Enhancing Critical Thinking through Project-Based Learning: A Systematic Literature Review across Educational Contexts

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ABSTRACT:
This systematic review explores how Project-Based Learning (PjBL) develops critical thinking skills in science learning, particularly in early childhood education, and identifies factors influencing its effectiveness. Following a systematic search in Web of Science, Scopus, and ERIC, 28 peer-reviewed publications from the last five years were selected. The analysis revealed four main themes: active learning and inquiry processes; integration of STEM and contextual learning; collaboration and social interaction; and the use of technology and digital tools. Four influencing factors were also identified: instructional design, teacher roles and pedagogical support, learning environment and context, and early childhood characteristics. The findings consistently demonstrate that PjBL significantly enhances critical thinking, creativity, and 21st-century skills across educational levels. However, research on PjBL in early childhood science learning remains limited, revealing a significant gap. The review concludes that while PjBL is highly effective, successful implementation depends on teacher competence, institutional support, and appropriate instructional design, especially for young learners.

Keywords: project-based learning, critical thinking, early childhood science, systematic review.

1. Introduction

The development of critical thinking skills has become a major concern in 21st century education, particularly in science learning. Critical thinking is widely recognised as a key competency that enables learners to analyse information, evaluate evidence, and solve complex problems. It is also closely associated with other essential competencies such as collaboration, communication, and creativity (Kocak et al., 2021). As a result, educational systems are increasingly expected to design learning environments that not only deliver content knowledge but also foster higher-order thinking skills. In response to this demand, student-centred learning approaches have gained significant attention, one of which is Project-Based Learning (PjBL). PjBL emphasises active engagement, inquiry, and real-world problem

solving, allowing students to construct knowledge through meaningful experiences. Previous studies have consistently demonstrated that PjBL contributes positively to the development of higher-order thinking skills. For instance, PjBL has been shown to significantly improve students' creative thinking compared to traditional instructional approaches (Biazus & Mahtari, 2022). Similarly, research by Baran et al. (2021) found that Project-Based STEM learning enhances multiple 21st century skills, including autonomy, cooperation, environmental awareness, and critical thinking. Furthermore, the integration of STEM approaches and formative assessment within PjBL has been found to strengthen its impact on critical thinking skills (Nur'aini et al., 2022). The development of contextual science learning materials based on PjBL and STEM has also been reported to effectively support the acquisition of 21st century skills, including critical thinking (Setyowati et al., 2022). In addition, several studies have highlighted that combining PjBL with innovative strategies such as flipped classrooms and project-based assessment can further enhance students' conceptual understanding and critical thinking abilities (Rapi et al., 2022). The use of technological tools, such as smartphone sensors, has also been shown to support the development of critical thinking within PjBL environments (Listiaji et al., 2022). Beyond critical thinking, PjBL has also been associated with improvements in other higher-order thinking skills such as creativity and problem-solving. For example, the application of PjBL in science learning has been found to enhance students' creativity and problem-solving abilities (Amalia et al., 2022; Pramesti et al., 2022). Moreover, differentiated PjBL approaches have been shown to effectively improve students' critical thinking abilities by accommodating diverse learning needs (Putri et al., 2023). These findings suggest that PjBL provides a flexible and effective framework for developing multiple dimensions of higher-order thinking. Despite these promising results, the implementation of PjBL in educational practice still faces several challenges. In many contexts, teaching practices remain predominantly teacher-centred, limiting students' opportunities to actively engage in inquiry and problem-solving processes. Effective science teaching requires approaches that encourage active participation and critical thinking; however, such approaches are not always consistently implemented (Olatunde-Aiyedun & Ogunode, 2021). As a result, the potential of PjBL to foster critical thinking is not fully realised in many classrooms. These issues become more critical when considering early childhood education, which represents a crucial stage for cognitive development. Early childhood is a foundational period in which higher-order thinking skills, including critical thinking, begin to develop. Research has shown that the application of project-based approaches can significantly improve problem-solving skills in preschool children (Güley, 2024). Similarly, empirical studies indicate that PjBL and inquiry-based learning can effectively enhance critical thinking skills even in early childhood contexts (Purba et al., 2024; Yuliani et al., 2025). These findings highlight the potential of PjBL to support cognitive development from an early age. However, despite the growing body of research on PjBL, most studies have been conducted at the secondary and higher education levels, with relatively limited focus on early childhood science learning. In addition, previous studies often examine specific variables or interventions without providing a comprehensive synthesis of findings across different contexts. There is still a lack of systematic reviews that integrate recent empirical evidence on the role of PjBL in fostering critical thinking, particularly in early childhood science education. Therefore, this study aims to systematically review and synthesise empirical research on the implementation of Project-Based Learning in developing critical thinking skills, with a specific focus on early childhood science learning. By analysing studies published within the last five years, this research seeks to provide a comprehensive overview of current trends, effectiveness, and research gaps related to PjBL and critical thinking.

2. Literature Review

Project-Based Learning (PjBL) has been widely recognised as an effective instructional approach

in promoting active and meaningful learning. PjBL emphasises student-centred learning, where learners engage in real-world problems, inquiry processes, and collaborative activities to construct knowledge. This approach aligns with the demands of 21st century education, which requires the development of critical thinking, collaboration, creativity, and problem-solving skills (Kocak et al., 2021).

In educational practice, PjBL has been implemented across various levels and disciplines, demonstrating its effectiveness in enhancing higher-order thinking skills. Studies have shown that PjBL significantly improves students' creative thinking compared to conventional teaching methods (Biazus & Mahtari, 2022). In addition, Project-Based STEM learning has been found to enhance multiple competencies, including autonomy, cooperation, and critical thinking, which are essential for 21st century learning (Baran et al., 2021). Similarly, PjBL has been identified as an effective approach for improving student achievement and engagement in different subject areas (Lazić et al., 2021; Hamidah & Citra, 2021).

In the context of science education, the integration of PjBL with other pedagogical approaches further strengthens its effectiveness. For instance, combining STEM approaches with formative assessment in PjBL has been shown to significantly improve students' critical thinking skills (Nur'aini et al., 2022). The development of science teaching materials based on PjBL-STEM and Education for Sustainable Development (ESD) has also been proven effective in supporting 21st century competencies (Setyowati et al., 2022). Furthermore, hybrid learning models, such as the integration of flipped classroom strategies with project-based assessment, have been found to enhance both conceptual understanding and critical thinking skills (Rapi et al., 2022; Sholahuddin et al., 2023).

The integration of technology within PjBL also plays an important role in enhancing learning outcomes. Studies have shown that the use of digital tools, such as smartphone sensors, can improve critical thinking skills among learners (Listiaji et al., 2022). In addition, technology-enhanced PjBL environments support the development of digital literacy, self-regulated learning, and higher-order thinking skills (Wu, 2024; Kong et al., 2024). The use of digital learning resources, such as PjBL-based eBooks, has also been found to improve critical thinking and creative learning outcomes (Himawan et al., 2024).

Beyond critical thinking, PjBL contributes to the development of other important cognitive skills. Research indicates that PjBL enhances students' creativity and problem-solving abilities in science learning contexts (Amalia et al., 2022; Pramesti et al., 2022). It also supports the development of literacy and writing skills, which are closely related to critical thinking processes (Suteja & Setiawan, 2022). Moreover, differentiated PjBL approaches have been shown to effectively improve critical thinking by accommodating diverse student needs (Putri et al., 2023).

In early childhood education, the application of PjBL is increasingly recognised as an effective approach for supporting cognitive development. Early childhood is a critical period for developing foundational thinking skills, including critical thinking and problem-solving. Empirical studies have demonstrated that project-based approaches can significantly improve problem-solving skills in preschool children (Güley, 2024). Similarly, the implementation of PjBL in early childhood contexts has been shown to enhance critical thinking skills among young learners (Purba et al., 2024). Inquiry-based project learning has also been found to effectively support critical thinking development in children aged 5–6 years (Yuliani et al., 2025).

However, despite the growing evidence supporting the effectiveness of PjBL, several challenges remain in its implementation. In many educational contexts, teaching practices are still dominated by teacher-centred approaches, which limit opportunities for students to engage in active learning and critical thinking. Effective teaching methods in science education require active student participation and inquiry-based learning, yet these approaches are not

consistently applied in practice (Olatunde-Aiyedun & Ogunode, 2021). In addition, variations in instructional design, teacher competence, and learning environments can influence the effectiveness of PjBL implementation.

Furthermore, although numerous studies have examined the impact of PjBL on various learning outcomes, many of these studies are conducted at the secondary and higher education levels. There is still limited research focusing specifically on early childhood science learning. In addition, previous studies often focus on isolated variables without providing a comprehensive synthesis of findings across different contexts. Therefore, a systematic understanding of how Project-Based Learning contributes to the development of critical thinking skills, particularly in early childhood science education, remains necessary. This study aims to address this gap by synthesising recent empirical research and providing a comprehensive overview of the effectiveness and implementation of PjBL in fostering critical thinking.

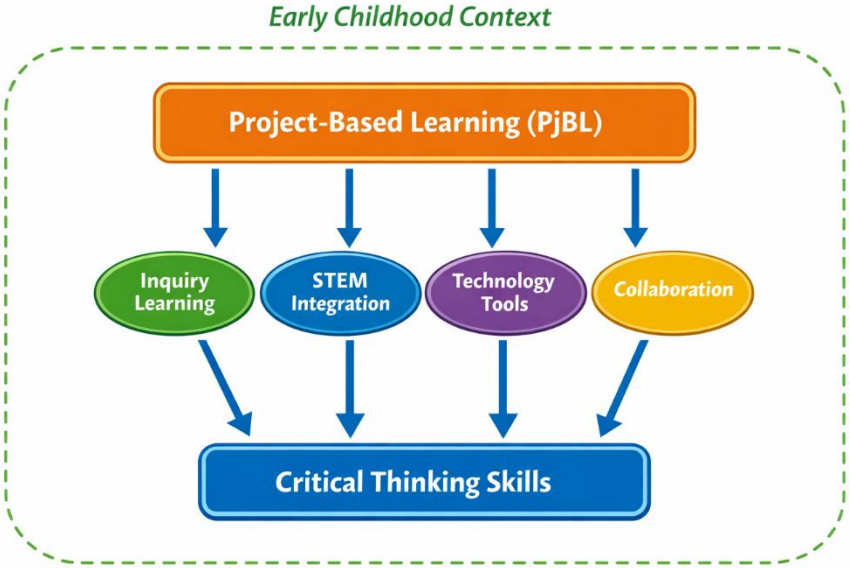

Figure 1. The Role of Project-Based Learning in Enhancing Critical Thinking Skills

3. Methodology

- **Design:**

This study adopted a Systematic Literature Review (SLR) design to investigate the role of Project-Based Learning (PjBL) in developing critical thinking skills in early childhood science learning. The SLR design was selected to ensure a structured and methodical approach in reviewing existing research evidence. The design of this study emphasises a systematic procedure in identifying, selecting, and analysing relevant literature. It involves defining clear research focus, establishing inclusion criteria, and applying a consistent process for selecting studies. This approach allows the review to be conducted in a transparent and replicable manner. In addition, the design is oriented toward empirical evidence by focusing only on peer-reviewed research articles. The scope of the review is limited to studies published within the last five years to capture recent developments in the field. The use of clearly defined criteria ensures that the selected studies are relevant to the research objective and comparable across different contexts.

- **Research Strategy and Data Sources:**

The literature search process began by identifying relevant keywords based on the main variables of the study, namely Project-Based Learning, critical thinking, early childhood, and science learning. These keywords were then combined into the following search string: ("Project-Based Learning" OR PjBL OR "Inquiry-Based

Learning") AND ("critical thinking") AND ("early childhood" OR preschool OR kindergarten) AND ("science learning") The search was conducted using three reputable international databases: Scopus, Web of Science (WoS), and Education Resources Information Center (ERIC). These databases were selected due to their extensive coverage of high-quality academic publications in the field of education. The initial search resulted in a total of 909 identified records.

- **Inclusion and Exclusion Criteria:**

To ensure the relevance and quality of the selected studies, specific inclusion and exclusion criteria were applied. The inclusion criteria were as follows: (1) articles published in peer-reviewed journals, (2) articles written in English, (3) articles published within the last five years to ensure the recency of the data, and (4) studies focusing on Project-Based Learning and/or critical thinking within educational contexts, particularly in science learning. The exclusion criteria included: (1) duplicate articles, (2) studies that were not relevant to the research topic, (3) non-empirical studies, and (4) publications such as reports, editorials, and conference proceedings that did not meet academic journal standards.

- **Study Selection Process (PRISMA):**

The study selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. In the initial stage, 909 records identified from the databases were screened to remove duplicates and irrelevant studies. Next, title and abstract screening was conducted to assess the relevance of each study. Articles that did not focus on Project-Based Learning, critical thinking, or relevant educational contexts were excluded. In the subsequent stage, full-text articles were reviewed in detail to ensure alignment with the objectives of the study. Studies that did not specifically address critical thinking, early childhood education, or science learning were excluded. To enhance the comprehensiveness of the review, a snowballing technique was applied by examining the reference lists of selected articles to identify additional relevant studies. Through this rigorous process, a total of 28 articles met all inclusion criteria and were included in the final analysis.

- **Data Extraction:**

Data from the selected articles were systematically extracted to ensure consistency and organisation. The extracted information included authors, year of publication, research methods, sample and context, learning models, main variables, and key findings. This process facilitated a structured comparison across studies and supported the subsequent analysis.

- **Data Analysis and Coding Scheme:**

The analysis of the selected studies was conducted using an open coding approach. Each article was carefully read and re-read to identify key themes and patterns. Based on this process, a coding scheme was developed to categorise the studies into several aspects, including type of study, context and target group, learning model or approach, main variables, and key findings. Each study was assigned specific codes according to these categories to ensure systematic classification and consistency in analysis. This coding scheme enabled the researcher to identify patterns, similarities, and differences across the selected studies.

- **Reliability and Validity:**

To ensure the reliability and validity of the findings, the analysis was conducted using clearly defined coding categories and systematic procedures. This approach minimised subjectivity in the interpretation of data. Furthermore, both deductive and inductive approaches were employed. The deductive approach was used to classify studies based on predefined categories, while the inductive approach allowed for the identification of emerging themes and patterns across the literature.

- **Data Synthesis:**

The final stage of the study involved synthesising the findings from the selected articles. This process aimed to identify common trends, differences, and relationships among the studies

regarding the use of Project-Based Learning in enhancing critical thinking skills. Through this synthesis, the study provides a comprehensive overview of recent research findings and highlights the effectiveness of Project-Based Learning, particularly in the context of early childhood science education.

4. Findings

The findings of this systematic literature review are based on the analysis of 28 selected studies related to Project-Based Learning (PjBL) and critical thinking skills across different educational contexts. The results reveal several dominant themes regarding how PjBL contributes to the development of critical thinking skills. In addition, several supporting factors that influence the effectiveness of PjBL implementation were identified. Overall, the findings indicate that PjBL consistently demonstrates a positive impact on critical thinking and other higher-order thinking skills across various educational levels, including early childhood, primary, secondary, and higher education.

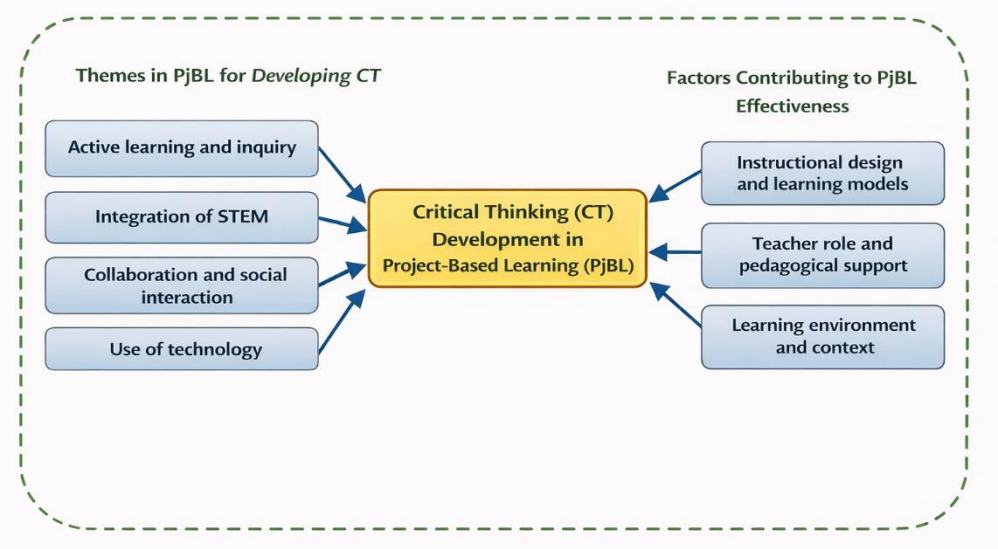

Figure 2. Key Themes and Factors Influencing Critical Thinking in Project-Based Learning

The development of critical thinking (CT) in Project-Based Learning (PjBL) has been conceptualised differently across the reviewed studies. In some studies, the focus was placed on students' engagement in active learning processes, particularly through inquiry and exploration activities. In these studies, critical thinking development was closely associated with students' ability to ask questions, investigate problems, and construct knowledge independently. In other studies, critical thinking was viewed as part of a broader set of higher-order thinking skills, including creativity, problem-solving, and self-regulation. In addition, several studies emphasised the importance of integrating interdisciplinary approaches, particularly STEM, within PjBL. This integration allows students to apply knowledge in real-world contexts, thereby strengthening their analytical and evaluative thinking. Other studies highlighted the role of collaboration and social interaction, where students develop critical thinking through discussion, idea exchange, and reflection with peers. Furthermore, the use of technology was identified as a supporting element that enhances students' ability to access information, analyse data, and solve problems more effectively.

Interestingly, while many studies provided clear conceptual frameworks for understanding critical thinking development, a number of studies did not explicitly define the theoretical basis of critical thinking. However, most studies implicitly linked critical thinking to 21st century skills and higher-order cognitive processes. Four main themes addressing how critical thinking is developed through PjBL emerged from the analysis. These include: (1) active learning and inquiry, (2) integration of STEM and contextual

learning, (3) collaboration and social interaction, and (4) the use of technology (see Figure 2). Furthermore, several contributing factors influencing the effectiveness of PjBL in developing critical thinking were identified. These factors include instructional design and learning models, teacher role and pedagogical support, and the learning environment and context. These factors act as both enabling and constraining elements in the implementation of PjBL and its impact on critical thinking development.

4.1 How Does Project-Based Learning Develop Critical Thinking?

4.1.1 Active Learning and Inquiry Processes

Most of the reviewed studies consistently indicate that Project-Based Learning (PjBL) promotes active learning through inquiry-based processes, where learners are actively involved in exploring problems, investigating phenomena, and constructing knowledge independently. Within PjBL environments, students are not positioned as passive recipients of information but as active participants who engage in questioning, analysing, and problem-solving activities. This active engagement enables learners to develop critical thinking skills through meaningful learning experiences.

In particular, inquiry-based processes embedded in PjBL encourage students to formulate questions, identify problems, design investigations, and evaluate solutions. These processes are closely aligned with higher-order thinking skills, especially critical thinking. Empirical evidence shows that inquiry-oriented PjBL significantly enhances students' ability to analyse and evaluate information, which are key components of critical thinking (Yuliani et al., 2025; Lin et al., 2021). In early childhood contexts, structured inquiry activities within project-based learning have been shown to improve children's problem-solving abilities and cognitive engagement (Güley, 2024; Purba et al., 2024).

Furthermore, studies have demonstrated that concept-based inquiry strategies, such as asking "why" and "how" questions, contribute to the development of higher-order cognitive responses among young learners. For example, Hu et al. (2022) found that inquiry-driven instructional strategies significantly increased children's higher-order thinking responses, indicating that guided inquiry plays an important role in developing critical thinking from an early age. In addition, inquiry-based PjBL has been found to support the development of critical thinking across different educational levels. In secondary education, students involved in PjBL demonstrate improved analytical and evaluative skills compared to those in traditional learning environments (Nur'aini et al., 2022; Rapi et al., 2022). Similarly, studies in higher education contexts indicate that active learning and inquiry processes contribute significantly to the development of critical thinking and 21st century skills (Kocak et al., 2021; Baran et al., 2021).

These findings suggest that active engagement and inquiry processes are central mechanisms through which PjBL fosters critical thinking. By involving students in exploration, questioning, and knowledge construction, PjBL creates a learning environment that supports deeper understanding and critical analysis.

4.1.2 Integration of STEM and Contextual Learning

Another prominent theme identified across the reviewed studies is the integration of STEM (Science, Technology, Engineering, and Mathematics) approaches within Project-Based Learning (PjBL), which has been shown to significantly enhance students' critical thinking skills, particularly in science education contexts. The interdisciplinary nature of STEM allows learners to connect concepts across different domains, thereby encouraging deeper understanding and analytical thinking.

Several studies have demonstrated that combining STEM approaches with PjBL creates a more meaningful and engaging learning environment. For example, Nur'aini et al. (2022) found that the integration of STEM and formative assessment within PjBL significantly improved students' critical thinking skills.

Similarly, Setyowati et al. (2022) reported that the development of STEM-based PjBL learning materials effectively supports 21st century competencies, including critical thinking, by enabling students to engage in problem-solving within real-life contexts. In addition to improving critical thinking, STEM-integrated PjBL also facilitates the development of other higher-order thinking skills such as creativity and problem-solving. Studies indicate that students who participate in STEM-based project learning demonstrate better performance in analysing complex problems and generating innovative solutions (Pramesti et al., 2022; Amalia et al., 2022). This suggests that STEM integration not only strengthens cognitive skills but also supports the development of flexible and adaptive thinking.

Contextual and real-world learning is another important aspect of this theme. PjBL provides opportunities for students to work on authentic problems that are relevant to their daily lives, which enhances their ability to apply knowledge in practical situations. This contextualisation of learning supports students in developing analytical and evaluative thinking skills, as they are required to interpret information, make decisions, and justify their solutions. Empirical evidence from early childhood education further supports this finding. For instance, Zhang et al. (2024) found that hybrid STEM learning integrated within project-based activities significantly improved critical thinking skills, including interpretation, explanation, inference, and self-regulation among young learners. Similarly, inquiry-based science and engineering projects have been shown to produce moderate to high effect sizes in improving problem-solving and critical thinking abilities in preschool children (Lin et al., 2021).

Moreover, the integration of STEM within PjBL aligns with the development of 21st century skills, including digital literacy and scientific literacy. Studies have shown that PjBL environments enriched with STEM components and technology support students in developing a more comprehensive understanding of scientific concepts while simultaneously enhancing their critical thinking skills (Kong et al., 2024; Ghazali et al., 2025).

4.1.3 Collaboration and Social Interaction

Collaboration and social interaction emerged as another key component in the reviewed studies, highlighting the importance of social constructivist learning environments in developing critical thinking skills. Within Project-Based Learning (PjBL), students are typically required to work in groups, engage in discussions, exchange ideas, and jointly solve problems. These collaborative processes create opportunities for learners to negotiate meaning, challenge assumptions, and refine their understanding, all of which are essential elements of critical thinking.

Several studies have demonstrated that collaborative project-based environments significantly enhance not only critical thinking but also communication and teamwork skills. For instance, Baran et al. (2021) found that Project-Based STEM learning improves students' autonomy, cooperation, and critical thinking through collaborative activities. Similarly, Suteja and Setiawan (2022) reported that PjBL environments that emphasise group discussion and interaction contribute to improvements in both critical thinking and literacy skills. Through collaborative learning, students are exposed to diverse perspectives and alternative viewpoints, which encourages them to analyse information more critically and reflect on their own thinking. This process of argumentation and peer interaction has been shown to strengthen reasoning skills and promote deeper cognitive engagement. In science learning contexts, collaborative inquiry allows students to test ideas, compare solutions, and justify their reasoning, thereby enhancing their analytical and evaluative abilities (Rapi et al., 2022; Nur'aini et al., 2022).

In addition, collaborative PjBL environments support the development of social and metacognitive skills that are closely related to critical thinking. For example, students learn to articulate their ideas clearly, evaluate the contributions of others, and regulate their own learning processes. Studies have shown that such

collaborative engagement contributes to the development of higher-order thinking skills and improves students' ability to solve complex problems (Amalia et al., 2022; Pramesti et al., 2022). The role of collaboration is also evident in early childhood education. Young learners involved in project-based and inquiry-based activities demonstrate improved interaction, communication, and problem-solving abilities when working with peers. Research indicates that structured group activities and guided interaction in early learning environments can support the development of critical thinking from an early age (Purba et al., 2024; Güley, 2024).

Furthermore, collaboration within PjBL is often supported by both face-to-face and technology-mediated interactions. Digital tools and online platforms can facilitate communication, idea sharing, and collaborative problem-solving, thereby extending learning beyond the classroom. This integration of social interaction and technology further enhances students' engagement and supports the development of critical thinking in diverse learning contexts (Kong et al., 2024).

4.1.4 Use of Technology and Digital Tools

The integration of technology and digital tools within Project-Based Learning (PjBL) has been identified as a significant factor in enhancing students' critical thinking skills. Technology-enhanced PjBL environments provide learners with access to diverse sources of information, tools for data analysis, and platforms for collaboration, all of which support deeper cognitive engagement and problem-solving processes. Several studies indicate that digital technologies enable students to explore complex problems more effectively by facilitating inquiry, experimentation, and evidence-based reasoning. Within PjBL contexts, technology functions not only as a supporting tool but also as a medium through which students construct knowledge and engage in higher-order thinking processes. For instance, the use of smartphone sensors in science-based PjBL has been shown to significantly improve critical thinking skills among pre-service teachers by allowing them to collect and analyse real-time data (Listiaji et al., 2022). This hands-on use of technology enhances students' ability to interpret data, draw conclusions, and justify their reasoning.

In addition, the development and use of digital learning resources, such as PjBL-based eBooks, have been found to support both critical thinking and creative learning outcomes. Himawan et al. (2024) reported that interactive digital materials designed within a PjBL framework enable students to engage more actively in reading, analysing, and reflecting on content, thereby improving their critical thinking skills. These findings suggest that well-designed digital resources can enhance the effectiveness of PjBL by providing structured yet flexible learning experiences. Furthermore, recent studies highlight the role of advanced technologies in supporting critical thinking within PjBL environments. For example, technology-integrated PjBL has been shown to improve students' digital literacy, analytical skills, and higher-order thinking abilities (Kong et al., 2024). Similarly, the implementation of technology-based PjBL models in early science education has been found to positively impact both critical and creative thinking skills among young learners (Ghazali et al., 2025).

Technology also facilitates collaborative learning and communication, which further contributes to critical thinking development. Digital platforms allow students to share ideas, discuss solutions, and receive feedback, thereby extending learning beyond traditional classroom settings. This interaction supports reflective thinking and helps students evaluate different perspectives, which are essential components of critical thinking. In early childhood education, the integration of technology within PjBL must be carefully designed to align with developmental characteristics. Studies indicate that age-appropriate digital tools, when combined with guided inquiry and project-based activities, can effectively support cognitive development and critical thinking skills in young learners (Purba et al., 2024; Zhang et al., 2024).

4.1.5 Development of Higher-Order Thinking Skills

Beyond its impact on critical thinking, Project-Based Learning (PjBL) has been consistently identified as an effective approach for fostering a broader range of higher-order thinking skills (HOTS), including creativity, problem-solving, and self-regulation. The nature of PjBL, which involves complex tasks, real-world problems, and open-ended inquiry, requires students to engage in advanced cognitive processes such as analysing, evaluating, and creating, which are central components of higher-order thinking.

Several studies have demonstrated that PjBL significantly enhances students' creativity and problem-solving abilities. For instance, Amalia et al. (2022) found that the implementation of PjBL in biotechnology learning improves students' ability to generate ideas and solve complex problems. Similarly, Pramesti et al. (2022) reported that STEM-based PjBL is more effective than traditional or discovery-based learning in developing creative thinking skills. These findings suggest that PjBL provides an environment that encourages innovation and flexible thinking. In addition to creativity and problem-solving, PjBL also supports the development of integrated cognitive skills. Studies indicate that students engaged in PjBL demonstrate improved conceptual understanding alongside critical thinking (Jamaludin et al., 2022). This integration of cognitive abilities highlights that PjBL does not target isolated skills but promotes a more comprehensive development of learners' intellectual capacities.

Furthermore, critical thinking has been identified as a key mediator in the development of broader competencies, particularly 21st century skills. Kocak et al. (2021) found that critical thinking plays a significant mediating role in enhancing skills such as collaboration and cooperativity. This indicates that the development of critical thinking within PjBL environments contributes to the strengthening of other essential competencies required in modern education. Other studies also emphasise that PjBL supports literacy and communication skills, which are closely linked to higher-order thinking. For example, Suteja and Setiawan (2022) found that students involved in PjBL demonstrate improvements in both critical thinking and writing skills, suggesting a strong relationship between cognitive and expressive abilities. In addition, differentiated PjBL approaches have been shown to further enhance critical thinking by addressing diverse learner needs and promoting deeper engagement (Putri et al., 2023).

In early childhood contexts, the development of higher-order thinking skills through PjBL is also evident. Research indicates that project-based and inquiry-based activities can improve problem-solving abilities and cognitive engagement among young learners (Purba et al., 2024; Güley, 2024). Similarly, hybrid STEM approaches in early education have been shown to enhance critical thinking and self-regulation, which are essential components of higher-order thinking (Zhang et al., 2024).

4.2 What Factors Influence the Effectiveness of PjBL?

4.2.1 Instructional Design and Learning Models

The effectiveness of Project-Based Learning (PjBL) in fostering critical thinking is strongly influenced by how the learning process is designed, structured, and implemented. Instructional design plays a crucial role in determining whether PjBL can facilitate meaningful inquiry, active engagement, and higher-order thinking. Well-designed PjBL environments typically include clear project goals, structured inquiry processes, opportunities for reflection, and appropriate assessment strategies. Several studies indicate that the impact of PjBL on critical thinking becomes more significant when it is combined with complementary learning approaches. For instance, the integration of differentiation strategies within PjBL allows teachers to accommodate diverse student abilities, thereby enhancing engagement and promoting deeper cognitive processing. Putri et al. (2023) found that differentiated PjBL significantly improves students' critical thinking skills by providing

learning pathways that align with individual needs and learning styles.

In addition, the combination of PjBL with flipped classroom models has been shown to strengthen students' conceptual understanding and critical thinking. Rapi et al. (2022) reported that flipped classroom-based project assessment enables students to engage with learning materials prior to class, allowing classroom time to be used for discussion, problem-solving, and project work. This approach supports deeper learning and encourages students to analyse and evaluate information more effectively. Formative assessment is another important component of instructional design in PjBL. Studies have shown that integrating formative assess. ment within PjBL provides continuous feedback that helps students reflect on their learning and improve their thinking processes. For example, Nur'aini et al. (2022) found that the combination of STEM and formative assessment in PjBL significantly enhances students' critical thinking skills by guiding them through structured evaluation and reflection activities.

Furthermore, instructional design that incorporates STEM integration and contextual learning has been shown to improve both engagement and critical thinking outcomes. Setyowati et al. (2022) demonstrated that STEM-based PjBL materials support the development of 21st century skills by engaging students in real-world problem-solving tasks. Similarly, hybrid STEM approaches have been found to improve critical thinking and self-regulation by providing interdisciplinary learning experiences (Zhang et al., 2024). The role of instructional design is also evident in the use of technology-enhanced PjBL models. Digital tools and resources can be integrated into project activities to support inquiry, collaboration, and data analysis. Studies indicate that technology-supported PjBL enhances students' ability to explore information and develop critical thinking skills (Listiaji et al., 2022; Himawan et al., 2024).

In early childhood education, instructional design must be adapted to align with developmental characteristics. Research shows that simplified and guided project-based activities, when properly structured, can effectively support critical thinking and problem-solving skills among young learners (Purba et al., 2024; Yuliani et al., 2025). This highlights the importance of designing age-appropriate PjBL experiences that balance guidance and exploration.

4.2.2 Teacher Role and Pedagogical Support

Teacher competence and pedagogical support play a crucial role in determining the effectiveness of Project-Based Learning (PjBL) in fostering critical thinking skills. In PjBL environments, the role of the teacher shifts from a knowledge transmitter to a facilitator who guides students through inquiry, exploration, and problem-solving processes. This shift requires teachers to possess not only content knowledge but also strong pedagogical skills to design and manage student-centred learning activities. Several studies emphasise that effective teaching methods that promote active and student-centred learning are essential for developing critical thinking. Olatunde-Aiyedun and Ogunode (2021) highlight that instructional approaches in science education must move beyond traditional teacher-centred practices to encourage inquiry, engagement, and critical analysis. Without appropriate pedagogical strategies, the potential of PjBL to develop higher-order thinking skills may not be fully realised.

In addition, teacher competence in facilitating inquiry and guiding project activities significantly influences students' learning outcomes. Studies show that teachers who are able to scaffold learning effectively by providing guidance, feedback, and structured support can enhance students' ability to think critically. For example, the integration of formative assessment within PjBL allows teachers to monitor students' progress and provide timely feedback, which supports the development of critical thinking (Nur'aini et al., 2022). Teacher support is also closely related to the ability to design meaningful and engaging learning experiences. Research indicates that well-prepared teachers who implement structured PjBL activities can improve students' conceptual understanding and

critical thinking skills (Rapi et al., 2022; Jamaludin et al., 2022). Conversely, insufficient pedagogical support may result in superficial learning experiences, where students engage in project activities without achieving deeper cognitive understanding.

Furthermore, teachers play a key role in facilitating collaboration and discussion within PjBL environments. By encouraging students to share ideas, ask questions, and reflect on their learning, teachers help create a learning atmosphere that supports critical thinking. Studies have shown that guided discussion and collaborative interaction, when properly facilitated by teachers, contribute significantly to the development of analytical and evaluative thinking skills (Suteja & Setiawan, 2022; Baran et al., 2021). The importance of teacher competence is also evident in the integration of technology within PjBL. Teachers need to be able to effectively use digital tools to support inquiry, data analysis, and collaboration. Research shows that when teachers successfully integrate technology into project-based activities, students demonstrate improved critical thinking and engagement (Listiaji et al., 2022; Himawan et al., 2024).

In early childhood education, pedagogical support becomes even more critical due to the developmental characteristics of young learners. Teachers must provide structured guidance while allowing opportunities for exploration and inquiry. Studies indicate that teacher-guided project-based and inquiry-based learning can effectively support critical thinking development in young children (Purba et al., 2024; Yuliani et al., 2025). This highlights the importance of balancing guidance and autonomy in early learning contexts.

4.2.3 Learning Environment and Context

The learning environment and contextual conditions were identified as important factors influencing the effectiveness of Project-Based Learning (PjBL) in developing critical thinking skills. The reviewed studies indicate that environments which support active engagement, interaction, and contextualised learning provide stronger opportunities for students to develop higher-order thinking skills. Several studies highlight that interactive and collaborative classroom environments play a key role in enhancing critical thinking. For example, Project-Based STEM learning environments that emphasise collaboration and student participation have been shown to significantly improve critical thinking, autonomy, and cooperation (Baran et al., 2021). Similarly, PjBL environments that integrate discussion and writing activities support both critical thinking and literacy development, indicating that social interaction within the learning environment contributes to deeper cognitive processing (Suteja & Setiawan, 2022).

In addition, the availability of supportive learning resources and contextual learning materials influences how effectively PjBL can be implemented. Studies show that STEM-based PjBL materials and contextual science learning resources enable students to engage more actively in problem-solving and critical analysis (Setyowati et al., 2022; Nur'aini et al., 2022). These environments allow students to connect theoretical concepts with real-world situations, thereby strengthening their analytical and evaluative thinking skills. The learning context, particularly the use of real-world and contextual problems, is also a significant factor. Research indicates that contextualised PjBL approaches, such as biotechnology-based projects or low-carbon STEM projects, enhance students' creativity and problem-solving skills, which are closely related to critical thinking (Amalia et al., 2022; Pramesti et al., 2022). Similarly, culturally integrated learning models, such as RANDAI (PBL combined with local culture), have been shown to be more effective in improving critical thinking than conventional PBL approaches (Arsih et al., 2021).

Institutional and broader educational contexts also influence the success of PjBL implementation. Studies suggest that supportive school environments and positive teacher perceptions toward PjBL contribute to more effective implementation and better learning outcomes. For example, Aisyah and Novita

(2025) found that teachers' positive perceptions of PjBL are associated with improved critical thinking and creativity among students. In addition, professional development programs for teachers have been shown to improve teaching practices, which in turn positively impact students' inquiry skills and learning outcomes (Chen et al., 2025). In early childhood education, the role of the learning environment becomes even more critical. Studies indicate that structured yet flexible learning environments that encourage exploration, interaction, and guided inquiry can significantly enhance young children's critical thinking and problem-solving skills (Purba et al., 2024; Güley, 2024). Similarly, inquiry-based science and engineering projects conducted in supportive classroom environments have been shown to produce significant improvements in cognitive development and problem-solving abilities among preschool children (Lin et al., 2021). Hybrid STEM learning environments have also been found to enhance critical thinking and self-regulation in early childhood contexts (Zhang et al., 2024).

Furthermore, observational studies suggest that classroom interaction patterns, such as the use of "why" and "how" questions, are strongly influenced by the learning environment and teacher background, and these factors significantly contribute to the development of higher-order thinking responses (Hu et al., 2022).

4.2.4 Early Childhood Context

A significant finding of this review is the increasing application of Project-Based Learning (PjBL) in early childhood education, particularly in supporting the development of critical thinking and problem-solving skills. Early childhood is a crucial period for cognitive development, where foundational thinking skills begin to emerge. The reviewed studies indicate that PjBL provides meaningful learning experiences that align with young learners' developmental characteristics, especially through exploration, play-based inquiry, and hands-on activities.

Several empirical studies demonstrate that PjBL effectively improves critical thinking and problem-solving skills in early childhood contexts. For example, Purba et al. (2024) found that the implementation of problem-based and project-based learning significantly enhances early childhood critical thinking skills. Similarly, Güley (2024) reported that project-based science education programs produce significant and long-lasting improvements in preschool children's problem-solving abilities. These findings suggest that PjBL is not only applicable but also highly effective in early learning environments. In addition, inquiry-based project learning has been shown to further strengthen critical thinking development among young learners. Yuliani et al. (2025) found that Inquiry Project-Based Learning significantly improves critical thinking skills in children aged 5–6 years. Likewise, structured inquiry and engineering-based project activities have been shown to produce moderate to high improvements in problem-solving, motivation, and cognitive development among preschool children (Lin et al., 2021). Observational studies also indicate that inquiry-driven classroom interactions, such as asking "why" and "how" questions, contribute to higher-order cognitive responses in early childhood learners (Hu et al., 2022).

Furthermore, the integration of STEM approaches within PjBL has shown promising results in early childhood contexts. For instance, hybrid STEM learning environments have been found to significantly improve critical thinking skills, including interpretation, explanation, inference, and self-regulation among young learners (Zhang et al., 2024). Similarly, technology-integrated project-based learning models have been shown to positively impact both critical and creative thinking in early science education (Ghazali et al., 2025). Despite these positive findings, the review also reveals that research on PjBL in early childhood education remains relatively limited compared to studies conducted at the secondary and higher education levels. Most existing studies focus on older students, while fewer studies specifically examine the implementation and impact of PjBL in early

childhood science learning. This indicates a clear gap in the literature and highlights the need for further research that explores age-appropriate instructional design, teacher support, and contextual factors in early childhood settings.

Moreover, the successful implementation of PjBL in early childhood requires careful adaptation to developmental characteristics. Young learners need structured guidance, scaffolding, and supportive learning environments to effectively engage in project-based activities. Studies suggest that balancing guidance and exploration is essential to ensure that children can develop critical thinking skills without experiencing cognitive overload (Purba et al., 2024; Güley, 2024).

5. Discussion

The findings of this study indicate that the implementation of Project-Based Learning (PjBL) consistently contributes to the enhancement of students' critical thinking, creativity, and broader 21st-century skills. This result is strongly supported by prior empirical evidence demonstrating that PjBL promotes higher-order thinking through sustained engagement in authentic, inquiry-driven, and problem-oriented learning tasks (Baran et al., 2021; Biazus & Mahtari, 2022; Wang, 2022). From a constructivist perspective, this can be explained by the fact that PjBL situates learners in complex learning environments where knowledge is actively constructed rather than passively received. As a result, learners are required to interpret information, generate hypotheses, test solutions, and reflect on outcomes, thereby facilitating deeper cognitive processing and metacognitive regulation.

More specifically, the effectiveness of PjBL in enhancing critical thinking can be attributed to its emphasis on authentic problem-solving cycles, which mirror real-world challenges. These cycles typically involve problem identification, investigation, design, implementation, and evaluation. Such processes inherently demand analytical reasoning, evaluation of evidence, and decision-making, which are core dimensions of critical thinking. Therefore, PjBL does not merely improve learning outcomes but also restructures how students approach knowledge and problem-solving in dynamic contexts.

A key strength of PjBL lies in its student-centered nature, which encourages inquiry, collaboration, and self-directed learning. In contrast to teacher-centered approaches, where knowledge transmission dominates, PjBL shifts the cognitive responsibility to learners. This shift is critical because it creates opportunities for students to engage in self-regulated learning, where they plan, monitor, and evaluate their own learning processes. Empirical studies confirm that such environments significantly enhance critical thinking, as students are required to navigate uncertainty, negotiate meaning with peers, and justify their reasoning (Issa & Khataibeh, 2021; Suteja & Setiawan, 2022).

Furthermore, the collaborative dimension of PjBL plays a pivotal role in cognitive development. Through structured group work, students are exposed to diverse perspectives, which promotes cognitive conflict and conceptual change both of which are essential for deep learning. Kocak et al. (2021) emphasize that collaboration not only improves cooperative skills but also strengthens critical thinking through argumentation, peer feedback, and collective problem-solving. This indicates that the social constructivist foundation of PjBL is instrumental in fostering both cognitive and interpersonal competencies simultaneously. Moreover, the incorporation of interdisciplinary approaches such as STEM within PjBL has been shown to further amplify its effectiveness. Interdisciplinary learning enables students to integrate knowledge across domains, thereby promoting transfer of learning and cognitive flexibility. Studies have demonstrated that PjBL integrated with STEM or formative assessment strategies leads to significantly improved learning outcomes compared to traditional methods (Nur'aini et al., 2022; Pramesti et al., 2022; Setyowati et al., 2022). This is because such approaches provide structured scaffolding while still maintaining learner autonomy, allowing students to connect abstract concepts with real-world applications.

In the context of early childhood education, although empirical evidence remains relatively limited, the available studies suggest promising outcomes. Purba et al. (2024) found that young learners engaged in project-based activities exhibited increased curiosity, inquiry skills, and early problem-solving abilities. This finding is particularly important because it challenges the traditional assumption that higher-order thinking skills are only suitable for older learners. Instead, it suggests that, when appropriately designed, PjBL can serve as an effective pedagogical approach even at early developmental stages. However, the limited number of studies in this area indicates a significant research gap, particularly regarding age-appropriate instructional design and assessment strategies for young learners.

Despite its demonstrated effectiveness, the success of PjBL implementation is highly contingent upon contextual and institutional factors. Teacher competence emerges as one of the most critical determinants. Effective PjBL requires teachers to adopt multiple roles, including facilitator, designer, and mentor. This demands not only strong pedagogical knowledge but also the ability to integrate technology and manage complex classroom dynamics (Farrow et al., 2024; Himawan et al., 2024). Without adequate preparation and support, teachers may struggle to implement PjBL effectively, thereby limiting its potential impact. In addition, institutional factors such as school culture, leadership support, and resource availability play a crucial role in shaping the success of PjBL. Research indicates that supportive leadership and collaborative professional environments significantly enhance teachers' willingness and ability to adopt innovative pedagogies (Gao et al., 2011; Starkey, 2020). Conversely, rigid curricula, limited resources, and high workloads may act as barriers to effective implementation. This suggests that the integration of PjBL requires systemic change rather than isolated instructional innovation.

Another critical dimension highlighted in this study is the role of teachers' professional digital competence (PDC) in supporting PjBL environments. In contemporary education, digital technologies are integral to project-based learning, particularly in facilitating research, collaboration, and presentation of findings. Studies show that teachers with higher levels of digital competence are better equipped to design technology-rich learning environments that enhance student engagement and learning outcomes (Gudmundsdottir & Hatlevik, 2018; Ottenbreit-Leftwich et al., 2018). Furthermore, recent perspectives argue that digital competence is no longer limited to technical skills but extends to pedagogical and ethical dimensions, reflecting a shift toward transformative teaching practices. Importantly, this study also reveals that the effectiveness of PjBL should be understood as a multidimensional construct, influenced by the interaction between pedagogical design, learner characteristics, teacher competence, and institutional context. This complexity underscores the need for a holistic and systemic approach to implementation. Future research should therefore focus on identifying optimal conditions for PjBL across different educational contexts, as well as developing frameworks that integrate pedagogical, technological, and organizational dimensions.

This study has several limitations that need to be acknowledged. One of the main limitations is the relatively small number of studies that met the inclusion criteria. Although the review focused on recent and relevant research, the selected articles may not fully represent the wide range of educational contexts in which Project-Based Learning (PjBL) is implemented. A broader inclusion of participants, such as pre-service teachers, in-service teachers, and students from different educational levels and cultural backgrounds, would likely provide a more comprehensive understanding of the effectiveness of PjBL. Another limitation concerns the dominance of short-term studies in the existing literature. Most of the reviewed research evaluates the impact of PjBL within a limited instructional period, making it difficult to determine whether improvements in critical thinking are sustained over time. Future research should consider longitudinal approaches to

examine how PjBL influences the development and retention of critical thinking skills across different stages of learning.

The findings also indicate that research on PjBL in early childhood education is still limited. Although some studies suggest that PjBL can support the development of basic inquiry and problem-solving skills in young learners, there is not enough empirical evidence to draw strong conclusions. Further studies are needed to explore how PjBL can be adapted to suit the developmental characteristics of early childhood learners, including appropriate learning designs and assessment methods. In addition, the role of teachers and institutional contexts has not been sufficiently explored. While several studies acknowledge the importance of teacher competence and school support, there is limited discussion on how these factors interact in practice. Future research should examine how teacher readiness, professional development, leadership support, and school culture influence the successful implementation of PjBL in classrooms.

Another important limitation is the lack of comprehensive analysis linking PjBL to a wider range of learning outcomes. Most studies focus primarily on critical thinking, with less attention given to other important aspects such as motivation, engagement, and academic achievement. Further research is needed to explore these relationships in a more integrated manner. This study also does not examine in depth how different components of PjBL, such as collaboration, inquiry processes, and the use of technology, are interconnected. Understanding how these elements influence each other would help in designing more effective learning models. Future studies are encouraged to investigate these relationships and develop a more coherent framework for PjBL implementation.

Finally, there is inconsistency in the use of theoretical frameworks across the reviewed studies. While some research is grounded in clear theoretical perspectives, others do not explicitly state their conceptual basis. This may lead to differences in how PjBL is interpreted and applied. Future research should strengthen the use of theoretical frameworks to support more consistent and rigorous findings.

6. Conclusion

This study concludes that Project-Based Learning (PjBL) is an effective pedagogical approach for enhancing students' critical thinking, creativity, and 21st-century skills through active, student-centered, and context-based learning processes. The integration of interdisciplinary approaches, such as STEM and formative assessment, further strengthens its impact on learning outcomes. Despite its demonstrated effectiveness across various educational levels, including early childhood education, the successful implementation of PjBL depends on multiple factors, including teacher competence, institutional support, and the availability of learning resources. Therefore, a systematic and well-supported implementation framework is essential to maximize the potential of PjBL in improving educational quality and fostering higher-order thinking skills in learners.

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Author Declaration

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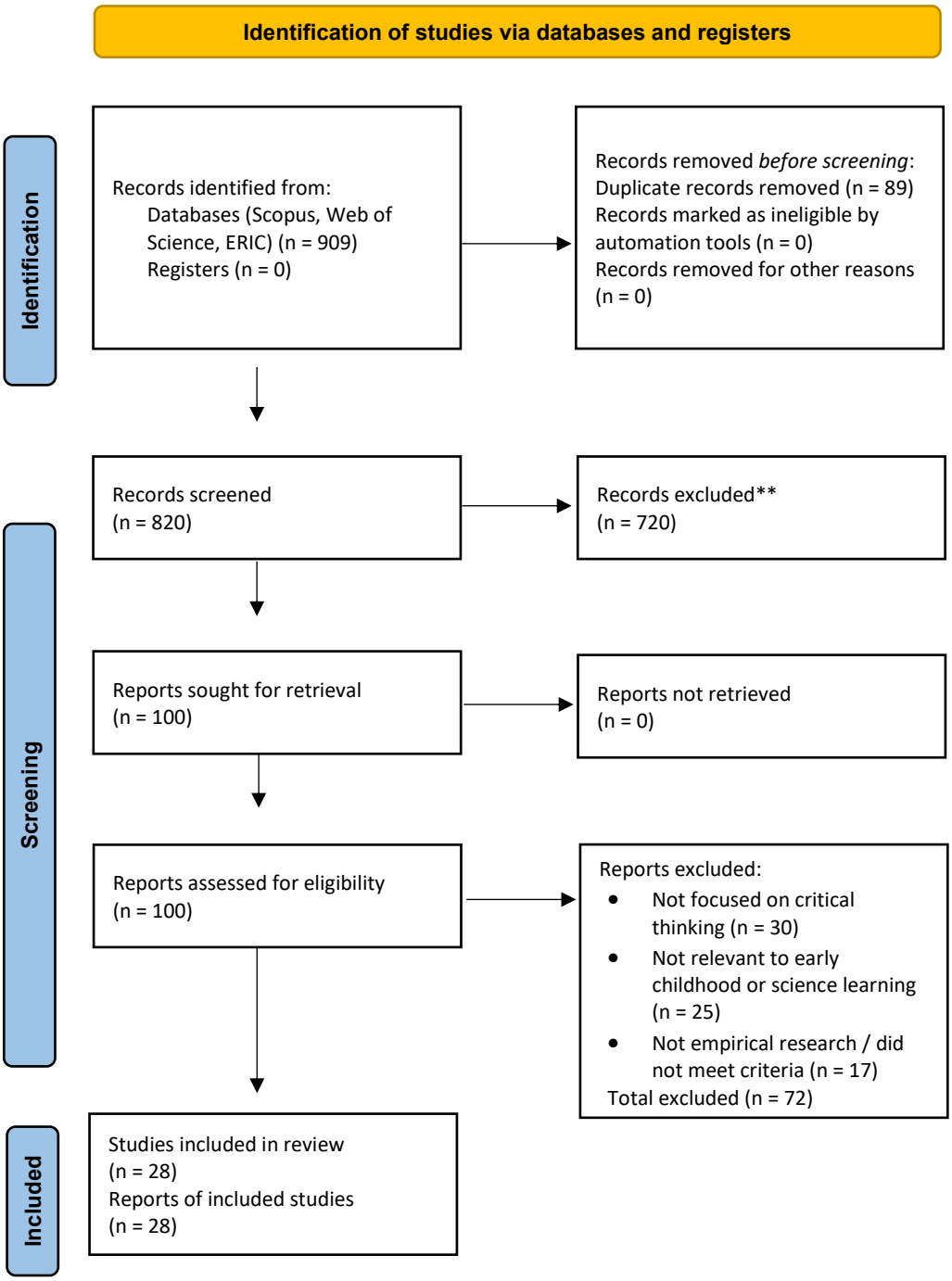
Appendices

Appendix 1: An overview of the screening and selection



Appendix 2: Coding scheme to analyse included studies

Category	Code	Label	Definition
Type of Study	A1	Quantitative	Refers to studies conducted using quantitative methods (e.g., SEM, statistical analysis)
	A2	Quasi-experimental	Refers to studies using quasi-experimental design
	A3	Experimental / Pre-experimental	Refers to studies using experimental or pre-experimental design
	A4	Mixed methods	Refers to studies combining qualitative and quantitative methods
	A5	Qualitative (interview/observation)	Refers to studies using interviews or systematic observation
	A6	Development research	Refers to studies involving development of materials/media with empirical testing
	A7	Survey	Refers to studies using survey methods
	A8	Literature / Systematic review	Refers to review-based studies
Context and Target Group	B1	Early childhood / Preschool / Kindergarten	Refers to studies conducted on children aged 4–7 years
	B2	Elementary school	Refers to studies conducted in primary school level
	B3	Secondary school	Refers to studies conducted in junior/high school
	B4	Higher education	Refers to studies conducted on university students
	B5	Teachers	Refers to studies involving teachers (pre-service/in-service)
	B6	Mixed / Various	Refers to studies involving multiple or unspecified groups
Learning Model / Approach	C1	Project-Based Learning (PjBL)	Refers to studies using PjBL as the main model
	C2	Problem-Based Learning (PBL)	Refers to studies using PBL
	C3	STEM-based PjBL	Refers to integration of STEM within PjBL
	C4	Inquiry-based PjBL	Refers to integration of inquiry approach in PjBL
	C5	Technology-integrated PjBL	Refers to PjBL combined with technology (e.g., TPBL, sensors, AI)
	C6	Hybrid / Combined models	Refers to combination models (flipped, differentiation, assessment integration)
	C7	Other learning models	Refers to non-PjBL/PBL approaches
Main Variables	D1	Critical thinking	Refers to studies focusing on critical thinking skills
	D2	Creative thinking	Refers to studies focusing on creativity
	D3	Problem-solving	Refers to studies focusing on problem-solving skills
	D4	21st century skills	Refers to broader competencies including CT

Category	Code	Label	Definition
	D5	Concept understanding / mastery	Refers to conceptual understanding in science
	D6	Literacy (scientific/AI/reading)	Refers to literacy-related outcomes
	D7	Motivation / attitude	Refers to affective variables
	D8	Multiple variables	Refers to combination of two or more variables
Key Findings	E1	Significant improvement in CT	Refers to studies reporting improvement in critical thinking
	E2	Improvement in higher-order thinking	Refers to creativity, problem-solving, or HOTS improvement
	E3	Effectiveness of PjBL over other models	Refers to comparative superiority
	E4	Integration effect (STEM/technology)	Refers to positive effect of integration approaches
	E5	Teacher-related impact	Refers to teacher perception, PD, or teaching practices
	E6	Development effectiveness	Refers to effectiveness of developed materials/media
	E7	Theoretical support / review findings	Refers to findings from literature or systematic reviews

Appendix 3: Summary of Previous Studies on Project-Based Learning and Critical Thinking

No	Author(s) (Year)	Research Method	Sample & Context	Learning Model & Main Variables	Main Findings
1	Kocak et al. (2021)	Quantitative, SEM	714 higher education students	21st century skills; Mediator: Critical thinking & cooperativity	Critical thinking plays a significant mediating role in 21st century skills
2	Arsih et al. (2021)	Quasi-experimental	107 pre-service biology teachers	RANDAI (PBL + local culture); Critical thinking skills	RANDAI is superior in improving critical thinking compared to pure PBL
3	Baran et al. (2021)	Pre-experimental + interviews	24 high school students	Project-Based STEM; 21st century skills (incl. critical thinking, creativity)	Significant improvement in autonomy, cooperation, environmental sensitivity & critical thinking
4	Biazus & Mahtari (2022)	Quasi-experimental	Secondary school students	PjBL vs direct instruction; Creative thinking skills	PjBL improves creative thinking (higher n-gain)

No	Author(s) (Year)	Research Method	Sample & Context	Learning Model & Main Variables	Main Findings
5	Nur'aini et al. (2022)	Quasi-experimental	High school students	STEM + formative assessment in PjBL; Critical thinking	The combination significantly improves critical thinking
6	Setyowati et al. (2022)	Development + empirical	High school students	PjBL-STEM + ESD; Environmental pollution materials	Materials are effective in supporting 21st century skills including critical thinking
7	Putri & Wardani (2021)	Quasi-experimental	4th grade elementary students	Online Problem-Based Learning; Thematic learning outcomes & CT	Online PBL improves learning outcomes and supports CT
8	Pramesti et al. (2022)	Quasi-experimental	High school students	Low Carbon STEM PjBL vs discovery; Creative thinking	Low Carbon STEM PjBL is more effective for creative thinking
9	Rapi et al. (2022)	Quasi-experimental	High school students	Flipped classroom + project assessment; Concept understanding & CT in physics	Approach improves understanding and critical thinking
10	Listiaji et al. (2022)	Quasi-experimental	Pre-service science teachers	PjBL + smartphone sensors; Critical thinking	Model improves pre-service teachers' CT
11	Amalia et al. (2022)	Quasi-experimental	High school students	PjBL on biotechnology; Creativity & problem-solving	Improvement in creativity and problem-solving
12	Jamaludin et al. (2022)	Quasi-experimental	High school students	Learning model; CT & concept mastery (temperature & heat)	Improves CT and concept mastery
13	Himawan et al. (2024)	Development + pre-post	Students	PjBL-based eBook "Critical and Creative Reading"; CT skills	PjBL-based eBook improves CT & creative reading
14	Kong et al. (2024)	Course evaluation	High school students	PjBL; AI literacy	PjBL effectively develops AI literacy & 21st century skills

No	Author(s) (Year)	Research Method	Sample & Context	Learning Model & Main Variables	Main Findings
15	Lesman et al. (2023)	Quasi-experimental	Vocational students	PjBL creative product; Creativity & CT	Improves creativity & CT in vocational context
16	Purba et al. (2024)	Empirical implementation	Early childhood	PBL; Early child's CT skill	PBL effectively improves CT in early childhood
17	Putri et al. (2023)	Quasi-experimental	Students	PjBL + differentiation; Critical thinking ability	Differentiated PjBL improves CT
18	Suteja & Setiawan (2022)	Mixed method	Students	PjBL; CT & writing skills	PjBL improves CT and literacy
19	Güley (2024)	Quasi-experimental	Preschool children	Project approach-based science education program; Problem-solving skills	Program significantly and permanently improves problem-solving skills
20	Hu et al. (2022)	Systematic observation	25 teachers & 800 kindergarten children (China)	Concept development strategies ("why/how" questions); Higher-order cognitive responses	Concept strategies improve higher-order responses (25.22%); correlated with teacher background
21	Lin et al. (2021)	Randomized controlled (12 weeks)	122 preschool children (~5 years)	Inquiry-based science & engineering project (EDP + 5Es); Science knowledge, problem-solving, motivation	Significant improvement (effect size 0.27–1.28); baseline competence moderates results
22	Zhang et al. (2024)	Empirical (hybrid STEM)	Kindergarten children (5–7 years)	Hybrid STEM curriculum; Critical thinking & self-regulation	Significant improvement in CT (interpretation, explanation, inference, self-regulation)
23	Aisyah & Novita (2025)	Survey + empirical	Early childhood teachers (Indonesia)	PjBL implementation; Perceptions & outcomes	Positive teacher perception; benefits for CT & creative thinking
24	Chen et al. (2025)	Pre-post PD program	22 preschool & 159 children (~4 years)	Science teaching PD (Farm to ECE); Teaching beliefs/practices & children's inquiry skills	Alignment between beliefs and practices improves; linked to children's science outcomes

No	Author(s) (Year)	Research Method	Sample & Context	Learning Model & Main Variables	Main Findings
25	Yuliani et al. (2025)	Empirical	Children aged 5–6 years	Inquiry Project-Based Learning; Critical thinking abilities	Inquiry-PjBL improves early childhood CT
26	Eliza (2025)	Literature review + empirical implications	Various studies	PjBL in science; Scientific literacy & CT	PjBL supports understanding of science phenomena & CT better than text-based learning
27	Ghazali et al. (2025)	Empirical	Early science preschool	Technology-Project-based Learning (TPBL); Creative & critical thinking	TPBL positively impacts CT & creative thinking in early science
28	DongJin et al. (2025)	Systematic review	Various child studies	PjBL; Children's critical thinking skills	PjBL effectively improves CT even in kindergarten & lower primary