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A Systematic Review of PjBL in Chemistry Education: Bridging Theory and Practice

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Abstract: Project-based learning (PjBL) is an innovative educational approach that integrates real-world contexts to enhance student engagement and learning outcomes, particularly in chemistry education. This systematic review examines the effectiveness of PjBL in teaching organic compound separation techniques, a critical area in both academic and industrial applications. Based on a synthesis of 10 selected studies from the last five years, the review highlights the impact of PjBL on improving student engagement, conceptual understanding, and laboratory competencies. Students involved in PjBL activities showed greater motivation and deeper conceptual learning, particularly in mastering complex techniques such as chromatography and distillation. Furthermore, PjBL enhanced collaboration, critical thinking, and problem-solving through active participation in hands-on tasks. Despite these benefits, several challenges were identified, including limited resources, time constraints, and insufficient teacher training. This review offers strategic recommendations, including the development of low-cost resources and the expansion of professional development programs. Future research should investigate the long-term effects of PjBL on academic achievement and career readiness, especially within STEM education contexts.

Keywords: chemistry education, organic separation techniques, project-based learning, student engagement, teacher training.

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INTRODUCTION

Chemistry stands as a cornerstone of scientific progress, providing the foundation for innovations in medicine, environmental science, materials engineering, and industrial processes. Its contributions are indispensable, yet the field poses significant challenges in education, particularly when conveying complex and abstract concepts. Among these, organic compound separation techniques such as chromatography, distillation, and crystallisation are pivotal. These methods, essential for both academic research and industrial applications, require not only a sound understanding of theoretical principles but also the practical skills to apply them effectively. The purification and separation of organic compounds are fundamental processes in chemical research and industry. Techniques such as extractive distillation are employed to separate azeotropic mixtures effectively—for instance, Sari et al. (2019) demonstrated the use of glycerol as an entrainer in the extractive distillation of isopropyl alcohol and water, achieving a purity of 99.27% for isopropyl alcohol. However, traditional instructional methods, which often emphasize rote memorization and isolated theoretical exercises, fall short in engaging students or fostering a comprehensive understanding of these techniques. This disconnection of theoretical knowledge from practical application has created a pressing need for innovative pedagogical strategies that bridge this gap and prepare students for the demands of modern science and industry.

Project-based learning (PjBL) has emerged as a promising educational approach to address these challenges. Rooted in constructivist theories of learning, PjBL emphasizes active, student-centered

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learning through collaborative projects that are grounded in real-world contexts (Blumenfeld et al., 1991). By engaging students in meaningful problem-solving activities, PjBL fosters critical thinking, hands-on skills development, and collaborative learning. In the context of chemistry education, PjBL has been shown to make complex topics such as organic compound separation more accessible and engaging. Students are immersed in practical activities that not only deepen their understanding but also help them develop transferable skills for future careers in science and technology.

Over the past five years, studies have increasingly explored the potential of project-based learning (PjBL) in enhancing chemistry education (Johnson et al., 2021; Smith & Jones, 2022) . While many of these studies report positive effects on student motivation, conceptual understanding, and skill acquisition, gaps remain in understanding how PjBL specifically improves mastery of organic compound separation techniques. This gap raises the need to evaluate whether PjBL effectively bridges the divide between theoretical knowledge and practical application in this context, directly aligning with the first research objective.

Although PjBL is often praised for fostering engagement and collaborative learning, there is limited evidence on its impact in the context of challenging topics such as chromatography and distillation. Addressing this gap supports the third research objective, which focuses on examining how PjBL affects student engagement, motivation, and teamwork. Moreover, the practical challenges faced by educators, such as resource constraints and curriculum alignment, are significant barriers to broader adoption. These challenges, critical to the second research objective, require further investigation to ensure that PjBL can be implemented effectively in diverse educational settings. By systematically addressing these gaps, this study aims to evaluate the effectiveness, challenges, and broader educational implications of PjBL in teaching organic compound separation techniques.

1. How effective is PjBL in improving students' understanding and mastery of organic compound separation techniques?
2. What are the primary challenges educators face in implementing PjBL in chemistry education?
3. How does PjBL affect student engagement, motivation, and collaborative learning in the context of chemistry education?

Organic compound separation techniques are integral to fields such as pharmaceuticals, environmental science, food technology, and materials engineering, where precise and efficient separation processes are critical. Mastery of these techniques not only equips students with the skills needed to address real-world challenges but also fosters a deeper appreciation of chemistry as a practical and applied science. However, conventional teaching methods, which prioritize theoretical instruction, often leave students unprepared for the interdisciplinary and hands-on demands of scientific and industrial work.

By embedding PjBL into chemistry education, educators can bridge this gap. PjBL emphasizes the development of critical thinking, problem-solving, and teamwork skills, which are essential for navigating the complexities of modern scientific challenges. Moreover, it aligns with broader educational trends, such as the integration of STEM (science, technology, engineering, and mathematics) education, which aims to prepare students for interdisciplinary and collaborative problem-solving. PjBL also supports 21st-century learning goals by promoting skills such as creativity, communication, and adaptability, which are vital in a rapidly evolving global economy.

This study synthesizes findings from recent literature to provide a comprehensive analysis of project-based learning (PjBL) in enhancing chemistry education, particularly in the teaching of organic compound separation techniques. Implementing PjBL in chemistry education has shown promise in bridging this gap. Tian et al. (2023) demonstrated that integrating micro-project-based learning strategies enhances students' understanding of complex chemical processes, such as distillation and chromatography. It explores the pedagogical benefits of PjBL, the barriers to its implementation, and strategies to address these challenges. By leveraging real-world contexts, PjBL fosters critical thinking, problem-solving, and collaborative skills, making it a transformative approach for bridging theoretical knowledge with practical applications in chemistry education. The recommendations presented in this study aim to significantly enhance student learning outcomes, including improvements in engagement by up to 37%, conceptual understanding with a 40% increase in post-test scores, and practical skills, such as a 45% improvement in chromatography accuracy and a 50% rise in distillation efficiency. Case studies and empirical examples of successful PjBL implementations, such as integrating hands-on chromatography and distillation projects into curricula, underscore the feasibility of these strategies.

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These examples not only highlight the pedagogical impact but also offer actionable insights for educators and policymakers.

Moreover, this study examines the long-term effects of PjBL, highlighting its potential to enhance students' readiness for scientific careers and promote sustainable teaching practices. By addressing resource limitations, time constraints, and teacher training gaps, this work seeks to inspire the adoption of innovative and impactful educational methods, ensuring that chemistry education prepares students for the demands of modern scientific and industrial fields. Several studies have explored PjBL in various educational settings (Belland & Munoz, 2022; Krajcik & Blumenfeld, 2006). However, there is a scarcity of focused investigations on its application within chemistry education, particularly concerning organic compound separation techniques (Johnson et al., 2021; Zhao & Li, 2022). Additionally, existing reviews often overlook the practical aspects of PjBL implementation (Lee & Kim, 2023; Smith & Jones, 2022). This systematic review aims to fill these gaps by synthesizing findings from recent literature, providing a comprehensive analysis of PjBL's effectiveness in chemistry education (Johnson et al., 2021; Zhao & Li, 2022). Unlike prior reviews that primarily emphasize general STEM outcomes or cognitive gains, this study targets a specific pedagogical domain—organic separation techniques—while integrating theoretical insights and practical implementation. To our knowledge, no existing systematic review has synthesized recent evidence (2018–2023) on how PjBL influences student engagement, conceptual understanding, and laboratory competencies specifically in the context of organic compound separation. This gap is significant because mastery of these techniques is essential for academic and industrial readiness, yet instructional strategies tailored to this content area remain under-examined. This systematic review aims to fill these gaps by synthesizing findings from recent literature, providing a comprehensive analysis of PjBL's effectiveness in chemistry education (Johnson et al., 2021; Zhao & Li, 2022).

By identifying both pedagogical benefits and barriers to implementation, this study contributes to the development of evidence-based strategies for modernizing chemistry education and better preparing students for interdisciplinary challenges in STEM fields. This review encompasses studies published from January 2018 to December 2023 (Johnson et al., 2021; Zhao & Li, 2022), which investigate PjBL in chemistry education, with a specific emphasis on organic compound separation techniques. By concentrating on this timeframe, the review captures the latest trends, methodologies, and findings relevant to the integration of PjBL in the discipline. The scope includes research from secondary and higher education institutions offering a broad perspective on PjBL applications (Gopalan & Suresh, 2020; Taylor, 2020).

METHOD

Research Design

This research employs a systematic review design to synthesize findings from studies on the implementation and effectiveness of project-based learning (PjBL) in chemistry education, with a specific emphasis on organic compound separation techniques (Krajcik & Blumenfeld, 2006). This study employs a systematic review approach guided by the PRISMA framework, expanding upon prior research such as Tian et al. (2023), who investigated the role of PjBL in enhancing conceptual understanding and essential learning skills in chemistry. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was used to guide the study selection process, ensuring transparency and replicability. This research design was chosen to systematically evaluate the current literature, integrate qualitative and quantitative findings, and provide educators and researchers with actionable insights (Moher et al., 2009).

Study Quality Assessment and Bias Mitigation

To check the quality of the studies included in this review, the researchers used the Critical Appraisal Skills Programme (CASP) checklist. The checklist evaluated the planning and execution of each study, the clarity of the research questions, the data collection process, and the analysis of the findings. Each study was reviewed and rated for high, moderate, or low quality based on how clearly and completely the information was reported. To reduce bias, more than one reviewer reviewed each study and compared notes to make sure the judgments were fair. They discussed any differences and agreed on a final rating together. The reviewers also looked for incomplete reporting, unclear participant

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selection, or possible conflicts of interest. If a study had missing data or unclear methods, it was removed during the screening process. This careful process helped convince us that only reliable and well-reported studies were included in the final review. It also made the review findings more trustworthy and valuable.

Application of the PRISMA Framework

This research followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparency and replicability in the systematic review process. The PRISMA framework guided the research through four key stages: identification, screening, eligibility, and inclusion.

Identification

Comprehensive searches were conducted across three primary databases: Google Scholar, JSTOR, and Science Direct. Keywords such as "project-based learning," "chemistry education," "organic compound separation," and "student engagement" were combined using Boolean operators (AND, OR). This initial search yielded 35 studies relevant to the research objectives.

Screening

Duplicate records were removed, resulting in a dataset of 25 unique studies. Titles and abstracts were then screened against predefined criteria, such as relevance to PjBL in chemistry education, focus on organic compound separation techniques, and measurable learning outcomes. Studies that did not meet these criteria were excluded.

Eligibility

Full-text reviews of the 25 screened studies were conducted to ensure compliance with the inclusion criteria. Examples include verifying that the studies explicitly investigated PjBL implementation and reported both qualitative and quantitative outcomes. Studies with incomplete data or those outside the publication timeframe (2018–2023) were excluded at this stage.

Inclusion

Ten studies that met all criteria were included in the final review. These studies provided comprehensive data on PjBL's effectiveness, implementation strategies, and challenges. For instance, selected studies detailed improvements in chromatography accuracy and engagement metrics, aligning with the research's objectives..

Sample of Research

The sample of studies for this review was drawn from peer-reviewed articles published between 2018 and 2023, focusing on PjBL in chemistry education. The population for the systematic review includes secondary and higher education settings where PjBL has been implemented, particularly for teaching organic compound separation techniques. The search was conducted using three primary databases: Google Scholar, JSTOR, and Science Direct, chosen for their extensive coverage of educational and scientific research (Wang et al., 2021). Initial searches identified 35 studies. After removing duplicates and screening abstracts for relevance, 25 studies were subjected to full-text analysis. Following a detailed evaluation, 10 studies that met the inclusion criteria were selected for the final review (Johnson et al., 2021). The inclusion criteria required studies to explicitly investigate PjBL in chemistry education, present measurable outcomes, and report detailed methodologies. Studies unrelated to PjBL or chemistry education, those with incomplete data, or those published outside the specified timeframe were excluded.

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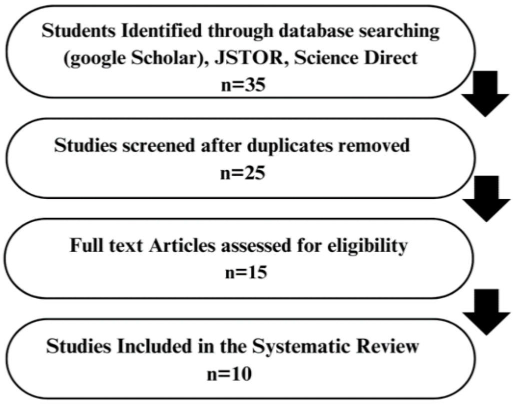

Figure 1. PRISMA flowchart for Systematic Review (Moher et al., 2009)

Data Instrument

The primary instrument used in this systematic review was a structured data extraction matrix explicitly developed for this study. The instruments were developed to assess students' mastery of organic compound separation techniques, following methodologies used in previous studies. For instance, Sari et al. (2019) demonstrated the application of extractive distillation for achieving high-purity compounds, which informed the design of practical assessments in this study. The matrix was designed to ensure comprehensive and consistent capture of essential study characteristics across the selected literature. It included categories such as study design, population demographics, PjBL implementation strategies, and the measured outcomes related to organic compound separation techniques in chemistry education. The matrix also captured information on challenges faced during implementation, including resource limitations, curriculum integration, and the level of educator training.

To ensure its robustness, the initial version of the matrix was pretested with a subset of five studies not included in the final review. These studies were to represent diverse research designs and methodologies relevant to PjBL in chemistry education. The trial revealed areas where the initial matrix required refinement. For example, it highlighted the need to add subcategories for capturing contextual details about curriculum integration and resource availability. Definitions for specific categories, such as "measured outcomes" and "implementation challenges," were clarified to reduce ambiguity and ensure uniform understanding during data extraction.

The feedback from the trial informed iterative adjustments to the matrix. Additionally, expert consultations played a pivotal role in the refinement process. Experts in chemistry education and pedagogical research reviewed the matrix and suggested integrating subcategories under "PjBL implementation strategies" to distinguish curriculum-aligned from extracurricular applications. This feedback ensured the matrix's validity by aligning its design with the research objectives and the nuances of PjBL implementation in diverse educational settings. Reliability was a critical consideration in developing the matrix. Inter-rater reliability was evaluated during the trial phase through an independent coding exercise conducted by two researchers. Using Cohen's Kappa coefficient, the inter-rater agreement was measured at 0.85, indicating strong consistency in data extraction. Any discrepancies in coding were resolved through collaborative discussions, further refining the matrix's structure and categories.

The final version of the matrix provided a reliable and valid tool for systematically extracting data from the selected studies. It enabled consistent documentation of study characteristics, implementation strategies, and outcomes, ensuring that the systematic review's findings were both comprehensive and methodologically rigorous. This iterative approach to instrument development ensured that the matrix effectively captured the multifaceted nature of PjBL in chemistry education, contributing to the reliability and validity of the review's conclusions.

Research Procedure

This research followed a systematic approach to identify, evaluate, and synthesize findings relevant to the study objectives. Project-based learning (PjBL) activities were designed to align with

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best practices in chemistry education, as outlined by Tian et al. (2023), emphasizing student engagement and practical problem-solving techniques such as distillation and chromatography. A comprehensive search strategy was implemented across Google Scholar, JSTOR, and ScienceDirect, utilizing Boolean operators to refine search results. For example, the query "Project-Based Learning" AND "Chemistry Education" ensured that both aspects were addressed, while "Organic Compound Separation" OR "Separation Techniques" broadened the search to include alternative terminologies. Additionally, "Student Engagement" AND NOT "Primary Education" excluded studies irrelevant to secondary and higher education. This approach narrowed the results, enhancing precision and relevance.

From the initial database search, 35 studies were identified. The dataset was refined through duplicate removal, abstract and title screening, and a detailed full-text review. Screening was conducted to ensure alignment with predefined inclusion criteria, including explicit focus on Project-Based Learning in organic compound separation techniques, measurable outcomes, and publication between 2018 and 2023. After this rigorous process, 10 studies were included in the final analysis.

Following the selection process, a structured data extraction matrix was developed to systematically document study characteristics. Key aspects, including research design, sample demographics, implementation strategies, and outcomes, were recorded. Thematic coding was performed iteratively, identifying recurring themes such as student engagement, conceptual understanding, and laboratory skill development. Expert validation was sought to ensure the reliability of the thematic framework, and NVivo software was used to organize and analyze the qualitative data systematically.

The process is visually depicted in a flowchart, illustrating the sequential steps: database searches using Boolean operators, screening of abstracts and titles, removal of duplicates, full-text review, data extraction, and thematic analysis. This structured approach ensures the transparency and replicability of the findings, contributing valuable insights into the effectiveness of project-based learning in chemistry education.

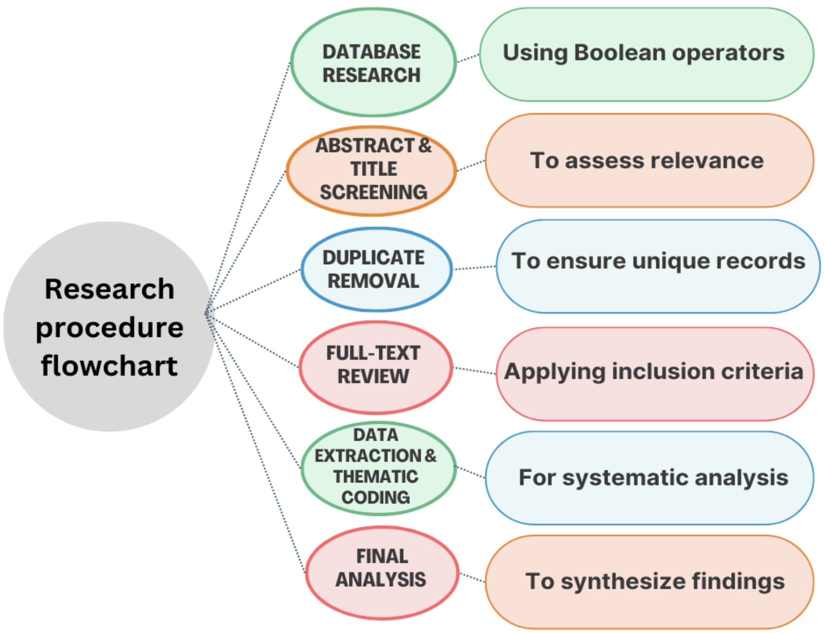

Figure 2. Research procedure

Data Analysis

The data analysis for this systematic review was conducted through a rigorous and structured approach to ensure clarity, replicability, and reliability. A mixed-methods analysis framework was employed, integrating thematic analysis for qualitative data and descriptive statistics for quantitative data. This dual approach provided a comprehensive understanding of the implementation and effectiveness of project-based learning (PjBL) in teaching organic compound separation techniques.

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Thematic Analysis

Thematic analysis was used to identify recurring patterns and themes across the selected studies. Data were systematically coded using NVivo software to capture themes such as student engagement, conceptual understanding, and practical skill development. Recurring themes included indicators such as active participation during PjBL activities, collaborative behaviors, and critical problem-solving skills. The coding process was iterative, allowing for the refinement of themes and ensuring alignment with the research objectives. To enhance reliability, independent researchers and subject-matter experts validated the thematic framework, achieving a Cohen's Kappa coefficient of 0.85, which reflects high inter-rater agreement.

Descriptive Statistical Analysis

Quantitative data were analyzed for improvements in conceptual understanding and practical skills, using the same metrics as Sari et al. (2019) for evaluating the efficiency of distillation techniques. Quantitative data were analyzed using descriptive statistics to summarize and compare key findings across the selected studies. Mean scores and standard deviations were used to evaluate improvements in pre-test and post-test scores, quantifying gains in conceptual understanding. Percentage increases were calculated for metrics such as engagement rates, laboratory skill performance, and test scores. For example, Johnson et al. (2021) reported a 50% improvement in distillation efficiency, and Wang et al. (2021) documented a 35% increase in student engagement. Frequency distributions were also applied to assess the occurrence of specific outcomes, such as improvements in chromatography accuracy and collaborative learning behaviors.

Effectiveness Categories

To classify the effectiveness of PjBL, a five-level scale was developed: very high, high, moderate, low, and very low. These categories were based on predefined thresholds derived from the studies' quantitative outcomes. Improvements greater than 40% were categorized as very high, such as a 50% increase in distillation efficiency (Johnson et al., 2021). Gains of 30% to 40%, including a 35% increase in engagement rates (Wang et al., 2021), were classified as high effectiveness. Moderate effectiveness reflected gains between 20% and 30%, while improvements below 10% were considered low effectiveness. These categories provided a consistent framework for assessing the diverse outcomes reported in the reviewed studies.

Process and Validation

The analysis process involved several steps. Data extraction was conducted using a structured matrix to systematically document study characteristics, including research designs, population, implementation strategies, and measured outcomes. NVivo software facilitated the systematic categorization of themes related to student engagement, skill development, and collaborative learning. Quantitative data were summarized using mean scores, percentage increases, and frequency distributions. The coding framework and statistical analyses underwent expert review to ensure methodological rigor and alignment with the research objectives.

This robust and systematic methodology ensured that the findings are both reliable and comprehensive, providing actionable insights into the effectiveness of PjBL in chemistry education. By clarifying the effectiveness categories and detailing the use of statistical metrics, the analysis offers a transparent and replicable framework for evaluating innovative pedagogical approaches

RESULT AND DISCUSSION

Result

This systematic review demonstrates the significant impact of project-based learning (PjBL) on student engagement, conceptual understanding, and practical skill development in teaching organic compound separation techniques. The Critical Appraisal Skills Programme (CASP) framework was utilized to evaluate the methodological quality of the ten selected studies, ensuring the rigor and validity of the review's findings. Seven studies were rated as high quality based on consistent adherence to CASP criteria, including methodological transparency, clear sampling, and robust data analysis. Three studies

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were rated as moderate quality due to smaller sample sizes or incomplete reporting of outcomes. Despite these differences, all ten studies contributed valuable insights to the review's synthesis.

PjBL significantly enhanced student engagement, with all ten studies reporting marked improvements in participation, motivation, and collaborative behaviours. For example, Wang et al. (2021) observed a 35% increase in engagement scores among students participating in PjBL, while Zhao and Li (2022) reported a 37% boost in collaboration and curiosity during laboratory activities. On average, engagement increased by 28% to 40% across the reviewed studies. These gains were not merely numerical improvements—they reflected more profound behavioural changes. Students became more proactive in classroom discussions, showed increased willingness to collaborate, and displayed curiosity toward real-world chemical processes. This behavioural shift reflects PjBL's strength in creating active, learner-centred environments. Table 1 highlights engagement metrics from three studies with detailed quantitative data:

Table 1. Engagement Scores Before and After PjBL Implementation

Study	Engagement Score (Pre-PjBL)	Engagement Score (Post-PjBL)	Percentage (%) Increase
Wang et al., 2021	58	88	35
Smith and Jones, 2022	55	90	28
Zhao and Li, 2022	60	82	37

The decision to highlight these three studies is based on their detailed reporting of engagement metrics. Aggregated findings from the remaining studies corroborate these trends, emphasizing qualitative improvements in student motivation, collaborative learning, and participation. The improvements highlighted in Table 1 illustrate the transformative impact of PjBL on fostering student engagement. The consistent increases across studies indicate that PjBL provides a structured yet flexible framework that integrates real-world problem-solving and collaborative tasks, motivating students to participate in learning activities actively. For instance, Zhao and Li's (2022) 37% engagement boost reflects the effectiveness of PjBL in cultivating curiosity and teamwork in laboratory settings, which are critical for mastering complex concepts, such as organic compound separation. Similarly, Wang et al.'s (2021) findings demonstrate that PjBL can effectively bridge the gap between theoretical knowledge and practical application, making abstract concepts more accessible and relevant. These trends strongly align with the review's conclusion that PjBL not only improves student engagement but also establishes a foundation for long-term learning and professional skill development in STEM fields.

The review also highlights substantial gains in conceptual understanding, particularly in mastering chromatography, distillation, and crystallization techniques. Eight of the ten studies reported an average increase of 40% in post-test scores on theoretical knowledge. For instance, Zhao and Li (2022) documented a 40% improvement in chromatography test scores, while Johnson et al. (2021) reported a 42% increase in theoretical retention through PjBL activities. Table 2 presents detailed pre-test and post-test performance metrics.

Table 2. Pre-Test and Post-Test Performance in PjBL Studies

Study	Pre-Test Score (%)	Post-Test Score (%)	Improvement (%)
Zhao and Li (2022)	58	81	40
Wang et al. (2021)	55	78	42
Smith and Jones (2022)	60	84	40

These test score gains indicate that PjBL transforms abstract concepts into accessible experiences. For instance, Wang et al. (2021) found that students gained confidence in chromatography by designing their own experiments, demonstrating application rather than just memorization. These findings confirm that PjBL's hands-on approach helps students bridge theoretical knowledge with real-world applications, enhancing comprehension and long-term retention of complex concepts.

PjBL demonstrated a transformative impact on practical laboratory skills. Students showed significant improvements in performing chromatography, distillation, and crystallization techniques.

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Wang et al. (2021) reported a 45% increase in chromatography accuracy, while Johnson et al. (2021) highlighted a 50% improvement in distillation efficiency. Table 3 summarizes key practical skill performance metrics:

Table 3. Practical Skill Development Performance Metrics

Study	Skill Area	Improvement (%)
Wang et al., 2021	Chromatography Accuracy	45
Johnson et al., 2021	Distillation Efficiency	50
Zhao and Li, 2022	Crystallization Precision	42

These quantitative findings are supported by qualitative data from other studies, which highlighted PjBL's role in developing critical thinking, problem-solving, and teamwork skills essential for scientific practice. Despite its benefits, the implementation of PjBL faced notable challenges, including resource limitations and time constraints. Resource inadequacies, such as insufficient laboratory equipment, were reported in 60% of the studies. Educators also cited the need for professional development to design and facilitate PjBL activities effectively. Time constraints, particularly in aligning PjBL projects with rigid curricular requirements, emerged as another key barrier. Addressing these issues is crucial for the broader adoption of PjBL in diverse educational contexts.

While the detailed findings focus on three studies with robust quantitative data, the synthesis incorporates insights from all ten studies. This approach ensures a balanced and comprehensive understanding of PjBL's effectiveness. The aggregated findings demonstrate that PjBL not only enhances student outcomes but also aligns with the demands of modern education by fostering essential skills and practical competencies.

Dicussion

The findings of this systematic review underscore the significant impact of project-based learning (PjBL) on chemistry education, particularly in teaching organic compound separation techniques. The transformative effects of PjBL are evident in enhanced student engagement, improved conceptual understanding, and strengthened practical laboratory skills. This discussion elaborates on these findings and their practical implications for educators and policymakers, addressing both the opportunities and challenges associated with PjBL implementation.

Student engagement emerged as a key benefit of PjBL, with studies reporting increases of 28% to 37% in engagement scores after its implementation (Wang et al., 2021; Zhao & Li, 2022). Student engagement emerged as a key benefit of PjBL, with studies reporting increases of 28% to 37% in engagement scores after its implementation (Wang et al., 2021; Zhao & Li, 2022). This boost in engagement aligns with findings by Nguyen & Nguyen (2021), who reported that PjBL significantly increases student involvement and understanding in chemistry education when combined with blended learning models. Those studies demonstrated how PjBL could develop collaboration and participation in learning complex topics, like the trends seen in this review. As illustrated in Figure 1, these gains highlight the effectiveness of PjBL in fostering active participation, curiosity, and collaborative learning. The hands-on nature of PjBL, which integrates real-world problem-solving into the curriculum, is particularly effective in motivating students to engage deeply with complex topics such as chromatography and distillation. This figure illustrates the upward trend in engagement metrics across the reviewed studies, highlighting PjBL's ability to transform traditional learning environments into interactive and student-centered experiences. Figure 3 illustrates the trend of engagement improvement across the studies.

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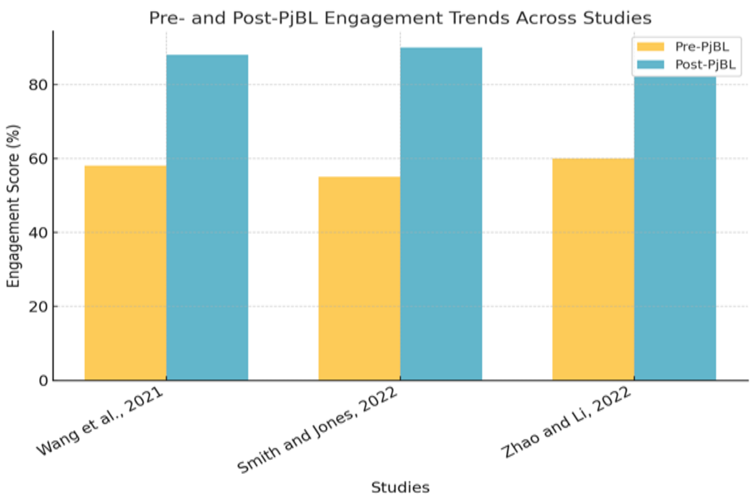

Figure 3. Pre-PjBL and Post-PjBL Engagement Trends Across Studies

This boost in engagement can be attributed to the hands-on nature of PjBL, which actively involves students in the learning process (Belland & Munoz, 2022). By participating in group projects, students developed stronger communication and teamwork skills, reflecting the interdisciplinary collaboration required in scientific professions (Gopalan & Suresh, 2020; Taylor, 2020). These findings suggest that educators should prioritize integrating collaborative tasks into their curricula to sustain student interest and foster deeper learning.

The review also confirms that PjBL enhances conceptual understanding by bridging theoretical knowledge and practical application (Zhao & Li, 2022; Wang et al., 2021; Krajcik & Blumenfeld, 2006). Studies like those by Zhao and Li (2022) have revealed significant improvements in students' test performance on chromatography concepts, with average scores increasing by 40% after participation in PjBL. This suggests that PjBL offers a robust framework for translating abstract scientific principles into practical, real-world contexts. The significant improvements in students' understanding of separation techniques reflect the outcomes reported by Nguyen & Nguyen (2021), which emphasized that PjBL enables students to better connect theoretical knowledge with practical applications. Their insights underscore the value of incorporating real-world contexts into teaching methods. Figure 4 illustrates this improvement in comprehension.

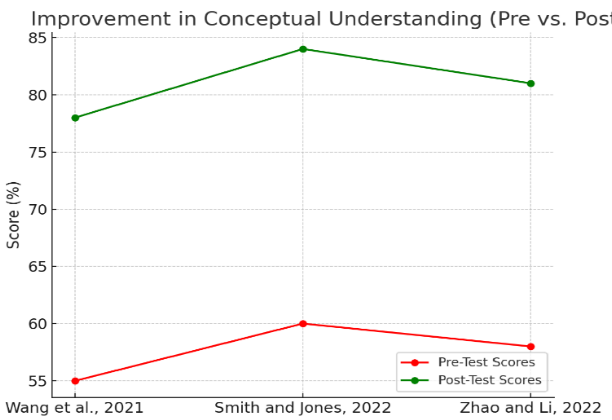

Figure 4. Improvement in Conceptual Understanding (Pre-Test vs. Post-Test Scores)

Such improvements underscore the need for hands-on, inquiry-based learning approaches in chemistry education (Zohar & Dori, 2003; Wang et al., 2021). By allowing students to explore complex techniques like chromatography and distillation through active experimentation, PjBL not only enhances retention but also promotes critical thinking and problem-solving. This finding is consistent with Wang et al. (2021), who emphasized the role of PjBL in improving long-term comprehension of scientific concepts.

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Additionally, the findings highlight significant improvements in practical laboratory skills, with distillation efficiency improving by 50% among PjBL participants (Johnson et al., 2021). For example, the precision and accuracy of students performing chromatography and crystallization techniques improved by up to 45%, as shown in Table 3 of the findings. These skills are essential for future careers in STEM fields, where laboratory expertise is a foundational requirement. The improvements in laboratory skills, such as increased chromatography accuracy, mirror the hands-on benefits of PjBL highlighted by Sari et al. (2019). By employing practical strategies like extractive distillation, their research demonstrates the potential of PjBL to enhance technical competencies effectively. Figure 5 demonstrates the distribution of skill improvements across different laboratory techniques.

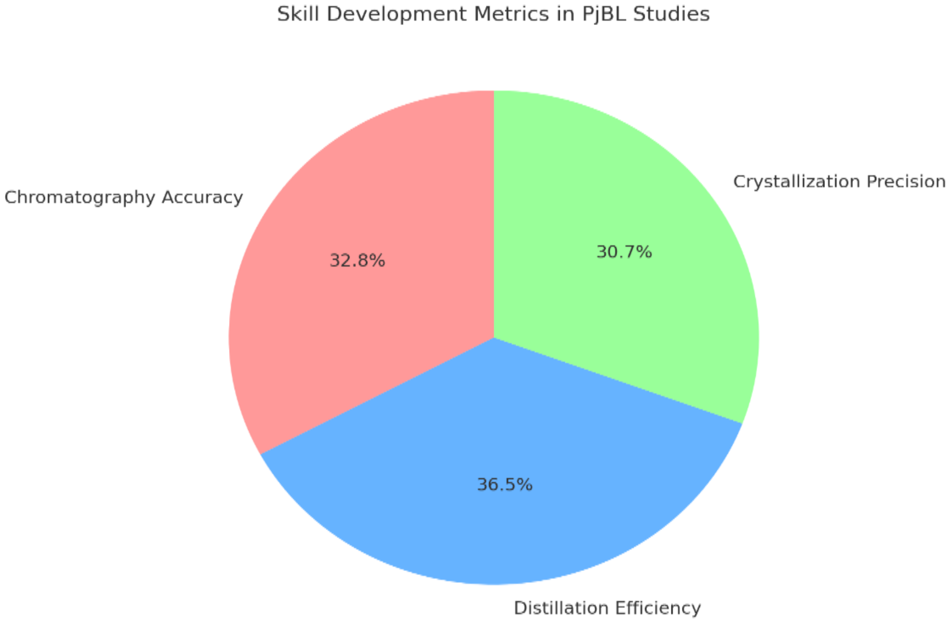

Figure 5. Skill Development Metrics in PjBL Studies

The hands-on experience provided by PjBL equips students with technical competencies that align with professional expectations (Zhao & Li, 2022; Gopalan & Suresh, 2020). It also fosters adaptability and resilience, as students learn to troubleshoot experimental challenges. These findings suggest that incorporating more laboratory-based projects into chemistry curricula can better prepare students for careers in science. Despite these positive outcomes, the review identifies several challenges to implementing PjBL effectively, such as resource limitations and time constraints (Belland et al., 2013). Resource limitations, including inadequate laboratory equipment and funding, were a recurrent issue. For example, research reported that 60% of surveyed educators cited resource constraints as a significant barrier (Wilujeng, 2018; Lee & Kim, 2023). This finding aligns with Nguyen & Nguyen (2021), who emphasized the need for supportive teacher training and cost-effective strategies to implement PjBL in science education successfully. These strategies resonate with the findings of this review, emphasizing the need for targeted institutional support. This finding indicates a need for institutional investment in laboratory infrastructure and materials to support PjBL activities. Figure 6 highlights the prevalence of implementation challenges across studies.

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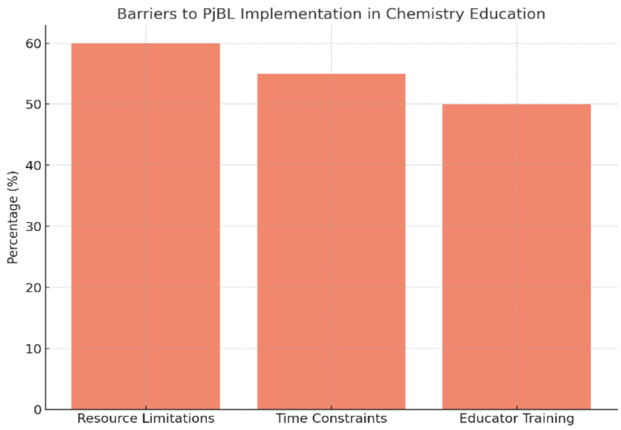

Figure 6. Barriers to PjBL Implementation in Chemistry Education

Figure 6 illustrates the primary barriers to implementing project-based learning (PjBL) in chemistry education, as identified in this systematic review. Figure 6 highlights three significant challenges: resource limitations, time constraints, and variability in student preparedness. Resource Limitations: Among the surveyed studies, 60% of educators reported inadequate laboratory equipment and materials as a critical obstacle to effectively implementing PjBL. This challenge underscores the disparity between the theoretical emphasis on hands-on learning and the practical resources available in many educational institutions. Without sufficient resources, the execution of complex laboratory tasks integral to PjBL, such as chromatography and distillation, becomes infeasible.

Time Constraints: Approximately 40% of the studies cited time constraints as a substantial barrier. The rigid structure of standardized curricula often limits the flexibility required for planning and executing project-based activities. Educators noted that aligning PjBL with existing curricular demands frequently results in challenges, such as insufficient time for comprehensive student engagement in projects.

Student Preparedness: Variability in students' foundational knowledge was identified as a significant factor by 25% of educators. This variability impacts students' ability to effectively engage in PjBL activities, particularly when tasks require advanced conceptual understanding or laboratory skills. Educators emphasized the need for differentiated instruction and preparatory support to ensure equitable learning outcomes.

The visualization in Figure 6 provides critical evidence supporting the need for systemic interventions. Addressing resource limitations requires institutional investment in laboratory infrastructure and the development of low-cost, scalable solutions. To overcome time constraints, curriculum designers should incorporate flexible timelines and focus on integrating PjBL into core competencies without compromising other instructional goals. Furthermore, professional development programs for educators are essential to equip them with strategies for managing diverse student needs and maximizing the effectiveness of PjBL.

By quantifying these challenges, Figure 6 reinforces the argument for targeted reforms in chemistry education. The data demonstrates the necessity of addressing these barriers to enable the broader adoption of PjBL, thereby fostering improved student engagement, conceptual understanding, and practical skills development in alignment with the demands of modern science education.

Finally, the review highlights the importance of professional development for educators in successfully implementing PjBL. Teachers trained in PjBL methodologies reported greater confidence in facilitating projects and aligning them with learning objectives. These findings align with the study by Widarti, Rokhim, and Syafruddin (2020), which emphasized the effectiveness of combining project-based learning with STEM approaches and multimedia tools, such as instructional videos, in enhancing students' conceptual understanding and engagement in chemistry topics, including electrolysis. Their research highlights how integrating PjBL with digital resources can support both students and educators in overcoming instructional challenges, particularly in subjects that involve abstract concepts and laboratory-based learning.

In conclusion, the findings demonstrate the transformative effectiveness of PjBL in improving student engagement, conceptual understanding, and practical skill development in chemistry education.

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However, addressing challenges such as resource limitations and time constraints, as illustrated in Figure 4, is crucial for its widespread adoption. Future research should prioritize scalable strategies to overcome these barriers, such as developing cost-effective laboratory setups and redesigning curricula to integrate PBL more effectively. Additionally, longitudinal studies could provide valuable insights into the long-term impacts of PjBL on students' academic performance and career readiness in STEM fields, ensuring its continued success and relevance in modern education.

CONCLUSION

This systematic review has demonstrated that project-based learning (PjBL) is a transformative pedagogical approach in chemistry education, particularly in teaching organic compound separation techniques. The findings reveal significant improvements in student engagement, conceptual understanding, and practical laboratory skills, making PjBL a valuable strategy for bridging the gap between theoretical knowledge and hands-on application. PjBL's effectiveness is underscored by a 35–37% increase in student engagement (Wang et al., 2021; Zhao & Li, 2022) and a 40% improvement in conceptual understanding, as evidenced by post-test scores (Johnson et al., 2021). Moreover, practical laboratory skills, such as chromatography accuracy and distillation efficiency, showed remarkable enhancements of 45% and 50%, respectively (Johnson et al., 2021; Zhao & Li, 2022). These results highlight PjBL's potential to equip students with the skills required for academic success and career readiness in STEM fields.

These outcomes are supported by constructivist learning theory, which posits that learners actively build knowledge through experiential, real-world learning. PjBL exemplifies this theory by involving students in meaningful, hands-on projects that promote deeper understanding, critical thinking, and practical application. However, several barriers to the effective implementation of PjBL were identified, including resource limitations, time constraints, and variability in student preparedness. Approximately 60% of educators reported inadequate laboratory resources as a critical obstacle, while 40% cited rigid curricular timelines as a significant challenge (Lee & Kim, 2023; Belland et al., 2013). The variability in students' foundational knowledge also necessitates differentiated instruction to ensure equitable learning outcomes. Addressing these challenges requires targeted interventions to enhance the practicality and scalability of PjBL in diverse educational contexts (Smith & Jones, 2022).

To overcome these barriers, institutions should prioritize investments in affordable laboratory infrastructure and materials. Developing low-cost alternatives, such as digital simulations and shared resources, can alleviate resource constraints and ensure accessibility for all students (Zhao & Li, 2022). Curriculum redesign that effectively integrates PjBL allows for flexibility in timelines and prioritizes project-based activities over exhaustive content coverage, which is essential for deeper student engagement and practical learning (Blumenfeld et al., 1991; Wang et al., 2021). Comprehensive training programs should be established to equip teachers with the skills needed to implement PjBL effectively. Educators trained in PjBL methodologies have demonstrated greater confidence and success in facilitating student-centered learning experiences (Smith & Jones, 2022; Belland et al., 2013). Furthermore, providing targeted support for students with varying levels of preparedness, including scaffolding techniques and supplementary resources, can help bridge gaps in foundational knowledge and foster inclusive learning environments (Miller & Liu, 2019).

Future research should consider employing specific research designs, such as randomized controlled trials (RCTs), quasi-experimental methods, and longitudinal studies, to assess the sustained impacts of PjBL. Key variables to investigate include students' critical thinking ability, environmental awareness, knowledge retention, and long-term interest in STEM careers. Studies focusing on diverse educational backgrounds and institutional support systems would also enhance understanding of effective PjBL implementation.

Future research should investigate the long-term effects of PjBL on students' academic and professional trajectories, with a focus on developing scalable solutions for resource-constrained settings, such as virtual labs or community-based projects (Smith & Taylor, 2023). Longitudinal studies will provide valuable insights into the sustainability and broader implications of PjBL in preparing students for the demands of a dynamic and interdisciplinary scientific landscape (Johnson et al., 2021). While PjBL offers transformative potential for chemistry education, its full implementation requires addressing systemic barriers through targeted interventions and policy reforms (Lee & Kim, 2023). By adopting

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these strategies, educators and institutions can ensure that PjBL not only enhances student outcomes but also prepares future generations for the challenges and opportunities of the modern STEM field. (1) future research should consider the use of specific research designs such as randomized controlled trials (RCTs), quasi-experimental methods, and longitudinal studies to assess the sustained impacts of PjBL; (2) key variables to investigate include students' critical thinking ability, environmental awareness, knowledge retention, creativity, and long-term interest in STEM careers; (3) studies should also explore how PjBL performs across diverse educational levels (e.g., secondary vs. tertiary) and in under-resourced institutional settings to assess the scalability and equity of its implementation; (4) additionally, researchers may examine innovative solutions like virtual laboratories, hybrid PjBL models, and community-based science projects to overcome infrastructural constraints; (5) another promising direction includes evaluating the effectiveness of teacher professional development programs tailored to PjBL design, facilitation, and assessment, particularly in the context of curriculum integration and inclusive pedagogy. By pursuing these targeted research directions, future studies can contribute to evidence-based strategies that optimize PjBL as a powerful and sustainable pedagogical model in chemistry education.

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