Zaidi et al., 2024) followed by Malaysia with 5 articles (Azizan & Shamsi, 2022; Ismail et al., 2015; Juan et al., 2020; Soeharto, 2021; Sulaiman et al., 2023),Thailand and China with 4 articles each (Chiu, 2020; (Duangmanee & Waluyo, 2023; Ladachart et al., 2022; Lin et al., 2018; Shi, 2024; Mart et al., 2021; Surakarn et al., 2020; Zhang & Ma, 2023), as well as South Korea 3 articles (Han & Carpenter, 2014; Viro, 2020; Yoon, 2014). Finlandia 3 articles (Haatainen & Aksela, 2021; Markula & Aksela, 2022; Reddy & Moate, 2024). Spain 3 articles (Domenici, 2022; López et al., 2024; Terrón-López et al., 2016). United States 3 articles (Espinosa et al., 2019; Seo et al., 2024; Wilhelm, 2014). Australia 2 articles (Meng et al., 2023; Wilson, 2021). These findings indicate that Indonesia has made the largest contribution to research on the application of Project-Based Learning in science education.

Figure 3.

Distribution of research articles by country of origin.



Indonesia's dominance in this review demonstrates the high level of research attention paid to the application of PjBL as a learning strategy to improve the quality of science learning, particularly in addressing misconceptions that remain problematic in various science concepts. However, this finding should not be interpreted as meaning that research on PjBL in other countries, particularly the United States, is less extensive than in Indonesia. The distribution of articles in this study was influenced by inclusion criteria that specifically selected empirical articles discussing the application of PjBL to improve conceptual understanding and reduce misconceptions in science learning in the 2014-2025 period.

Further analysis shows that PjBL research in the United States is generally more oriented towards developing STEM education, engineering design, 21st-century skills, creativity, problem-solving, and academic achievement, while research explicitly examining misconception reduction as a learning outcome is relatively limited. In contrast, most research in Indonesia is more directed at solving conceptual problems in physics, chemistry, and biology learning, thus meeting the selection criteria in this systematic review.

These findings indicate that the focus of research on PjBL is still influenced by the educational priorities and needs of each country. Asian countries, particularly Indonesia, tend to utilize PjBL as a strategy to improve conceptual understanding and address misconceptions, while Western countries are more likely to explore PjBL as an approach to developing 21st-century competencies. These differences in research orientations demonstrate that the role of PjBL is multidimensional, not only as a learning model that enhances critical thinking and collaboration skills, but also as a pedagogical strategy capable of facilitating conceptual change when designed systematically.

Thus, the distribution of articles by country better reflects the direction of PjBL research development in the context of misconception reduction than the productivity of PjBL research in general. These results also identify opportunities for future research, particularly through cross-country and cross-educational context collaboration to obtain more comprehensive empirical evidence regarding the mechanisms by which PjBL improves conceptual understanding and reduces misconceptions in science learning.

Characteristics of Project-Based Learning Implementation in Science Learning

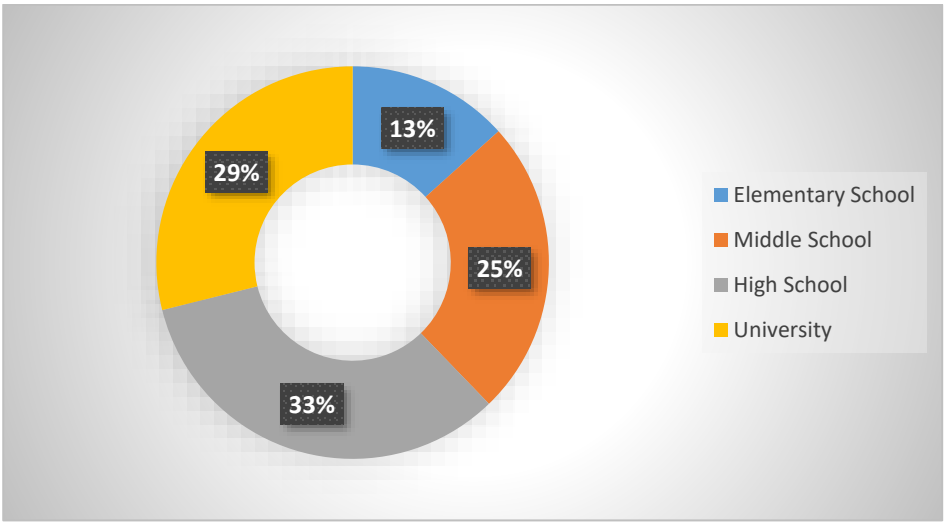
The characteristics of PjBL implementation in the analyzed studies show quite wide variations in terms of educational level, scientific field of study, research design, and instruments used to evaluate learning outcomes. This variation reflects that PjBL has been implemented in various science learning contexts with the primary goals of improving conceptual understanding, developing higher-order thinking skills, and facilitating conceptual change through authentic learning experiences.

Based on educational level, the implementation of PjBL was most frequently carried out in senior high schools with 15 articles (33.3%), followed by universities with 13 articles (28.9%), junior high schools with 11 articles (24.4%), and elementary schools with 6 articles (13.3%), as shown in Figure 3. The dominance of research at the senior high school and university levels

indicates that PjBL is more often applied to students who already have abstract thinking skills so they are better prepared to conduct scientific investigations, problem solving, and conceptual reflection. This condition is in line with the characteristics of PjBL which requires students to build knowledge through exploration, scientific argumentation, and the completion of complex projects. Conversely, the still limited research at the elementary school level indicates that the implementation of PjBL to build scientific concepts from an early age still requires further attention.

Figure 4.

Distribution of research by level of education.



In terms of research design, the majority of studies used a quasi-experimental approach (28 articles (62.2%), followed by mixed methods (9 articles (20.0%), qualitative research (5 articles (11.1%), and Research and Development (R&D) or design-based research (3 articles (6.7%), as presented in Figure 4. The dominance of quasi-experimental designs indicates that most studies focused on testing the effectiveness of PjBL on improving learning outcomes and changing conceptual understanding through comparing conditions before and after learning implementation. On the other hand, the relatively small proportion of qualitative and design-based research indicates that studies on the mechanisms of conceptual change during the learning process are still relatively rare. In fact, this approach has the potential to provide a deeper understanding of how students reconstruct scientific concepts during project-based learning.

Based on the field of study, the implementation of PjBL was most often found in physics with 19 articles (42.2%), followed by chemistry with 14 articles (31.1%), biology with 10 articles (22.2%), and integrated science with 2 articles (4.5%), as shown in Figure 5. The dominance of research in physics and chemistry indicates that these two fields have characteristics of more abstract concepts, involve a lot of mathematical and symbolic representations, and are more prone to causing misconceptions than other science fields. Therefore, PjBL is widely used as a learning strategy that allows students to connect abstract concepts with real phenomena through investigations, experiments, and project completion. Conversely, the still limited

research on integrated science shows that there is an opportunity to develop the implementation of PjBL in interdisciplinary learning so that it can build interdisciplinary conceptual linkages.

Figure 5.

Distribution of research based on research design.

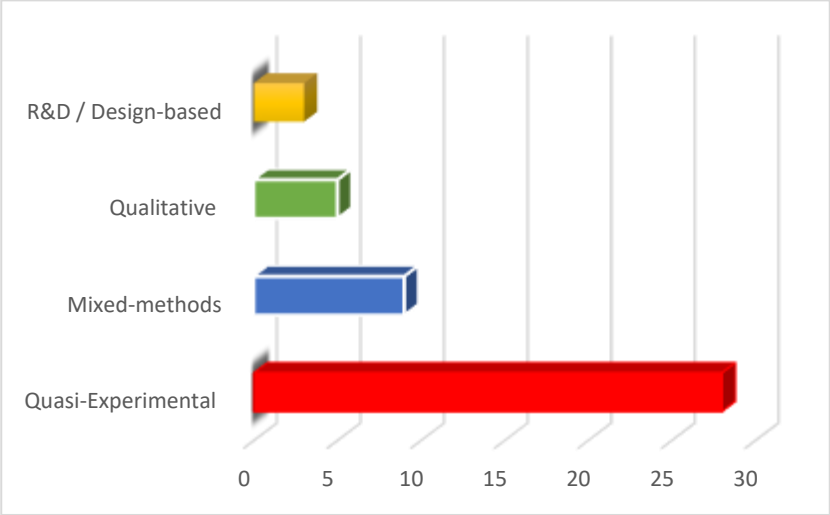
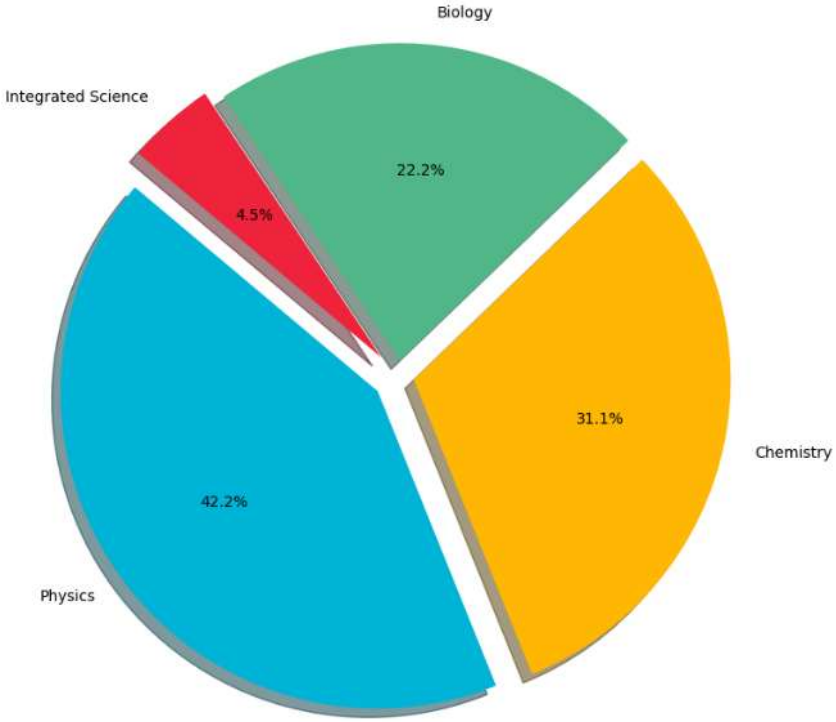


Figure 6.

Distribution of research based on scientific fields of study



In addition to variations in educational levels, research designs, and fields of study, the analyzed studies also demonstrate a diversity of evaluation instruments used to measure the effectiveness of PjBL. Most studies used diagnostic tests, conceptual understanding tests, learning outcome tests, critical thinking instruments, and observation sheets to evaluate

changes in conceptual understanding and identify misconceptions. The use of tiered diagnostic instruments, such as two-tier and four-tier diagnostic tests, was relatively more common in studies specifically examining misconceptions because they are able to distinguish students who truly understand a concept from those who still maintain alternative concepts. This finding suggests that evaluating the effectiveness of PjBL is not only oriented towards improving learning outcomes but also on the quality of conceptual change that occurs during the learning process. Overall, the characteristics of the implementation of PjBL in the analyzed research indicate that this model is more widely applied in learning contexts that require higher-order thinking skills and in-depth conceptual understanding. The dominance of research at the high school level, in the fields of physics and chemistry, and the use of quasi-experimental designs indicate that the focus of research so far is still directed at testing the effectiveness of PjBL as a learning strategy. However, the continued open opportunities for research at the elementary school level, integrated science, design-based research approaches, and the use of longitudinal designs indicate that the development of PjBL research is still needed to gain a more comprehensive understanding of the mechanisms of conceptual change and the sustainability of its impact on science learning (Arista et al., 2026).

The Role of Project-Based Learning in Improving Conceptual Understanding and Reducing Misconceptions

A synthesis of 45 articles that met the inclusion criteria showed that Project-Based Learning (PjBL) plays a role not only as a learning model that improves learning outcomes but also as a pedagogical strategy that facilitates the formation of conceptual understanding through authentic learning experiences. Unlike learning that focuses on information delivery, the implementation of PjBL positions students as active subjects who construct knowledge through investigation, real-world problem solving, collaboration, reflection, and product development. This process allows students to evaluate their prior knowledge, compare it with empirical evidence, and then reconstruct concepts to better align with scientific (Anazifa, 2017; Haatainen & Aksela, 2021; Markula & Aksela, 2022; Zhang & Ma, 2023).

The synthesis results indicate that the effectiveness of PjBL in science learning is not solely determined by the use of projects as learning activities, but by how the projects are designed to encourage students to experience cognitive conflict, conduct scientific investigations, and reflect on their findings. In most of the studies analyzed, project activities begin with contextual problems that require students to identify prior knowledge, formulate hypotheses, collect evidence through experiments or observations, and then discuss the results collaboratively before drawing conclusions. This series of activities creates learning conditions that enable conceptual change, so that students' previous misconceptions can be gradually reduced (Kaniawati, 2021; Mufit, 2023; Samsudin et al., 2024) Analysis of various fields of study shows that the role of PjBL is relatively consistent in physics, chemistry, and biology learning, although its implementation mechanisms adapt to the characteristics of the material being studied. In physics learning PjBL is widely used to help students understand abstract concepts,

such as force, energy, electricity, heat, and waves through experiments, designing simple tools, and solving problems based on everyday phenomena (Kaniawati, 2021; Mufit, 2023; Sarwanto, 2021). In chemistry learning, the implementation of PjBL helps students connect macroscopic, submicroscopic, and symbolic representations through laboratory investigations and product development activities, making abstract concepts easier to understand (Haryono et al., 2024; Samsudin et al., 2026; Solihah et al., 2024). Meanwhile, in biology learning, PjBL is more often applied through environmental, health, and ecosystem-based projects that encourage students to link biological concepts to real-world problems around them (Dewi et al., 2021; Hasyim & Sujiono, 2023).

Another important finding suggests that misconception reduction is not a standalone outcome, but rather a consequence of improved conceptual understanding throughout the learning process. Nearly all of the studies analyzed reported that students engaged in investigative activities, group discussions, project presentations, and reflections improved their ability to explain scientific concepts, connect concepts to everyday life phenomena, and apply these concepts to solve new problems. In other words, the better the knowledge construction process facilitated by PjBL, the greater the opportunity for conceptual change and the less likely students are to retain misconceptions (Haryono et al., 2024; Negoro et al., 2023; Rustaman, 2020; Wahono et al., 2021).

Based on the overall synthesis, this study identified four main mechanisms explaining how PjBL improves the quality of science learning. First, the use of authentic problems helps students connect abstract concepts to real-world situations, thereby enhancing the meaningfulness of learning. Second, investigative and experimental activities enable students to obtain empirical evidence to evaluate the validity of their prior knowledge. Third, collaboration between students encourages scientific discussion, argumentation, and conceptual clarification through social interaction. Fourth, the reflection and presentation stages of project results provide opportunities for students to reorganize their knowledge structures, thus forming more accurate and long-term conceptual understandings. These four mechanisms consistently emerge across various studies, strengthening PjBL's position as a learning strategy that supports conceptual change in science education (Haatainen & Aksela, 2021; Markula & Aksela, 2022; Zhang & Ma, 2023).

Thus, the results of this systematic review indicate that the primary role of PjBL in science learning is not only to improve learning outcomes, but more fundamentally, namely building a learning process that allows students to reconstruct scientific concepts through authentic learning experiences. From this perspective, misconceptions are seen as the starting point of the learning process, not simply errors to be eliminated. PjBL provides a learning environment that allows students to test, revise, and strengthen their understanding through project-based investigations, so that learning becomes more meaningful, contextual, and sustainable.

DISCUSSION

The results of this systematic review indicate that PjBL not only functions as a learning model that improves learning outcomes but also as a pedagogical approach that supports conceptual change through authentic, collaborative, and investigation-based learning experiences. This finding is in line with constructivism theory, which views knowledge as actively constructed through interactions between learning experiences and students' existing knowledge structures. In science learning, this process is crucial because students often enter the learning process with prior knowledge that is not fully aligned with scientific concepts, thus giving rise to misconceptions that can hinder the formation of correct conceptual understanding. The results of this research synthesis indicate that the implementation of PjBL provides opportunities for students to test their prior knowledge through investigative activities, experiments, group discussions, presentations, and reflections. These activities generate cognitive conflict, which is a key prerequisite for conceptual change as described in the Conceptual Change Theory by Posner et al. This finding is consistent with the research of (Krajcik et al., 2023) which shows that project-based learning creates a learning environment that allows students to build connections between scientific concepts and authentic problems through a systematic inquiry process. Research by (Markula & Aksela, 2022) also shows that active student involvement in science-based projects can improve the quality of scientific argumentation and strengthen conceptual understanding more meaningfully than conventional learning. Similarly, (Haatainen & Aksela, 2021) emphasize that the effectiveness of PjBL is not solely determined by the existence of projects, but rather by the quality of the investigation, collaboration, and reflection processes that occur during learning. Thus, projects are not the ultimate goal of learning, but rather a means for students to reconstruct prior knowledge into more accurate scientific concepts.

A synthesis of the analyzed articles also shows that the effectiveness of PjBL is relatively consistent across various science learning areas, although its implementation characteristics vary depending on the complexity of the material. In physics learning, PjBL is widely used to help students understand abstract concepts such as force, energy, electricity, and heat through experiments and problem-solving based on everyday phenomena. These findings align with research by (Kaniawati, 2021; Mufit, 2023; Samsudin et al., 2024) which shows that investigative experiences enable students to identify, test, and revise previously held misconceptions. In chemistry learning, the implementation of PjBL helps students connect macroscopic, submicroscopic, and symbolic representations through laboratory activities, experiments, and product development, making abstract concepts easier to understand. These results support the findings of (Solihah et al., 2024; Zaidi et al., 2024) which show that project activities can strengthen concept visualization and improve students' conceptual understanding. Meanwhile, in biology learning, PjBL is more often applied through environmental, health, and ecosystem-based projects that encourage students to connect biological concepts with real-world phenomena around them (Dewi et al., 2021; Hasyim & Sujiono, 2023) . These findings indicate that the effectiveness of PjBL is not determined by the specific subject, but by its ability to create

learning experiences that enable students to connect theory with practice through meaningful investigations. These results also support the meta-analysis findings of (Zhang et al., 2024), which concluded that PjBL consistently has a positive impact on learning outcomes, critical thinking skills, and conceptual understanding across various disciplines.

This study further demonstrates that the success of PjBL implementation in improving conceptual understanding is strongly influenced by the quality of the learning design. A synthesis of the analyzed research shows that projects that begin with authentic problems, followed by scientific investigations, group discussions, presentations of results, and conceptual reflections produce better changes in understanding than project-based learning that is only oriented towards product completion. These findings support the research of (Retno et al., 2025) which emphasizes the importance of integrating authentic problems in science learning so that students are able to connect abstract concepts with real phenomena. In addition, (Sumo et al., 2024) show that group discussions and scientific argumentation during the project process play a significant role in correcting misconceptions through the process of negotiating meaning among students. Thus, the effectiveness of PjBL is determined more by the quality of the learning process than the complexity of the resulting product, so that the role of the teacher as a learning facilitator is an important factor in guiding students to conduct investigations, develop scientific arguments, and reflect on learning outcomes.

Based on the overall synthesis, the main contribution of this study lies in its ability to explain the mechanisms by which PjBL improves conceptual understanding and reduces misconceptions, rather than simply concluding that PjBL is effective. This study identifies four main mechanisms that consistently emerge across various studies: the use of authentic problems as learning triggers, project-based scientific investigations to obtain empirical evidence, collaboration and scientific argumentation in building shared understanding, and conceptual reflection that enables learners to reorganize their knowledge structures. These findings extend previous studies that generally only report improvements in learning outcomes after PjBL implementation, by showing that the reduction in misconceptions is a consequence of the increased quality of conceptual changes that occur during the learning process. Therefore, future PjBL development needs to place greater emphasis on learning designs that facilitate cognitive conflict, scientific investigation, collaboration, and reflection rather than simply producing project products. Furthermore, this synthesis also identifies opportunities for PjBL development through the integration of digital technology, virtual laboratories, artificial intelligence (AI), and data-driven learning, which have the potential to strengthen the visualization of abstract concepts, broaden the learning context, and improve the quality of learners' learning experiences. Thus, PjBL not only functions as a learning strategy to improve learning outcomes, but also as a pedagogical framework that supports the transformation of science learning towards more meaningful, adaptive education, and in line with the achievement of Sustainable Development Goal (SDG) 4 regarding quality, inclusive, and

evidence-based education (Hamidaha & Widodo, 2026; Maria et al., 2026; Sanjaya, 2026; Xie & Yusuf, 2026)

Research Implications, Research Gaps, and Further Research Directions

The results of this study provide implications that PjBL is a pedagogical strategy that supports conceptual change through investigation, collaboration, cognitive conflict, and reflection, thereby improving the quality of students' conceptual understanding. This finding strengthens the theory of constructivism and Conceptual Change Theory by showing that the reduction of misconceptions is a consequence of the process of knowledge reconstruction that is actively built during project-based learning. From a practical perspective, the implementation of PjBL needs to be designed using authentic problems, investigative activities, scientific argumentation, and conceptual reflection so that learning is not only oriented towards project completion, but also towards the formation of in-depth scientific understanding.

However, this synthesis still identifies several research gaps. Most studies still focus on physics and chemistry learning, using quasi-experimental designs with relatively short implementation durations, and evaluating learning outcomes through cognitive instruments without in-depth exploration of the mechanisms of conceptual change that occur during the learning process. Furthermore, research on the integration of PjBL with digital technology, virtual laboratories, Artificial Intelligence, and learning analytics is still limited, as is cross-national comparative research. Therefore, further research is needed to develop PjBL implementation through a multidisciplinary approach, digital technology integration, longitudinal designs, and international collaboration to obtain more comprehensive empirical evidence regarding the effectiveness and mechanisms of PjBL in improving conceptual understanding and reducing misconceptions in various science learning contexts.

Limitations

This study has several limitations that need to be considered in interpreting the synthesis results. First, the articles analyzed were limited to empirical research published during the 2014–2025 period and indexed in the Scopus database and the national journal SINTA 1–2. Therefore, there may be relevant research in other databases that has not been accommodated. Second, this study did not include gray literature, such as proceedings, theses, dissertations, and research reports, so some empirical evidence that could potentially enrich the synthesis was not included. Third, the characteristics of the studies analyzed were very diverse in terms of educational level, field of study, research design, instruments, and implementation duration. Therefore, interpretation of the effectiveness of PjBL needs to consider the context of each study. Fourth, this study used a qualitative synthesis approach through thematic analysis and comparative descriptive analysis, so it did not calculate the effect size as in meta-analysis. Therefore, future research is recommended to combine a Systematic Literature Review with meta-analysis to obtain a quantitative estimate of the magnitude of the influence of PjBL on improving conceptual understanding and reducing misconceptions.

CONCLUSION

A systematic review of 45 articles published between 2014 and 2025 indicates that Project-Based Learning (PjBL) is an effective pedagogical approach for improving conceptual understanding and reducing misconceptions in science learning. This synthesis demonstrates that the implementation of PjBL not only improves learning outcomes but also facilitates conceptual change through investigation, authentic problem-solving, collaboration, scientific argumentation, and reflection. This study identifies four main mechanisms explaining the effectiveness of PjBL: the use of authentic problems, project-based scientific investigation, scientific collaboration and argumentation, and conceptual reflection. These four mechanisms enable students to reconstruct prior knowledge into more accurate scientific understanding, resulting in a reduction in misconceptions as a consequence of the improved quality of knowledge construction. These findings strengthen PjBL's position as a relevant learning strategy to support 21st-century science learning and provide a scientific basis for the development of more adaptive, innovative, and sustainable project-based learning models to support the achievement of Sustainable Development Goal (SDG) 4, namely quality, inclusive, and evidence-based education.

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Table 1.

Research Results

No	Author (Year)	Number of Samples	Research Instruments	Research Results (Details)
1	(Yoon, 2014)	100 students	Learning outcome test	Students who participate in PjBL achieve better learning outcomes than those in traditional learning.

2	(Han & Carpenter, 2014)	120 students	HOTS Test	PjBL significantly encourages the development of higher-order cognitive processes.
3	(Wilhelm, 2014)	47 students	Problem-solving test	Students' problem-solving abilities increased significantly after the implementation of PjBL.
4	(Ismail et al., 2015)	58 students	Learning outcome test	Students who participated in PjBL learning showed significantly higher learning outcomes ($p < 0.05$).
5	(Terrón-López et al., 2016)	83 students	Project rubric	The quality of the project products demonstrates the high effectiveness of PJBL implementation.
6	(Anazifa, 2017)	60 students	Critical thinking test	The implementation of PjBL is effective in developing critical thinking skills through inquiry-based activities.
7	(Lin et al., 2018)	60 students	Critical test	PjBL significantly improves students' critical thinking skills.
8	(Espinosa et al., 2019)	80 students	Problem-solving test	PjBL significantly strengthens students' problem-solving abilities.
9	(Amini, 2019)	54 students	Questionnaires & tests	Student learning outcomes and motivation increased significantly through the implementation of PjBL.
10	(Rustaman, 2020)	28 students	Observation & test	PjBL enhances science process skills through project-based investigative activities.
11	(Santyasa, 2020)	40 students	Tests & questionnaires	The implementation of PjBL significantly increases students' self-efficacy and academic achievement.
12	(Juan et al., 2020)	62 students	Pretest–posttest	The experimental group showed significantly higher posttest scores than the control group.
13	(Surakarn et al., 2020)	55 students	Tests & observations	Student learning activities and participation increased significantly in project-based learning (PjBL).
14	(Viro, 2020)	52 students	Observation & test	PjBL strengthens students' collaborative behavior and teamwork.
15	(Wahono et al., 2021)	66 students	Conceptual test	PjBL can reduce resistant misconceptions and deepen conceptual understanding.
16	(Kaniawati, 2021)	31 students	Diagnostic tests	PjBL facilitates meaningful conceptual change and minimizes misconceptions.
17	(Sarwanto, 2021)	48 students	Literacy test	PjBL contributes to increasing scientific literacy in the medium to high categories.
18	(Soeharto, 2021)	153 students	Conceptual test	PjBL is effective in reducing misconceptions and improving conceptual understanding.

19	(Mart et al., 2021)	44 students	Creativity test	Students' creative thinking abilities increased to a high category after implementing PjBL.
20	(Haatainen & Aksela, 2021)	65 students	Literacy test	PjBL improves students' scientific literacy and inquiry competencies.
21	(Wilson, 2021)	50 students	Test & interview	PjBL develops students' metacognitive awareness and reflection on learning.
22	(Dewi et al., 2021)	30 students	Motivational questionnaire	PjBL positively influences students' learning motivation and engagement in class.
23	(Umar & Ko, 2022)	72 students	Science literacy test	Students' scientific literacy increased significantly after the implementation of PjBL.
24	(Azizan & Shamsi, 2022)	75 students	Test & interview	PjBL significantly improves students' collaboration and communication skills.
25	(Markula & Aksela, 2022)	58 students	Project observation	Students' scientific collaborative practices developed significantly through PjBL.
26	(Domenici, 2022)	69 students	Conceptual test	PjBL produces deeper conceptual understanding in students.
27	(Ladachart et al., 2022)	73 students	HOTS Test	PjBL is effective in developing higher-order thinking skills.
28	(Hariyono, 2023)	32 students	Pretest–posttest	The implementation of PjBL significantly improves students' learning outcomes and critical thinking skills compared to conventional learning.
29	(Negoro et al., 2023)	64 students	HOTS test, observation	PjBL has been shown to improve higher-order thinking skills (HOTS) significantly.
30	(Hasyim & Sujiono, 2023)	34 students	Project rubric	Student project products demonstrate high quality, serving as an indicator of PjBL effectiveness.
31	(Mufit, 2023)	60 students	Critical & creative test	PjBL significantly improves creative and critical thinking skills.
32	(Sulaiman et al., 2023)	70 students	Response questionnaire	Student responses to the implementation of PjBL were in the very positive category.
33	(Duangmanee & Waluyo, 2023)	68 students	Literacy test	PjBL significantly improves students' scientific literacy.
34	(Zhang & Ma, 2023)	85 students	Experimental test	Student learning outcomes in the PjBL class were significantly higher than those using the traditional method ($p < 0.05$).
35	(Meng et al., 2023)	92 students	HOTS Test	Students' higher-order thinking skills improved significantly.
36	(Reddy & Moate, 2024)	76 students	Tests & questionnaires	The implementation of PjBL significantly increases student

				engagement and academic achievement.
37	(Haryono et al., 2024)	35 students	Tests & questionnaires	Student learning outcomes and motivation increased significantly through PjBL.
38	(Samsudin et al., 2024)	74 students	Literacy test	Students' scientific literacy increased significantly after project-based learning (PjBL).
39	(López et al., 2024)	81 students	Tests & observations	PjBL strengthens students' communication and collaboration skills.
40	(Seo et al., 2024)	95 students	Conceptual test	PjBL significantly and deeply improves conceptual mastery.
41	(Solihah et al., 2024)	33 students	Critical test	Students' critical thinking skills increased to a high category after implementing PjBL.
42	(Zaidi et al., 2024)	78 students	HOTS test & questionnaire	PjBL improves higher-order thinking skills and positive attitudes towards learning.
43	(Shi, 2024)	88 students	Literacy test	Students' scientific literacy increased, with more students falling into the moderate-to-high category.
44	(Shi, 2024)	90 students	Tests & questionnaires	Students' conceptual understanding and learning motivation increased significantly through PjBL.
45	(Elvianasti, et al, 2024)	150 students	HOTS Test	PjBL effectively develops students' high-level cognitive abilities.