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Project-based Learning in Early Science Education A Systematic Review

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Abstract

This study systematically reviews the effectiveness of Project-Based Learning (PjBL) in early science education, focusing on its impact on children's critical thinking and cooperative skills. Employing the PRISMA guidelines, a systematic search was conducted across major databases, resulting in the selection of 49 relevant studies published between 2019 and 2023. The analysis reveals that PjBL not only enhances scientific understanding and 21st-century skills among young learners but also significantly improves their engagement and collaborative abilities through real-world problem-solving and interdisciplinary learning. However, challenges such as resource limitations and the need for teacher training are identified. The study underscores the necessity for future research to explore optimized PjBL implementations and assess long-term learning outcomes. The findings provide substantial evidence of PjBL's potential in reforming early science education, advocating for integrated approaches to foster critical thinking and cooperation among young learners, thereby preparing them for future academic and professional challenges.

Keywords: Project-Based Learning, Early Science Education, Critical Thinking, Cooperative Skills, Teaching Method

Introduction

Project-based learning (PjBL) is a children-centered educational approach. This approach implements the learning process by exploring and solving real-world challenges (Tamim & Grant, 2013). There are many key elements of PjBL, like children autonomy, critical thinking, interdisciplinary learning, and cooperative learning (Tamim & Grant, 2013). Children have autonomy in the PjBL process. In the PjBL process, they are responsible for planning the project, gathering information, analyzing information, solving problems and presenting the results (Boud, 2012). Critical thinking means children could find the problems and try to solve them. Interdisciplinary learning means PjBL involves multiple subject areas in its implementation. Children need to use their knowledge and skills from different disciplines to solve problems (Markham et al., 2003). Cooperative learning means children will work together in teams. In order to accomplish project tasks in PjBL, which helps to develop children's communication and collaboration skills (Laal & Ghodsi, 2012). There is great potential for using PjBL in early science education. PjBL can provide authentic problem contexts for early science teaching. Stimulating children's curiosity and inquisitiveness, and enable children to actively participate in early science activities (Krajcik & Czerniak, 2018). PjBL plays a crucial role in developing 21st century skills. 21st century skills include critical thinking, creativity, cooperative skills, and communication skills. These skills are widely recognized as necessary for students to cope with a rapidly changing globalized world (Trilling & Fadel, 2012). In recent years, more and more researchers focuse on the use of PjBL in early science education. Many sresearch have shown that PjBL in science learning can promote children's critical thinking and cooperative skills. For example, reasoning, analysing, solving problems, communication and resource sharing (Bell, 2010; Han et al., 2015).

Although PjBL shows many great potential in early science education, current research in China has focused on specific case studies or small-scale experiments and lacks extensive and systematic evaluation (Eshach, 2006). In addition, there are still many unanswered questions in China about how to effectively design and implement PjBL in early science learning. How to assess children's learning outcomes (Savery, 2015). Therefore, it is necessary to systematically analyze existing research worldwide to determine the current status of PjBL in early science education, assess its effectiveness, identify gaps, and provide guidance for future research and practice in China (Mergendoller & Thomas, 2005; Eshach, 2006; Savery, 2015).

This study will systematically review and analyze the relevant literatures. In order to explore the use of PjBL in early science education and PjBL's impact on children's development. The purpose of this review was to explore the use of project-based learning (PjBL) in early science education. Given the limitations and shortcomings of existing research, the main questions to be answered are as follows. RQ1: What are some of the modules and methods of PjBL design applicable to early science education? RQ2: What are the implications and challenges of PjBL for children in early science education, particularly with regard to critical thinking and cooperative skills?

This review will reveal the current status and trends in the use of PjBL in early science education, identify gaps and shortcomings in the research, and suggest directions for future research.

Method

In this study, a systematic review is used to select published literatures related to PjBL in early science. Relevant literatures are screened by conducting systematic searches in databases such as Scopus, Springer and Web of Science. For this sysenatic review, the literatures selection process followes the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

Literature Search Strategy

There are 3 databases be used in the literature search strategy, such as Web of Science, Scopus, and Springer databases. In order to search for relevant literatures published between 2019 and 2023. Search strings like project-based learning and early science education. Project-based learning string include "Project-based Learning" or "Inquiry-based Learning" or "Experiential Learning" or "Hands-on Learning". Early Science Education strings include "Early Science Education" or "Science Education in Early Childhood" or "Preschool Science Education" or "Science Learning in Early Years". After removing duplicates from each database, 579 articles were generated. The literature search process is shown in Figure 2 PRISMA flowchart.

Table 1
Inclusion and exclusion criteria

Inclusion	Exclusion
Published studies from 2019-2023	Not published from 2019-2023
PjBL as a module for early science programs only	PjBL as a module, but not limited to teaching and learning Early Science
The research focuses on PjBL	PjBL is not a primary focus of research
PjBL as a module for preschool education	PjBL as a module, but not in preschool
Full text is available	Full text not available
The article is written in English	Articles in languages other than English

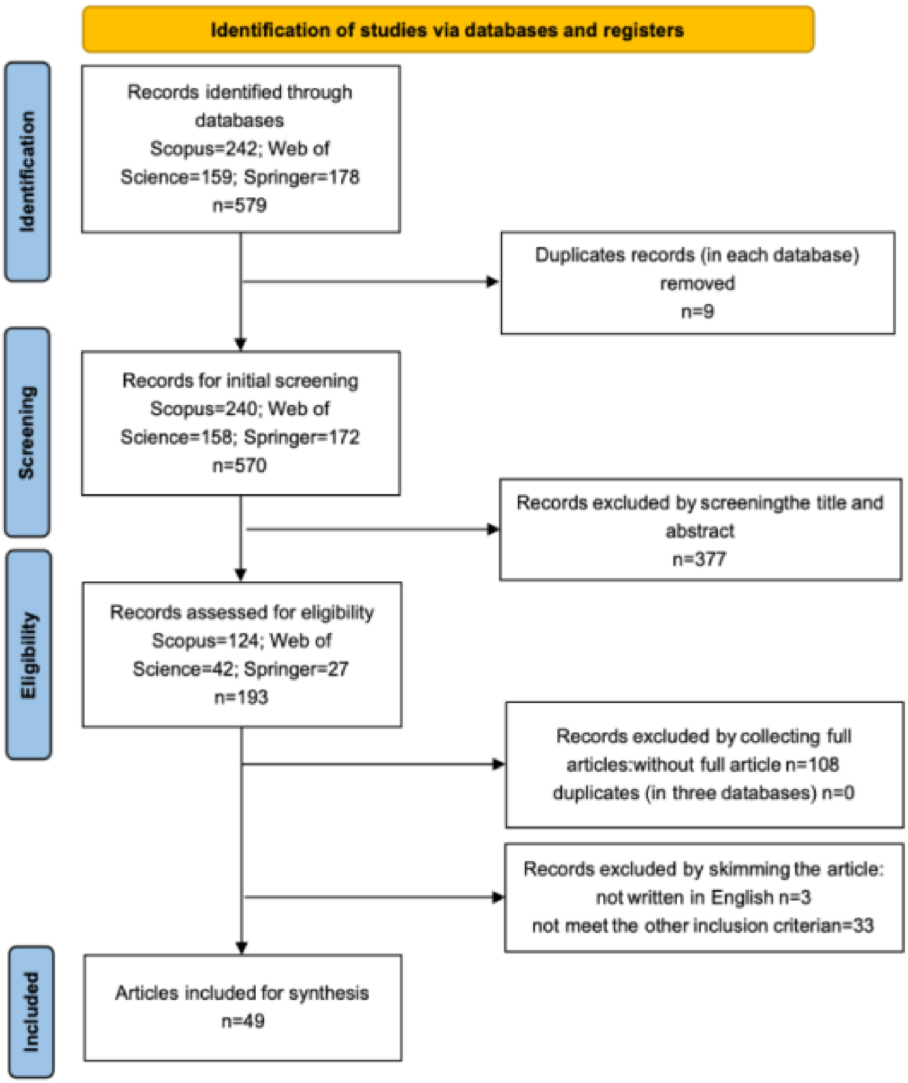

Figure 2. PRISMA flow chart

Eligibility Criterion

As shown in Table 1, a set of inclusion and exclusion criteria are utilized to select appropriate research, thus maintaining the focus of the literature screening. Titles and abstracts are screened and 377 papers are excluded from a total of 570 papers. The remaining 193 papers are assessed for eligibility. Based om these, 144 papers failed the inclusion criteria, 0 duplicate. Ultimately, 49 studies are selected for inclusion in this systematic evaluation. An overview of the PRISMA-based research selection process is shown in Figure 2.

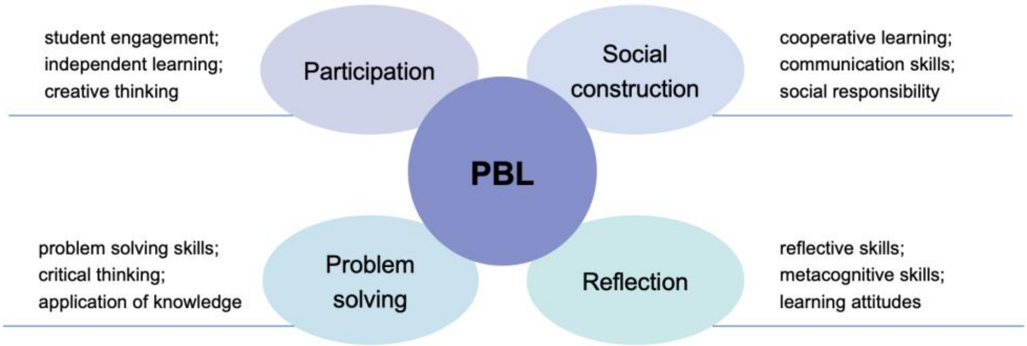

Figure 3. Analytical framework of PjBL and coding scheme

Data Extraction and Data Synthesis

This research uses an analytical framework based on a constructionist learning module, as shown in Figure 3. In order to explore the use of project-based learning (PjBL) in early science education and its implications. The framework focuses on four core elements, active learner engagement, social construction of knowledge, real-world problem solving, and reflection on the learning process (Piaget, 2013; Daneshfar & Moharami, 2018; Bajracharya, 2019). Allowing for detailed analysis and comparison of research in the literature. Each element is further subdivided into specific indicators, such as student engagement, cooperative learning, and problem solving (Lave & Wenger, 1991; Kolb, 2014). Through this analytical framework, this review aims to shed light on the effectiveness and challenges of PjBL in promoting active learning and scientific literacy among students in early science education.

Results and Discussion

In this section, it is explained the results of research and at the same time is given the comprehensive discussion.

Year of Publication

This systematic review analyzed a total of 49 pieces of literatures. The literatures focuse on studies of project-based learning (PjBL) implementation in early science education. These studies are carefully selected based on predetermined inclusion and exclusion criteria to ensure study relevance and quality. The range of publication years in the literatures are from 2019 to 2023. According to Figure 4, the number of studies showed a gradual increase, with a significant peak in 2023. The trend in figure 4 suggests that research interest in PjBL in early science education has increased in recent years. The increase in the number of studies in 2023 may indicate a higher emphasis on this educational approach. This is because a shift in educational focus or a reaction to new research findings in the field. This growing trend reflects researchers' awareness and recognition of the applied value of PjBL in promoting scientific literacy and preparing children for the challenges of the 21st century. As educators and researchers continue to explore and refine the implementation of PjBL in early science education, this educational approach will play an increasingly important role in shaping young children's future science learning.

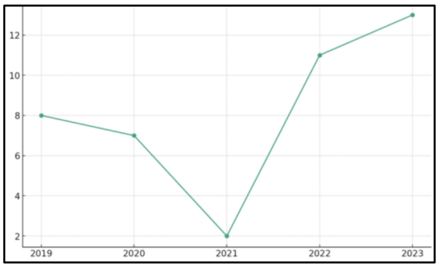

Figure 4. Distribution of publication years

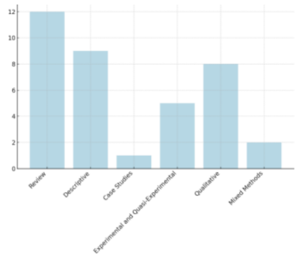

Figure 5. Research design and methodology

Research Design and Methodology

The analysis of the literature shows that these studies used a variety of research design methods. These included reviews, descriptive studies, case studies, experimental and quasi-experimental designs, qualitative studies and mixed methods. At the same time, these studies used different data collection methods, such as surveys, interviews, observations and assessments, and different data analysis techniques, ranging from qualitative thematic analysis to quantitative statistical analysis. Figure 5 shows the categories and corresponding numbers of research designs in the different literatures, highlighting the diversity of research methods for project-based learning in early science education.

Research on project-based learning (PjBL) in early science education has used a variety of research designs, reflecting the multifaceted nature of PjBL research. The literature review found that the methodologies of these studies fell into six main categories. Synthesis, descriptive and qualitative research are the most commonly used research methods. A total of 12 studies used integrative research methods, including systematic reviews, narrative reviews and literature reviews, to synthesise the existing literature and identify future research directions (Howitt et al., 2020; Christenson et al., 2020; Fenrich, 2022). A total of nine studies used a descriptive research design to provide detailed descriptions of PjBL implementation, student experiences and outcomes (Gealy et al., 2022; Jamali et al., 2023). Nine studies used qualitative research methods to explore the experiences and perceptions of students and teachers involved in PjBL through interviews, observations and content analysis (Das, 2020; Kallery et al., 2022; Goos et al., 2023). One study used a case study design to provide a specific PjBL implementation and outcomes (Amos et al., 2020). Five studies used experimental or quasi-experimental designs to assess the impact of PjBL interventions on student learning outcomes (Johnson, 2019; Chen et al., 2023; Cheng et al., 2023). Two studies combined quantitative and qualitative methods to gain a comprehensive understanding of the implementation of PjBL and its impact on early science education (Dinsmore & Fryer, 2023; Kang, 2019).

Participants

This study analysed this literature and produced a graph for the study population as shown in Figure 6. Figure 6 shows that the participants are divided into two categories, students and non-students. Students are mainly children of different ages and backgrounds. Non-students are mainly kindergarten teachers. As can be seen from the figure, 68.2% of the participants are children. More than half of this percentage proves that the focus of the study in the context of PjBL in early science education is student centred. The diversity of participants demonstrates the broad applicability of PjBL across educational levels and contexts.

This study also analysed the impact of PjBL on the research participants, producing graphs and charts to present this clearly. Figure 7 shows that PjBL had a significant impact on children's social construction and problem-solving skills. Both impacts are seen in terms of improved cognitive skills, motivation to participate in activities, practical skills, teamwork skills, science practice and communication skills. The variety of impacts highlights the multiple benefits of project-based learning in early science education.

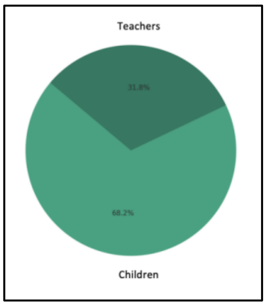

Figure 6. Distribution of participants

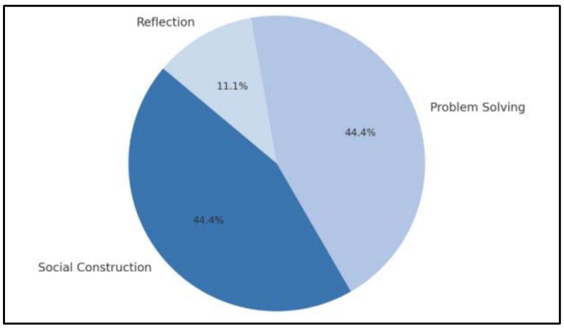

Figure 7. Categorization of impact on children

Implementation of PjBL

In summary, there are different ways to implement PjBL. Figure 8 illustrates different scenarios of PjBL implementation in different studies. A variety of approaches to implementing PjBL in early science education are also illustrated in Figure 8, including inquiry-based pedagogy, collaborative learning and game-based learning (Ortiz-Revilla et al., 2020; Chen et al., 2023; Li & Wong, 2023). This reflects the flexibility and adaptability of PjBL in different educational settings and objectives.

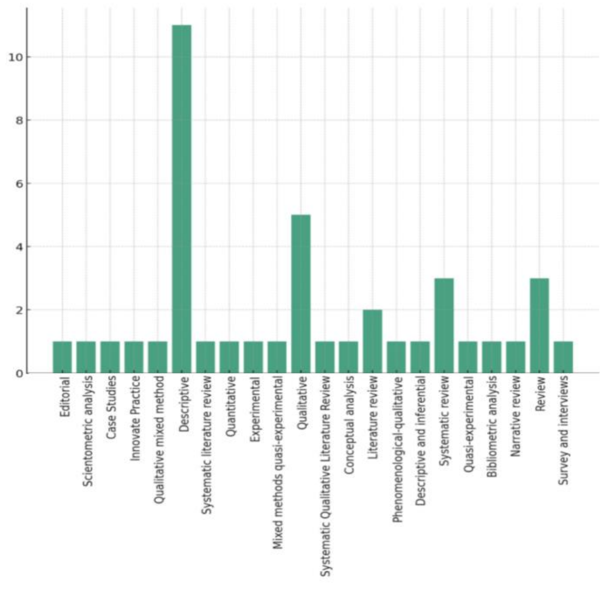

Figure 8. PjBL Implementation Categories

Across the 49 papers, project-based learning (PjBL) has been implemented in a variety of ways. Interdisciplinary approaches combine science with other disciplines, such as literature, to enhance learning through language interaction and improve children's communication skills (Chen et al., 2023). Hands-on STEM activities improve students' ability to acquire knowledge and solve problems in different areas of science, such as aerospace projects as an activity theme (Fenrich, 2022). Cooperative projects promote teamwork among children (Hsin & Wu, 2023). Inquiry-based learning approaches encourage students to take informed action based on their learning (Li & Wong, 2023). Digital tools and technologies create dynamic environments for resource development, information sharing and assessment, such as the Moodle platform (Ortiz-Revilla et al., 2020). Despite the positive results, three articles pointed out that PjBL also faces challenges in implementation, such as curricular constraints, communication barriers, and time management issues (Ortiz-Revilla et al., 2020; Skamp, 2022; Sun et al., 2022).

Effectiveness

In early science education, project-based learning (PjBL) has been recognised as an effective method for enhancing children's learning experiences. A literature review found that PjBL promotes the development of scientific understanding, critical thinking, and cooperative skills. This section will analyse the effectiveness of PjBL in detail.

Assessment of Teaching Effectiveness

PjBL enhances children's level of scientific understanding. Scientific understanding refers to children's mastery of scientific concepts and their ability to apply the scientific method. During PjBL, children learn about science and understand the scientific process more through hands-on practice. For example, a PjBL activity on plant growth allowed children to plant seeds themselves and observe the effects of growth under different conditions, leading to a deeper understanding of the concepts of photosynthesis and plant ecosystems. Studies have shown that children who participate in such programmes perform better on tests of scientific understanding than children who are taught through traditional methods (Kallery et al., 2022).

PjBL enhances children's critical thinking. Critical thinking, the ability to evaluate information and arguments, is an integral part of scientific inquiry. PjBL develops children's critical thinking skills by encouraging them to ask questions, analyse data and evaluate results. By observing children's performance in solving real-world problems, it was found that children's skills in problem solving and logical reasoning significantly improved by the end of the programme (Dinsmore & Fryer, 2023).

PjBL enhances children's cooperative skills. Cooperative skills refer to an individual's ability to communicate effectively, share resources, and work together to solve problems in a team environment. PjBL typically requires children to work cooperatively in groups to complete project tasks. This not only promotes the development of social skills but also enhances the experience of teamwork. It was found that children involved in PjBL performed significantly better than non-PjBL participants in terms of teamwork and leadership skills, especially when required to coordinate and manage project resources (Cheng et al., 2023).

Comparative Analyses

Project-based learning (PjBL) differs significantly from traditional direct instruction teaching methods in several ways. Particularly in terms of enhancing motivation, depth of learning and persistence of learning. A detailed comparison of these two teaching methods follows.

Firstly, there is the aspect of enhancing learning motivation. Whereas direct instruction typically focuses on teacher direction and control, project-based learning (PjBL) provides more child autonomy and choice, which is essential for enhancing children's motivation to learn. In a PjBL setting, children feel the practical application of their learning by engaging in real-world problem solving, which enhances their intrinsic motivation. The study revealed that children who participated in PjBL showed higher levels of engagement and motivation in completing tasks. This group of children reported feeling that their learning was more meaningful and relevant (Bell, 2010).

The next aspect was the depth of learning. PjBL promotes deeper learning than direct instruction. Rather than just passively receiving knowledge, children need to actively explore, research and apply their learning to complex problems. This deeper learning process helps children build rich knowledge structures and better understanding. Comparative studies have found that children experiencing PjBL outperform children receiving traditional instruction on tests of conceptual understanding, especially in science and maths (Han et al., 2015).

Finally, there is the aspect of persistence of learning.A key advantage of PjBL is that it promotes persistence of learning. Children working on projects are able to repeatedly apply and reflect on learnt concepts over a long period of time, and this repetition and reflection contributes to the long-term retention of knowledge. As opposed to direct instruction teaching, PjBL enhances the internalisation and retention of learning by providing opportunities for practical application. Some long-term studies have shown that children involved in PjBL have significantly higher recall of learning content after one year than children who received only traditional instruction (Han et al., 2015).

Influence of Variables

According to a systematic review of the literature, the effectiveness of project-based learning (PjBL) is influenced by a variety of variables, including the age of the children, the experience of the teacher, the availability of resources, and the teaching and learning environment and resourcing. These factors exhibit complex dynamics in different teaching and learning scenarios that affect the implementation and effectiveness of PjBL.

Children's age has a significant impact on PjBL acceptance and engagement. Younger children may require more structured instruction and support to effectively participate in project activities, while older children are able to handle more complex tasks and demonstrate higher levels of autonomy. The study suggests that appropriately adjusting the difficulty of the programme and the age of the children can significantly improve children's sense of engagement and learning outcomes (Lave & Wenger, 1991).

Teachers' experience and familiarity with the PjBL methodology directly affects the quality of project design and implementation. Experienced teachers are usually more effective in integrating interdisciplinary content, designing challenging and engaging projects, and providing the necessary support and guidance. One study found that classes with experienced teachers demonstrated higher motivation and achievement in PjBL activities (Lave & Wenger, 1991).

The availability of teaching resources is one of the key factors in the successful implementation of PjBL. Resources include not only physical facilities such as laboratory materials and technological tools, but also time resources and freedom of curriculum design. Resource-rich schools are able to provide more diverse project options and deeper exploration opportunities. Studies have shown that children in resource-rich environments perform significantly better in PjBL than resource-poor environments (Howitt et al., 2020; Gealy et al., 2022).

The teaching and learning environment and the allocation of resources have a decisive impact on the effectiveness of PjBL. A supportive learning environment should include an appropriate spatial layout, adequate lab materials, access to external experts, and technical support, all of which can significantly enhance learning. In addition, integrating information technology into PjBL can increase children's participation and the variety of projects. Studies have shown that learning outcomes and child satisfaction are significantly higher in PjBL than in traditional classroom environments in environments equipped with modern technology and appropriate instructional materials (Gealy et al., 2022).

In this systematic review, we explore in detail the use of project-based learning (PjBL) in early science education and its significant enhancement of children's scientific understanding, critical thinking, and cooperative skills. The study confirms that PjBL not only enhances children's specific science knowledge, but also promotes their thinking and cooperative skills in solving real-world problems. In addition, PjBL demonstrated significant benefits in enhancing motivation, deepening learning understanding, and maintaining learning persistence compared to traditional direct instruction instruction. These results underscore the importance of the practical application of PjBL in early education and provide important guidance for future educational models.

Discussion

This part provides an in-depth discussion of the overall findings, with particular attention to the answers to the research questions and recommendations for future research and practice.

The current preschool implementation of PjBL modules and methods (RQ1)

This systematic review identified several PjBL design modules and approaches that have been widely implemented in early science education, including inquiry-based pedagogy, collaborative learning, game-based learning, and interdisciplinary approaches. Each of these approaches has its own characteristics and strengths and offers diverse pathways for promoting children's learning in science.

About inquiry-based pedagogy. This approach encourages children to learn science through experimentation and exploration, enabling them to interact directly with the learning materials and experiments, thereby enhancing understanding and retention. The inquiry-based approach stimulates children's curiosity and desire to explore, and makes the learning process more natural and responsive to children's learning characteristics (Piaget, 2013; Krajcik & Czerniak, 2018).

Collaborative learning emphasises group support and communication, and through teamwork to complete science projects, children not only learn scientific knowledge, but also develop social skills and team spirit. This model helps children learn to communicate, negotiate, and resolve conflicts in a practical way, and is an effective way to develop 21st century skills (Lave & Wenger, 1991; Laal & Ghodsi, 2012).

In addition, game-based learning. Through the combination of games and science activities, children learn science concepts and skills while playing, and this approach enhances learning in a fun and engaging way. Game-based learning is particularly suitable for young learners because it is consistent with children's psychological and behavioural characteristics and enables effective learning in a relaxed and enjoyable environment (Howitt et al., 2020).

Finally, some studies refer to interdisciplinary approaches. Interdisciplinary learning promotes deeper learning by integrating knowledge points from different disciplines to help children make connections between knowledge. This approach enables children to apply knowledge and skills from multiple disciplines in solving complex problems and enhances their integrative skills (Goos et al., 2023).

Although each of the above approaches has its own strengths, PjBL, as an integrative learning strategy, is able to combine these strengths in a more holistic way. pjBL not only incorporates elements of inquiry-based learning, but also naturally blends collaborative and interdisciplinary learning, as well as introduces the fun and motivation of playful learning through the playful design of project activities. In early science education, the implementation of PjBL can provide children with a more authentic and challenging learning environment in which they can naturally acquire scientific knowledge and skills in the process of solving real-world problems, while developing essential 21st century skills such as critical thinking, creativity, teamwork and communication skills.

Therefore, the implementation of PjBL is not only a supplement to existing teaching methods, but also a necessary innovation, which can effectively improve the quality of education and better meet the needs of modern education. Through comparative analyses and empirical studies, this study highlights the importance and urgency of implementing PjBL in early science education and provides new directions and ideas for future educational practice and research.

The impact and challenges of implementing PjBL on children (RQ2)

This systematic review reveals the positive impact of PjBL on children's critical thinking and cooperative skills in early science education. However, despite the significant educational value of PjBL, the challenges encountered during implementation should not be overlooked.

On the one hand, PjBL promotes children's critical thinking.PjBL develops children's critical thinking skills by providing authentic problem situations that motivate them to explore and solve problems on their own. This approach encourages children to develop their analytical and critical skills by questioning available information, exploring multiple solutions, and evaluating the validity of the results (Dinsmore & Fryer, 2023). On the other hand, PjBL promotes the development of children's cooperative skills. Through team projects, children learn how to cooperate with others, share resources, resolve conflicts, and work together to complete tasks in a PjBL setting. This interaction not only enhances teamwork skills, but also improves their social and communication skills (Lave & Wenger, 1991; Laal & Ghodsi, 2012).

However, PjBL has encountered challenges in its implementation. Resource availability is a major barrier to PjBL implementation. In schools with limited resources, lack of adequate materials and facilities may limit the scope and quality of the programme. In addition, the lack of technological resources may hinder the implementation of quality projects (Gealy et al., 2022; Sun et al., 2022). Teachers are key to the successful implementation of PjBL. However, not all teachers have received professional training on how to effectively design and instruct PjBL. This lack of training can lead to poorly implemented projects that affect learning outcomes (Gealy et al., 2022). Children's participation can also affect research outcomes. Although PjBL aims to enhance children's motivation through engagement and hands-on activities, individual children may become bored or disinterested in long-term projects (Dinsmore & Fryer, 2023). Teachers need to develop strategies to maintain children's participation and interest, which requires a high degree of creativity and adaptability.

These challenges can affect the effectiveness of PjBL implementation. In order to overcome these challenges and optimise the implementation of PjBL, it is necessary for schools to invest in PjBL resources and develop teacher training in the teaching of PjBL. It is through these measures that PjBL can realise its potential educational benefits in early science education and provide sustained support for children's overall development.

Research Limitations and Challenges

While this systematic review provides valuable insights into the use and effectiveness of PjBL in early science education, there are a number of research limitations that may affect the interpretation and generalisability of the results.

Sample selection bias. Since review articles are primarily based on published academic literature, there may be a publication bias, i.e., a tendency to report positive findings. In addition, most of the studies focused on specific educational settings or geographical regions, which may not fully reflect the reality in different global contexts. This bias may lead to overly optimistic assessments of the effects of PjBL (Mergendoller & Thomas, 2005; Savery, 2015).

The uneven geographical distribution of the study sample is also an important limitation. Most of the studies were from high-income countries, which usually have better educational resources and more sophisticated education systems. Therefore, findings may not be applicable to low-income countries with fewer resources (Das, 2020). Differences in educational contexts, such as teacher strength, educational funding, and educational policies, may affect the effectiveness of PjBL implementation (Eshach, 2006; Savery, 2015).

Methodological limitations of data collection. In many of the studies included in the review, data collection methods relied on qualitative descriptions, self-report questionnaires, or small-scale observations, which may be subject to subjectivity. For example, teachers' and children's feedback may be influenced by their expectations of the effects and not fully reflect the actual effects of the programme (Sun et al., 2022).

Diversity of research methods. Among the studies reviewed, there was a great deal of diversity in research design, types of PjBL programmes implemented, evaluation criteria, and assessment tools used. While this diversity enriches the findings, it also makes it difficult to draw direct comparisons from across studies, limiting the general conclusions that can be drawn from systematic reviews (Eshach, 2006; Sun et al., 2022).

Given these limitations, future studies should focus on the diversity and balance of sample distribution, including countries and regions with different economic levels and cultural backgrounds, to enhance the general applicability of findings. At the same time, more standardised and objective methods of data collection and analysis should be used to enhance the reliability and accuracy of the findings. In addition, cross-cultural and multi-regional comparative studies are encouraged to assess the effectiveness and adaptability of PjBL implementation globally more comprehensively.

Strategies and Recommendations

Based on the limitations and challenges of this study, this section presents specific strategies and recommendations for improvement with the aim of optimising the design and implementation of project-based learning (PjBL).

Effective utilisation of available resources is key to the successful implementation of PjBL. Schools can consider using local materials and community resources as project components to reduce costs while increasing the relevance and practicability of teaching resources (Gealy et al., 2022; Goos et al., 2023). In addition, teachers are encouraged to use flexible PjBL teaching strategies to adapt the programme content to the specific needs and interests of the children. By introducing digital tools and technologies, such as online collaboration platforms and educational software, PjBL can be made more flexible and engaging while allowing for wider information sharing and innovation (Li & Wong, 2023; Ortiz-Revilla et al., 2020). Conduct teacher training programmes to ensure continuous professional development. It is important to ensure that teachers receive ongoing training on PjBL. Training should include basic design and implementation skills for project-based learning, but also how to enhance children's engagement and assess children's learning outcomes (Gealy et al., 2022; Sun et al., 2022). In addition, teacher training should include hands-on workshops, peer observations, and regular feedback sessions (Sun et al., 2022).

By implementing these strategies, the quality and effectiveness of PjBL implementation in early science education can be effectively improved while creating a more interactive and productive learning environment for teachers and children.

Future Research Directions

Future research could investigate the following three areas.

Firstly, future research should explore differences in children's responses to PjBL and learning outcomes across age groups. Research could consider how the design of PjBL can be adapted to the cognitive and social developmental stages of different age groups to maximise its educational impact. For younger children, the focus might be on gamification and visual stimulation, whereas for older children, more complex scientific concepts and project tasks could be introduced (Lave & Wenger, 1991; Howitt et al., 2020).

Second, systematic evaluation of PjBL design elements. Although existing research has identified a variety of effective PjBL modules and methods, there is a need to systematically assess how these design elements individually or collectively affect learning outcomes (Ortiz-Revilla et al., 2020; Fenrich, 2022). Future research could use experimental and controlled study designs to clarify which specific item components best promote scientific understanding and skill development.

Finally, the integration of gamified learning. Examining how gamified learning strategies can be more effectively integrated into PjBL, particularly in terms of motivating and engaging children. Gamification can increase the fun and interactivity of learning. Research should assess how these elements affect children's long-term commitment to learning and scientific knowledge acquisition (Li & Wong, 2023).

With the above proposed directions for future research, we can gain a deeper understanding of the effectiveness of PjBL in different contexts and how to enhance the effectiveness of this teaching strategy.

Conclusion

This systematic review explores the use of project-based learning (PjBL) in early science education and validates the effectiveness of PjBL in promoting children's critical thinking and cooperative skills. Findings show that PjBL greatly stimulates children's interest and motivation in learning by providing a hands-on, interactive, and interdisciplinary learning environment.

The study demonstrated that PjBL effectively integrates inquiry-based pedagogy, collaborative learning, game-based learning, and interdisciplinary approaches, all of which are key pedagogical methods for enhancing the quality of early science education. Through these methods, PjBL enhances children's scientific knowledge and develops their critical thinking and problem-solving skills. Incorporating PjBL into early science education can provide more hands-on opportunities for children to develop essential 21st century skills such as creativity, teamwork, and communication in authentic learning situations. PjBL is not only a pedagogical approach, but also an educational innovation that promotes active learning and in-depth inquiry through authentic project-based tasks. Implementing PjBL in early education can provide a solid foundation for children's holistic development and help them build their interest and understanding of science, which can have a long-term impact on both their future academic and professional careers. In addition, this review suggests strategies on how to optimise the implementation of PjBL, including using existing resources, providing teacher training and support, and integrating new technologies. These recommendations not only provide practical guidance for educational practitioners, but also offer new directions for future research, especially in exploring technology integration and cross-cultural research.

In summary, this study examines the use of project-based learning (PjBL) in early science education and its effectiveness, with a particular focus on the development of critical thinking and cooperative skills. As such, this study contributes to existing theories and research contexts. In terms of theory, this paper highlights the practical application of constructivist learning theory in PjBL through a systematic review that demonstrates how learners construct knowledge in an interactive and problem-solving process. Furthermore, by linking PjBL to the need for 21st century skills, this study provides a new perspective on how PjBL can help prepare students to face the challenges of the modern world. These theoretical contributions not only enhance the understanding of PjBL pedagogy, but also provide important theoretical support for future educational models. In terms of context, this study clarifies the current status and trends in the application of PjBL in early science education, identifying key barriers and challenges in the implementation process. By analysing in detail national and international research differences, this paper demonstrates the adaptability and flexibility of PjBL in different educational systems, emphasising the impact of culture and resource availability on PjBL effectiveness. This contextual contribution provides educational policy makers and practitioners with a basis for optimising PjBL implementation strategies according to regional conditions and helps to promote and deepen the application of PjBL globally.

Overall, this study clarifies the understanding of the application of PjBL in early science education and highlights the dual value of PjBL in theory and practice. The findings have important implications for educational researchers, policy makers, and practitioners as they provide practical insights into how PjBL can be used to promote the development of children's critical skills and provide a solid foundation for future research and application in this area.

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