STEM Education Review

REVIEW ARTICLE

Project-Based Learning and the Development of Problem-Solving Competencies among STEM Students in Higher Education

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ABSTRACT

Project-Based Learning (PBL) has become a foundational approach in STEM higher education, aiming to bridge theoretical knowledge and practical application. This systematic review synthesizes recent empirical evidence on PBL's impact on problem-solving competencies among STEM undergraduates. Following PRISMA guidelines, 32 studies published between 2019 and 2026 were analyzed, drawn from ERIC, Scopus, and Web of Science. The majority of studies reported that PBL interventions significantly enhanced students' analytical skills, interdisciplinary understanding, and engagement. However, challenges such as resource constraints, assessment standardization, and teacher preparedness were common. The review concludes that PBL offers substantial promise for cultivating problem-solving abilities in STEM students but highlights the need for further research on scalable implementation and equitable access.

Keywords: STEM education; project-based learning; problem-solving; higher education; systematic review; competencies

INTRODUCTION

The capacity to identify, analyse, and solve complex problems is increasingly regarded as a central graduate competence in science, technology, engineering, and mathematics (STEM) education. Contemporary STEM professionals are expected to work with problems that are rarely confined to a single disciplinary boundary and that often require the integration of theoretical knowledge, practical skills, creativity, collaboration, communication, and evidence-based decision-making. Consequently, higher education institutions are under increasing pressure to move beyond instructional approaches that emphasize the transmission and reproduction of disciplinary knowledge toward pedagogies that enable students to apply knowledge in authentic and unfamiliar situations. The development of problem-solving competence is therefore not only an educational objective but also an important component of graduate employability, innovation, and participation in knowledge-based economies (National Academies of Sciences, Engineering, and Medicine, 2020; Odhiambo, 2026).

Technology integration can improve students' academic performance by expanding access to learning resources, supporting interactive instruction, and increasing learner engagement (Odhiambo, 2026). Traditional lecture-centred approaches remain important for establishing foundational disciplinary knowledge; however, their effectiveness can be limited when students must transfer theoretical concepts to complex real-world situations. Problem-solving competence involves more than obtaining a correct answer to a structured academic question. It encompasses recognizing and defining problems, identifying relevant information, generating alternative solutions, evaluating evidence, selecting appropriate

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Received: 7 March 2025; Revised: 11 March 2025; Accepted: 6 July 2025
https://doi.org/10.67229/stemer.26080004

strategies, implementing solutions, and reflecting on outcomes. In STEM contexts, these capabilities are particularly important because graduates frequently encounter open-ended problems marked by uncertainty, incomplete information, competing constraints, and multiple possible solutions. Active and experiential approaches have consequently attracted considerable attention because they offer opportunities for students to apply disciplinary knowledge while engaging with realistic problems and collaborative tasks.

Project-Based Learning (PBL) is a pedagogical approach characterized by sustained engagement with a meaningful question, problem, or challenge through which learners investigate, design, create, test, and communicate a product or solution. Rather than treating knowledge acquisition as an end in itself, PBL organizes learning around purposeful activity and the application of knowledge to authentic situations. Students are typically required to make decisions, conduct inquiry, collaborate with peers, manage project activities, respond to feedback, and revise their work. These characteristics make PBL particularly relevant to STEM education, where connecting conceptual understanding with practical application is fundamental to professional practice (Kokotsaki et al., 2016; Larmer et al., 2019).

The theoretical foundations of PBL are closely associated with constructivist perspectives of learning, which conceptualize students as active participants in the construction of knowledge rather than passive recipients of information. Within a project-based environment, learners encounter a problem or challenge that requires them to draw upon prior knowledge, acquire new information, test ideas, and negotiate meaning with others. Learning therefore occurs through an iterative process of inquiry, application, feedback, reflection, and revision. Such processes can create conditions for deeper conceptual understanding because students are encouraged to understand not only what a concept means but also how and when it can be used to address a particular problem. The collaborative and inquiry-oriented nature of PBL may also support the development of higher-order cognitive skills that are difficult to cultivate through approaches dominated by memorization and highly structured exercises.

The relevance of PBL is especially pronounced in higher education STEM programmes because these programmes are expected to prepare students for professional environments characterized by interdisciplinary collaboration and rapidly changing technological demands. Engineering students, for example, may need to integrate mathematics, physical science, computing, design, and economic considerations when developing a solution. Similarly, students in computer science may be required to combine programming knowledge with user requirements, systems thinking, project management, and ethical considerations. Mathematics students may need to translate abstract concepts into models that explain real-world phenomena, while students in the natural sciences may need to design investigations, interpret evidence, and communicate findings. PBL provides a pedagogical structure within which such integration can occur.

Empirical research has increasingly associated PBL with positive learning outcomes, including academic achievement, student engagement, collaboration, motivation, and the application of theoretical knowledge. Students involved in projects are often required to assume greater responsibility for defining objectives, organizing tasks, monitoring progress, and evaluating outcomes. These activities can strengthen learner autonomy and encourage students to become more active participants in their education. The opportunity to work on meaningful and authentic problems can also enhance motivation because students are able to recognize the relevance of academic concepts to practical and professional contexts. Chua and Kong (2021), for example, emphasize the importance of engagement and collaborative learning within STEM-oriented project environments, while broader PBL literature identifies authenticity, sustained inquiry, student voice, and reflection as important characteristics of effective project-based learning (Kokotsaki et al., 2016; Larmer et al., 2019).

Despite these potential benefits, the relationship between PBL and problem-solving competence should not be assumed to be automatic. Merely assigning students a project does not necessarily constitute high-quality PBL or guarantee the development of higher-order competencies. The effectiveness of a project depends on how the learning experience is designed, the complexity and authenticity of the problem, the extent of student autonomy, the quality of scaffolding, opportunities for feedback and reflection, collaboration among learners, and the alignment between project activities and assessment. Inadequately designed projects may result in students concentrating on producing a final product rather than developing the reasoning processes required to solve complex problems. Effective PBL therefore requires deliberate pedagogical design and appropriate institutional support.

Assessment is one of the most significant challenges in this regard. Conventional examinations are often designed to measure individual recall, procedural knowledge, or the ability to solve well-defined problems under controlled conditions. PBL, by contrast, frequently yields complex outcomes that reflect both individual and collaborative contributions. Assessing problem-solving competence therefore requires attention to the processes by which students define problems, generate and evaluate alternatives, apply disciplinary knowledge, justify decisions, revise solutions, and reflect on their learning. Rubrics, portfolios, presentations, project reports, peer and self-assessment, and performance-based assessment may therefore be necessary to capture the breadth of competencies developed through PBL. However, variations in assessment practices can make it difficult to compare outcomes across institutions and studies.

The implementation of PBL also presents institutional and instructional challenges. Effective projects may require substantial time for planning, supervision, collaboration, experimentation, feedback, and revision. STEM projects may additionally require laboratories, software, digital platforms, equipment, materials, reliable internet connectivity, and other forms of infrastructure. Institutions with limited resources may consequently face difficulties implementing resource-intensive projects equitably. Teacher preparedness is another critical consideration. Instructors accustomed to lecturer-centred approaches may require professional development to design authentic projects, facilitate inquiry without removing student autonomy, manage collaborative learning, provide formative feedback, and assess complex competencies. These considerations indicate that the outcomes of PBL are influenced not only by the pedagogical model itself but also by the institutional context in which it is implemented.

The geographical distribution of PBL research also raises important questions about contextual transferability. A substantial proportion of published research on innovative STEM pedagogies has emerged from North America, Europe, and parts of Asia, while evidence from African higher education remains comparatively limited. Educational systems differ considerably in terms of class sizes, infrastructure, curriculum structures, lecturer preparation, funding, digital access, and student backgrounds. Consequently, findings generated in highly resourced institutions cannot automatically be generalized to universities operating under different socioeconomic and institutional conditions. Evidence from Kenya and other African contexts is particularly valuable because it can demonstrate how project-based approaches function within environments where resource constraints, curriculum demands, technological inequalities, and institutional capacity may shape implementation and outcomes (Odhiambo, 2026).

Another emerging dimension of PBL concerns the use of digital technologies and artificial intelligence (AI). Digital platforms can facilitate collaboration, information gathering, project management, simulation, modelling, data analysis, prototyping, and communication. AI-supported tools may additionally provide students with personalized feedback, assist with brainstorming and coding, support data interpretation, and enable adaptive learning experiences. At the same time, the incorporation of AI into project-based STEM education raises questions concerning academic integrity, student dependency on automated tools, digital inequality, assessment validity, and the development of authentic problem-solving abilities. The educational value of these technologies therefore depends on whether they are used to extend students' reasoning and inquiry or simply to replace the cognitive processes that PBL is intended to develop.

The growing interest in PBL has consequently generated an expanding body of empirical literature, but important gaps remain. Individual studies vary in their disciplinary focus, research designs, sample sizes, intervention characteristics, outcome measures, and geographical settings. Some studies emphasize academic achievement, whereas others examine engagement, collaboration, creativity, or problem-solving. Differences in definitions and measurement approaches make it difficult to determine the consistency and magnitude of PBL's contribution to problem-solving competence across STEM disciplines. Moreover, although existing reviews have established the broader educational value of PBL, fewer reviews have specifically concentrated on problem-solving competencies among STEM students in higher education and on the contextual factors that influence implementation.

A systematic synthesis is therefore necessary to consolidate the available evidence and identify patterns across empirical studies. Systematic review methodology provides a transparent approach for identifying, screening, evaluating, and synthesizing relevant research while reducing the risk of selectively emphasizing individual findings. The present review responds to this need by examining empirical evidence published between 2019 and 2026 concerning the relationship between PBL and problem-solving competencies among students in higher education STEM programmes. The review considers evidence across disciplines and geographical contexts and pays particular attention to academic and cognitive outcomes, student engagement, interdisciplinary learning, personalization, and implementation challenges.

The review is guided by the broader premise that effective STEM education should enable students not merely to acquire disciplinary knowledge but to mobilize that knowledge in response to complex and authentic challenges. Accordingly, the review seeks to answer the following questions: (1) What evidence exists regarding the effects of PBL on problem-solving competencies among STEM students in higher education? (2) What learning outcomes and mechanisms are most consistently associated with PBL? **(3)** What institutional, instructional, technological, and resource-related challenges affect the implementation of PBL? and **(4)** What implications do the findings have for STEM curriculum development, instructional practice, assessment, and educational policy?

By synthesizing the recent evidence, this review contributes to the continuing discussion on how higher education can prepare STEM graduates for complex professional and societal challenges. It also highlights the importance of moving beyond a simple comparison between PBL and traditional teaching toward a more nuanced understanding of the conditions under which PBL is most effective. Such an approach is particularly important for institutions seeking to implement PBL at scale and for policymakers interested in developing STEM graduates who can think critically, collaborate across disciplinary boundaries, adapt to changing circumstances, and develop innovative solutions to complex problems (National Academies of Sciences, Engineering, and Medicine, 2020; Odhiambo, 2026).

METHODOLOGY

This study employed a systematic review design to synthesize empirical evidence concerning the relationship between Project-Based Learning (PBL) and the development of problem-solving competencies among STEM students in higher education. A systematic review was considered appropriate because the literature on PBL is dispersed across different STEM disciplines, geographical settings, methodological traditions, and educational contexts. The review was designed to identify relevant studies systematically, evaluate their methodological quality, extract comparable information, and synthesize findings in a manner that provides a transparent account of the available evidence. The review process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which promotes transparency in the identification, screening, eligibility assessment, and inclusion of studies in systematic reviews (Page et al., 2021). The methodology was also informed by established principles of evidence synthesis and qualitative thematic analysis to ensure that both quantitative and qualitative findings could be incorporated.

The literature search covered studies published between January 2019 and August 2026. This period was selected to capture relatively recent evidence on PBL in higher education while allowing sufficient time for the emergence of empirical research examining problem-solving, interdisciplinary learning, student engagement, and technology-supported project work. Searches were conducted in three major scholarly databases: ERIC, Scopus, and Web of Science. These databases were selected because they provide extensive coverage of educational research, interdisciplinary STEM scholarship, higher education studies, and peer-reviewed empirical literature. Additional manual searches of reference lists of relevant review articles and highly cited empirical studies were used to identify potentially eligible publications that may not have been retrieved through the database searches. The search strategy combined controlled and free-text terms relating to the intervention, outcome, population, and educational context. Core search terms included "project-based learning," "project based learning," "PBL," "problem-solving," "problem solving skills," "problem-solving competence," "STEM," "science," "technology," "engineering," "mathematics," "undergraduate," "higher education," "university students," and "tertiary education." Boolean operators such as AND and OR were used to combine the terms and broaden or narrow the search where appropriate. The search was designed to maximize sensitivity while maintaining sufficient specificity to identify studies directly relevant to the review objectives.

The population of interest comprised students enrolled in higher education STEM programmes, including undergraduate and, where relevant, postgraduate students whose learning occurred within formal university or tertiary education settings. STEM was interpreted broadly to include science, technology, engineering, and mathematics disciplines and interdisciplinary programmes substantially grounded in these fields. Studies were considered relevant when PBL constituted the principal pedagogical intervention or when project-based learning was a clearly identifiable component of the instructional approach being investigated. The review focused specifically on problem-solving competencies and closely related outcomes, including analytical reasoning, critical thinking, decision-making, application of theoretical knowledge, design thinking, creative problem-solving, systems thinking, interdisciplinary problem-solving, and students' capacity to develop and evaluate solutions to authentic problems. Studies examining general academic achievement or student engagement were considered only when these outcomes were connected to the development or application of problem-solving competencies.

Studies were eligible for inclusion when they met several predefined criteria. First, the study had to report empirical evidence derived from quantitative, qualitative, or mixed-methods research. Second, participants had to be students in higher education STEM programmes. Third, the study had to examine PBL as an instructional approach, intervention, or substantial component of the learning experience. Fourth, the study had to report at least one outcome related directly or indirectly to problem-solving competence. Fifth, the publication had to be available in English and published within the specified review period. Peer-reviewed journal articles were prioritized because of their formal quality-control processes, although relevant empirical conference publications were considered where they provided sufficient methodological and outcome information. Studies were excluded when they were theoretical papers, editorials, opinion pieces, book reviews, dissertations without sufficient accessible methodological information, or purely conceptual discussions of PBL. Studies focusing exclusively on primary or secondary education were excluded because the review was specifically concerned with higher education. Similarly, studies outside STEM disciplines were excluded unless STEM students formed a clearly identifiable study population. Research focusing on problem-based learning without a substantive project-based component was also excluded where the two approaches could not reasonably be treated as equivalent.

The identification and selection of studies followed a multistage process. Database searches initially produced a broad pool of potentially relevant records. All retrieved records were compiled and duplicate publications were removed before screening. Titles and abstracts were then examined against the predefined eligibility criteria. Records that clearly failed to address PBL, STEM higher education, or problem-solving outcomes were excluded at this stage. Studies that appeared potentially relevant or for which eligibility could not be established from the title and abstract were retained for full-text assessment. Full-text articles were subsequently examined in detail to determine whether they satisfied all inclusion criteria. Reasons for excluding articles at the full-text stage were recorded to enhance transparency and reproducibility. The final selection resulted in 32 studies meeting the eligibility requirements and forming the evidence base for the synthesis. The identification, screening, eligibility, and inclusion stages were documented using a PRISMA flow diagram, allowing the progression from the initial search results to the final sample of studies to be clearly reported (Page et al., 2021).

To strengthen methodological consistency, the quality of the included studies was assessed before data synthesis. Because the evidence base incorporated quantitative, qualitative, and mixed-methods research, the appraisal process used methodological assessment tools appropriate to different study designs. The Mixed Methods Appraisal Tool (MMAT) was used to assess studies employing quantitative, qualitative, or mixed-methods approaches, while relevant Critical Appraisal Skills Programme (CASP) checklists were consulted for studies requiring design-specific appraisal. The assessment considered aspects such as clarity of research questions, appropriateness of study design, sampling procedures, adequacy of measurements, completeness of outcome reporting, appropriateness of analytical procedures, consideration of potential bias, and the coherence between research questions, methods, findings, and conclusions. Each study was assigned an overall quality assessment based on the proportion of applicable criteria satisfactorily addressed. Consistent with the review protocol, studies achieving an overall quality rating of at least 70% were retained for the final synthesis. Quality appraisal was not used merely to assign numerical scores; it was also used to identify methodological limitations that could influence interpretation of the findings.

Data were extracted systematically from each included publication using a structured extraction framework. The extracted information included bibliographic details, publication year, country or geographical region, STEM discipline, participant characteristics, sample size, research design, data collection methods, duration of the PBL intervention, nature of the projects undertaken, comparison conditions where applicable, measures of problem-solving competence, and principal findings. Information relating to implementation was also extracted, including instructor preparation, availability of technological and physical resources, collaboration arrangements, assessment strategies, project duration, and reported barriers or facilitators. Where studies investigated additional outcomes such as motivation, engagement, collaboration, academic achievement, creativity, or interdisciplinary learning, these were also recorded because they provided contextual evidence concerning the mechanisms through which PBL may influence problem-solving development.

The extraction process placed particular emphasis on operational definitions of problem-solving competence. Rather than treating problem-solving as a single uniform construct, the review considered the different dimensions reported across studies. These included problem identification and formulation, information gathering, analytical reasoning, generation of alternative solutions, application of disciplinary knowledge, decision-making, experimentation, evaluation of proposed solutions, reflection, and transfer of learning to unfamiliar contexts. This approach allowed the review to identify similarities and differences in the ways researchers conceptualized and measured problem-solving. It also reduced the risk of treating heterogeneous outcome measures as though they represented the same competency.

The review employed a narrative and thematic synthesis rather than a statistical meta-analysis. This decision was based on the methodological and conceptual heterogeneity of the included studies. The studies differed substantially in sample characteristics, STEM disciplines, PBL designs, intervention duration, comparison groups, assessment instruments, and outcome measures. Quantitative findings were therefore summarized descriptively, with attention to the direction and consistency of reported effects rather than combining effect sizes that were not sufficiently comparable. Where studies included experimental or quasi-experimental comparisons, evidence concerning differences between PBL and conventional instructional conditions was examined. Where studies employed qualitative methods, findings relating to students' experiences, perceptions, engagement, collaboration, and development of problem-solving processes were coded and synthesized thematically.

Thematic synthesis involved an iterative process of identifying recurring concepts across the included studies, grouping related findings, and developing broader analytical themes. Initial themes included problem-solving and analytical competence, academic achievement and knowledge application, student engagement and motivation, collaboration and interdisciplinary learning, personalized learning, technological support, and implementation challenges. These themes were subsequently compared across disciplines and geographical contexts to determine whether similar patterns appeared across different educational environments. Particular attention was given to findings that were consistently reported across multiple studies, as well as evidence that contradicted or qualified the broader positive effects of PBL. This approach enabled the review to distinguish between outcomes that appeared relatively consistent and those that were dependent on contextual or implementation conditions.

To improve the credibility of the synthesis, findings were interpreted in relation to methodological quality, study design, sample characteristics, and contextual factors. Greater interpretive weight was given to findings supported by multiple methodologically sound studies rather than isolated claims from individual investigations. Differences between studies were not automatically interpreted as contradictory evidence; instead, they were examined in relation to variations in intervention design, disciplinary context, student characteristics, institutional resources, instructor expertise, and assessment approaches. This was particularly important because PBL is not a standardized intervention. Projects can differ substantially in complexity, authenticity, duration, student autonomy, collaboration requirements, scaffolding, and assessment. Consequently, the review sought to identify not only whether PBL was associated with improved problem-solving but also the conditions under which such benefits appeared most likely to occur.

The review also considered the geographical distribution of the evidence. Each included study was categorized according to its reported country and broader geographical region. Studies were subsequently grouped into regions such as Africa, North America, Europe, Asia, Latin America, and other regions where appropriate. This analysis was undertaken to determine whether the evidence base was geographically concentrated and to identify potential gaps in research from underrepresented contexts. Particular attention was given to African evidence because higher education institutions in the region may experience different resource, infrastructure, policy, and instructional conditions from those commonly represented in international PBL research. Evidence from Kenya was therefore interpreted within its contextual setting rather than assumed to be directly equivalent to evidence generated in highly resourced educational systems.

The review further examined implementation factors that could facilitate or constrain the development of problem-solving competencies through PBL. These included instructor preparedness, institutional leadership, curriculum flexibility, project duration, class size, access to laboratories and digital technologies, availability of learning materials, student collaboration, assessment practices, and institutional funding. Technology-related factors were considered where studies reported the use of learning management systems, simulation environments, collaborative platforms, programming tools, digital fabrication technologies, data-analysis applications, or artificial intelligence. The review distinguished between technology functioning as an enabling resource for project work and technology functioning as an instructional intervention in its own right.

Ethical considerations were addressed at the level appropriate to a systematic review of published literature. Because the study did not involve direct interaction with human participants or collection of primary personal data, institutional participant consent was not required for the review itself. Nevertheless, the review followed principles of responsible scholarship by accurately representing the findings of the original studies, avoiding selective reporting, acknowledging methodological limitations, and maintaining appropriate attribution through citations. The synthesis was designed to avoid overstating causal conclusions where the underlying studies employed observational, qualitative, or non-randomized designs.

Several methodological limitations were recognized in interpreting the review findings. Restricting the search to English-language publications may have excluded relevant evidence published in other languages and may introduce language bias. The decision to focus on studies published from 2019 to 2026 may also have excluded earlier empirical research that could provide useful historical or theoretical context. In addition, differences in how researchers define PBL and problem-solving competence create challenges for direct comparison across studies. The use of databases such as ERIC, Scopus, and Web of Science provides broad coverage but does not guarantee that every relevant study was identified. Finally, the decision to require a minimum quality threshold may have excluded studies that contained useful contextual evidence despite methodological limitations. These limitations were considered when interpreting the synthesized findings and formulating recommendations.

Overall, the methodological approach was designed to provide a transparent, systematic, and context-sensitive synthesis of contemporary evidence concerning PBL and problem-solving competencies in higher education STEM. By combining structured database searching, explicit eligibility criteria, PRISMA-guided study selection, methodological quality appraisal, systematic data extraction, and thematic synthesis, the review provides an evidence base for evaluating the educational contribution of PBL while also identifying the institutional and pedagogical conditions that influence its effectiveness. (Table 1)

Table 1: Eligibility Criteria

Inclusion Criteria	Exclusion Criteria
Empirical studies	Non-empirical papers
STEM in higher education	Non-STEM disciplines
Focus on PBL & problem-solving	Studies outside higher education
Published 2019–2026, English	Non-English, pre-2019 studies

Following the initial database search, all identified records were exported into a reference management system and examined for duplication. Duplicate records were removed before the screening process commenced to ensure that individual studies were not counted more than once. The remaining records were subjected to title and abstract screening against the predetermined inclusion and exclusion criteria. At this stage, studies were assessed according to their relevance to Project-Based Learning, STEM education, higher education, and problem-solving competencies. Records that clearly focused on primary or secondary education, non-STEM disciplines, conventional teaching approaches without a project-based component, or outcomes unrelated to problem-solving were excluded. Studies for which relevance could not be determined from the title and abstract were retained for full-text assessment. The screening process was designed to minimize the possibility of prematurely excluding potentially relevant evidence and to maintain consistency with the objectives of the systematic review.

The full texts of potentially eligible studies were subsequently retrieved and assessed in detail. Each article was examined to establish whether it satisfied all predefined eligibility requirements, including publication within the 2019–2026 period, empirical research design, focus on students in higher education STEM programmes, substantive use of PBL, and reporting of findings relevant to problem-solving competencies or closely related cognitive and learning outcomes. Studies that did not provide sufficient information about the PBL intervention, participant population, methodology, or outcomes were excluded from the final synthesis. Where eligibility was uncertain, the study was examined against the research questions and eligibility criteria rather than being included solely on the basis of its title or abstract. Following this multistage screening and eligibility assessment, 32 studies were retained as the final evidence base for the review. The selection process, including the number of records identified, duplicates removed, records screened, full-text articles assessed, excluded articles, and studies ultimately included, was documented using a PRISMA flow diagram presented as Figure 1 (Page et al., 2021). The PRISMA framework was used to improve transparency and enable readers to understand how the final evidence base was derived from the initial literature search.

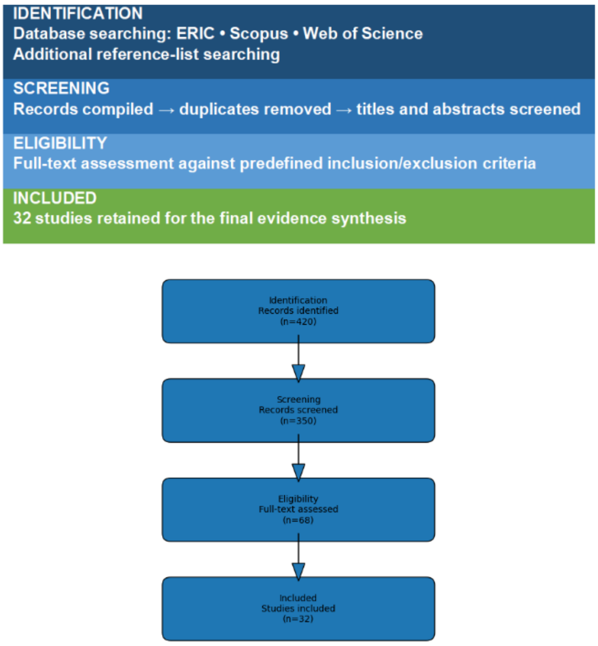

Figure 1. PRISMA Flow Diagram

The methodological quality of the 32 included studies was evaluated before their findings were incorporated into the synthesis. Because the selected literature included quantitative, qualitative, and mixed-methods investigations, the appraisal process incorporated the Mixed Methods Appraisal Tool (MMAT) and relevant Critical Appraisal Skills Programme (CASP) checklists. The MMAT was appropriate for evaluating studies using different methodological approaches, while CASP checklists provided additional design-specific criteria for assessing the credibility and methodological rigor of individual studies. The appraisal considered the appropriateness of the research design, clarity of research questions, suitability of sampling strategies, adequacy of data collection procedures, validity and appropriateness of measurement instruments, completeness of outcome reporting, suitability of analytical techniques, consideration of potential sources of bias, and consistency between the research questions, methods, results, and conclusions. The assessment also considered whether the reported PBL intervention was sufficiently described to permit interpretation of its relationship with problem-solving outcomes.

A structured quality-rating procedure was used to promote consistency across the appraisal process. Studies were assessed against applicable methodological criteria, and an overall quality percentage was calculated based on the proportion of criteria satisfactorily addressed. A minimum threshold of 70% was established for inclusion in the final synthesis. Studies that fell below this threshold were excluded because their methodological limitations were considered sufficiently substantial to undermine the reliability or interpretability of their findings. The quality assessment was not, however, treated as evidence of whether a study reported positive or negative findings. Instead, methodological quality was considered separately from study results so that studies were not advantaged or disadvantaged on the basis of whether they supported the expected benefits of PBL. The quality appraisal also informed interpretation of the findings by allowing greater caution to be applied when concluding studies with weaker designs, smaller samples, limited outcome measures, or potential sources of bias.

Data extraction was undertaken systematically using a structured extraction framework developed around the objectives and research questions of the review. For each included study, information was recorded concerning the author or authors, year of publication, country and geographical region, STEM discipline, institutional setting, sample size, participant characteristics, research design, data collection methods, duration and nature of the PBL intervention, comparison conditions where applicable, instruments used to assess problem-solving, and principal findings. Information concerning the implementation of PBL was also extracted, including the type of project undertaken, degree of student autonomy, collaboration requirements, instructor involvement, availability of technological and physical resources, feedback mechanisms, and assessment strategies. Extracting these details enabled the review to move beyond a simple identification of whether PBL was effective and to examine the characteristics of PBL environments associated with particular outcomes.

Particular attention was given to the operationalization and measurement of problem-solving competence. Since the concept was defined differently across the included studies, data were extracted on the specific dimensions of problem-solving that were investigated. These included problem identification, problem formulation, information gathering, analytical reasoning, generation of possible solutions, application of disciplinary knowledge, decision-making, experimentation, evaluation of alternatives, solution implementation, reflection, creativity, and transfer of knowledge to unfamiliar situations. Measures could include standardized tests, researcher-developed assessments, performance tasks, project rubrics, portfolios, interviews, questionnaires, observations, reflective reports, and student perceptions. Recording the different measures made it possible to identify areas of convergence and divergence across the evidence base and to avoid treating substantially different measures as though they represented an identical construct.

The extraction process also captured secondary outcomes that were relevant to understanding the mechanisms through which PBL may influence problem-solving competencies. These included academic achievement, student engagement, motivation, collaboration, communication, creativity, critical thinking, interdisciplinary understanding, learner autonomy, and satisfaction with learning. Implementation challenges and enabling conditions were recorded whenever the included studies reported them. Such information included inadequate resources, limited instructional time, large class sizes, insufficient instructor preparation, difficulties in group management, assessment challenges, technological limitations, curriculum rigidity, and unequal student access to learning resources. Conversely, factors such as effective instructor facilitation, institutional support, access to digital technologies, authentic project design, formative feedback, collaborative learning structures, and flexible assessment were recorded as potential facilitators of successful PBL implementation.

Following data extraction, the evidence was synthesized using a combination of thematic synthesis and descriptive analysis. A thematic synthesis approach was used primarily for qualitative findings and for interpreting recurring patterns across the literature. The extracted findings were initially examined to identify concepts that appeared repeatedly across studies. Related concepts were then grouped into broader analytical themes. The principal themes included the development of analytical and problem-solving skills, application of theoretical knowledge, academic achievement, student engagement and motivation, collaboration and interdisciplinary learning, personalization of learning, technological support, and institutional and implementation challenges. These themes were subsequently compared across STEM disciplines and geographical settings to determine whether similar patterns were evident in different contexts.

Quantitative findings were summarized descriptively because substantial methodological heterogeneity prevented reliable statistical pooling across all included studies. The studies differed in sample sizes, research designs, intervention durations, assessment instruments, outcome definitions, and comparison conditions. Rather than combining incompatible statistics, the synthesis considered the direction, consistency, and nature of reported findings. Where studies reported that PBL groups performed better than conventional-learning groups, this evidence was recorded as an indication of a positive comparative outcome. Where studies reported mixed, neutral, or negative findings, these were retained and considered in the interpretation rather than being omitted. This approach reduced the risk of presenting an overly positive assessment of PBL and enabled the review to acknowledge variation in outcomes.

The synthesis also considered the relationship between PBL implementation characteristics and reported outcomes. Studies were examined to determine whether positive problem-solving outcomes were associated with particular features of project design, such as authentic real-world problems, sustained inquiry, interdisciplinary collaboration, student autonomy, iterative feedback, reflection, and opportunities to apply disciplinary knowledge. Similarly, reported challenges were examined in relation to institutional conditions, including resource availability, instructor preparedness, technological infrastructure, curriculum flexibility, and assessment practices. This contextual analysis was important because PBL represents a broad pedagogical approach rather than a single standardized intervention, meaning that differences in implementation can substantially influence its educational effects.

To enhance the credibility of the synthesis, findings were compared across multiple studies rather than relying on isolated results. Greater interpretive emphasis was placed on findings that appeared consistently across studies with stronger methodological quality. At the same time, differences between studies were examined carefully to determine whether variations could be explained by differences in discipline, student population, project duration, institutional context, measurement strategy, or implementation quality. The synthesis therefore sought to distinguish between general patterns in the evidence and findings that appeared dependent on specific contextual circumstances. Evidence from African settings, including Kenya, was considered particularly important because it provides insight into the feasibility and effectiveness of PBL in contexts that may differ from the highly resourced institutions represented in much of the international literature (Odhiambo, 2026).

The final synthesis was organized around the review's principal research questions. Evidence concerning the effects of PBL on problem-solving competence was considered first, followed by findings concerning related academic, cognitive, and engagement outcomes. The analysis then examined implementation barriers and enabling factors before considering implications for STEM curriculum development, instructor professional development, assessment, digital infrastructure, and educational policy. This structure enabled the review to connect empirical findings with practical implications while maintaining a clear distinction between evidence directly reported by the included studies and interpretations developed through the synthesis.

Overall, the study selection, quality appraisal, data extraction, and synthesis procedures were designed to ensure that the conclusions were based on a transparent and systematically evaluated body of evidence. The use of explicit eligibility criteria, PRISMA-guided screening, methodological quality assessment, structured data extraction, and thematic and descriptive synthesis provided a coherent framework for examining how PBL contributes to problem-solving competencies among STEM students in higher education. The approach also enabled the review to identify not only the reported benefits of PBL but also the contextual conditions, methodological limitations, and implementation challenges that must be considered when interpreting the evidence and translating it into educational practice.

RESULTS

Characteristics of Included Studies

The systematic review identified 32 studies that satisfied the predefined eligibility and methodological quality criteria. Collectively, the studies represented a broad range of STEM disciplines, including engineering, mathematics, computer science, information technology, physics, chemistry, biology, environmental science, and interdisciplinary STEM programmes. The studies were conducted across different higher education contexts and employed a variety of research designs, including randomized controlled trials, quasi-experimental studies, surveys, case studies, qualitative investigations, and mixed-methods approaches. This methodological diversity provided evidence from multiple perspectives and enabled the review to examine both measurable learning outcomes and students' experiences of participating in PBL.

The geographical distribution of the studies demonstrated that PBL research is internationally established but unevenly distributed. Evidence was identified from North America, Europe, Asia, and Africa, although studies from highly developed educational systems were more prominent than those from African higher education institutions. The inclusion of evidence from Kenya was particularly important because it extended the geographical scope of the review and provided contextual insight into the implementation of PBL in an African university environment. The diversity of national settings also demonstrated that PBL has been adapted to different institutional, disciplinary, technological, and cultural contexts.

The sample sizes varied considerably across the studies. Some investigations involved relatively small groups of students participating in intensive project-based interventions, whereas others included larger samples drawn from several courses or institutions. Differences in study duration and intensity accompanied the variation in sample size. Some projects were implemented over a single academic module, while others extended across an entire semester or involved sustained interdisciplinary activities. Despite these differences, a common feature across the studies was the use of authentic or relatively open-ended tasks requiring students to apply disciplinary knowledge to practical problems.

The methodological characteristics of the selected studies also varied. Quantitative studies commonly employed achievement tests, problem-solving assessments, questionnaires, or comparisons between PBL and conventional instructional groups. Qualitative studies frequently used interviews, observations, reflective journals, focus groups, and project documentation to examine students' experiences and perceptions. Mixed-methods studies combined quantitative measures of learning outcomes with qualitative evidence concerning student engagement, collaboration, and experiences of project implementation. The methodological variation was considered during synthesis to avoid treating findings derived from fundamentally different research designs as directly equivalent.

The studies generally reported positive associations between PBL and problem-solving-related outcomes. Several investigations found that students exposed to project-based environments demonstrated stronger analytical reasoning, greater ability to apply theoretical concepts, improved collaboration, and increased engagement compared with students experiencing more traditional forms of instruction. Other studies emphasized the development of motivation, learner autonomy, interdisciplinary thinking, and confidence in addressing complex problems. However, the evidence also identified important implementation constraints, particularly limited resources, insufficient instructor preparation, time requirements, difficulties in group management, and challenges associated with assessing complex problem-solving competencies. (Table 2)

Effects on Academic Achievement

The synthesis indicated that PBL was generally associated with improvements in academic achievement and problem-solving performance among STEM students. Across the included studies, students participating in project-based learning frequently demonstrated stronger performance on problem-solving assessments and greater capacity to apply theoretical concepts to practical situations than students exposed primarily to conventional lecture-based instruction. The reported benefits were particularly evident where projects required students to investigate authentic problems, integrate knowledge from several sources, generate possible solutions, and justify their decisions.

Table 2: Characteristics of Included Studies

Author	Year	Country	Sample	Method	Key Findings
Odhiambo	2026	Kenya	120 undergraduates	Mixed methods	PBL improved analytical skills
Smith et al.	2024	USA	200 engineering students	RCT	PBL outperformed control
Lee & Chen	2023	Taiwan	85 mathematics majors	Case study	Increased engagement
Chua & Kong	2021	Singapore	150 STEM students	Survey	Raised motivation
Adams et al.	2022	UK	65 science undergraduates	Qualitative	Resource constraints

An important finding was that the contribution of PBL extended beyond the acquisition of factual knowledge. Students engaged in project-based environments were frequently required to interpret information, identify relationships between concepts, test assumptions, evaluate alternatives, and modify their approaches in response to emerging evidence. These activities provided opportunities for students to develop analytical reasoning and transfer classroom knowledge into unfamiliar contexts. Consequently, PBL appeared particularly relevant to forms of problem-solving that require students to work with incomplete information and multiple possible solutions rather than simply reproduce procedures previously demonstrated by an instructor.

The evidence also suggested that PBL can improve students' understanding of the relationship between theory and practice. In traditional instructional settings, students may acquire theoretical concepts without having sufficient opportunities to determine how those concepts can be applied to real-world problems. PBL addresses this limitation by embedding disciplinary knowledge within a purposeful task. Engineering students, for example, may use mathematics and scientific principles to design and test a solution, while computer science students may apply programming concepts to develop a functional system. Such experiences can strengthen conceptual understanding because students encounter disciplinary knowledge as a tool for solving problems rather than as information that must simply be memorized.

However, the magnitude and consistency of reported academic benefits varied across studies. Differences were associated with the duration and structure of projects, the degree of student autonomy, instructor support, assessment practices, and availability of resources. Projects that incorporated clear learning objectives, authentic problems, appropriate scaffolding, formative feedback, and opportunities for reflection tended to produce more substantive learning experiences. This finding suggests that the effectiveness of PBL depends not simply on replacing lectures with projects but on the quality and intentionality of project design.

Student Engagement

Student engagement emerged as another consistent outcome across the reviewed literature. Students participating in PBL frequently reported greater interest in learning, increased motivation, and stronger involvement in classroom activities. The opportunity to investigate authentic problems and produce tangible outputs appeared to make learning more meaningful and relevant. Rather than completing isolated exercises with limited connection to professional practice, students were able to see how disciplinary knowledge could contribute to addressing practical challenges.

The collaborative dimension of PBL was particularly important. Many projects required students to work in teams, divide responsibilities, exchange ideas, negotiate disagreements, and collectively develop solutions. These activities created opportunities for students to encounter different perspectives and to explain and defend their reasoning to peers. Collaboration may therefore reinforce problem-solving by requiring students to articulate assumptions, evaluate alternative viewpoints, and reconsider solutions when confronted with evidence or arguments from other team members. Chua and Kong (2021) similarly highlight the importance of engagement and collaboration within STEM project-based environments.

The findings further suggested that PBL can promote learner autonomy. Students were frequently involved in deciding how to approach a problem, identifying information sources, allocating project responsibilities, selecting tools, and determining how to present their final outputs. Such autonomy can encourage students to take greater ownership of their learning. At the same time, the evidence indicated that autonomy needs to be balanced with appropriate instructional guidance. Students who lack sufficient experience with independent inquiry may require scaffolding, milestones, feedback, and clear assessment criteria to prevent project activities from becoming confusing or overly demanding.

The relationship between engagement and problem-solving was therefore considered mutually reinforcing. Students who were more actively engaged had more opportunities to persist when encountering difficulties, seek information, test alternative approaches, and revise unsuccessful solutions. Conversely, successful experiences of solving authentic problems could strengthen students' confidence and motivation. PBL may consequently create a learning cycle in which meaningful tasks encourage engagement, engagement supports sustained inquiry, and successful inquiry reinforces students' willingness to undertake increasingly complex problems.

Personalized Learning

Several studies indicated that PBL can create opportunities for more personalized learning experiences. Unlike highly standardized classroom activities in which all students are expected to complete identical exercises using the same procedures, projects can provide students with some flexibility in selecting topics, defining project questions, determining approaches, assigning responsibilities, and developing final products. This flexibility may allow students to connect learning activities with their interests, prior knowledge, career aspirations, and individual strengths.

Personalization was particularly relevant in interdisciplinary STEM projects. Students may enter a project with different levels of knowledge and skills across mathematics, computing, scientific reasoning, communication, and design. Project-based environments can allow students to contribute according to their existing strengths while simultaneously developing less familiar competencies. For example, a student with strong programming skills may take responsibility for computational modelling while another student contributes expertise in scientific analysis or communication. Through collaboration, students can subsequently develop competencies beyond their initial areas of strength.

The evidence also suggested that PBL can support different approaches to learning by allowing students to investigate problems through multiple pathways. Open-ended projects may accommodate differences in students' interests and preferred ways of demonstrating understanding. Some students may excel in designing prototypes, others in data analysis, programming, experimentation, or oral and written communication. Such diversity can make PBL potentially valuable for inclusive STEM education, although the benefits depend on whether institutions provide equitable access to the resources required for meaningful participation.

Personalization, however, does not necessarily mean that students work entirely independently or at their own pace. Effective project-based learning generally combines student choice with structured milestones, instructor feedback, collaborative expectations, and explicit learning outcomes. Excessive freedom without sufficient scaffolding may disadvantage students who have limited experience with self-directed learning. Thus, the reviewed evidence suggests that personalization is most effective when student autonomy is supported by appropriate instructional structure.

Challenges of PBL Implementation

Despite the generally positive findings, the reviewed studies identified several challenges that may constrain the effectiveness and scalability of PBL in higher education STEM. Resource limitations were among the most frequently reported barriers. STEM projects may require laboratory facilities, specialist equipment, software, computing resources, consumable materials, reliable internet connectivity, and access to digital learning platforms. Where these resources are unavailable or unevenly distributed, students may experience substantial differences in their ability to participate in project activities. Resource constraints may therefore create equity concerns in addition to limiting the quality of project implementation.

Time was another significant challenge. PBL generally requires more instructional time than conventional content delivery because students need opportunities to understand the problem, conduct inquiry, develop solutions, receive feedback, revise their work, and present outcomes. Instructors must also devote considerable time to project planning, supervision, assessment, and coordination. Rigid academic calendars and content-heavy curricula may therefore make it difficult to allocate sufficient time for sustained projects. This challenge is particularly important in programmes where instructors are expected to cover extensive disciplinary content within relatively short semesters.

Instructor preparation was also identified as a major implementation factor. Effective PBL requires instructors to move from primarily transmitting information toward facilitating inquiry, designing authentic problems, coordinating collaboration, providing formative feedback, and supporting students' independent decision-making. Instructors may require professional development to develop these competencies. Without adequate preparation, projects may become poorly structured, overly teacher-directed, or disconnected from intended learning outcomes. The findings therefore support the importance of continuous professional development focused not only on the theory of PBL but also on project design, facilitation, digital tools, collaborative learning, and performance-based assessment.

Assessment standardization presented another substantial challenge. Problem-solving is a multidimensional competency, and students' project outputs may differ considerably even when they are addressing the same learning objectives. Conventional examinations may not adequately capture processes such as problem definition, generation of alternative solutions, collaboration, experimentation, iteration, and reflection. Instructors therefore require assessment frameworks that combine clear criteria with sufficient flexibility to recognize different legitimate solutions. Rubrics, portfolios, project reports, presentations, demonstrations, peer assessment, and reflective activities may provide complementary evidence, but their implementation can increase instructor workload and require substantial assessment expertise. (Table 3)

Table 3: Implementation Challenges

Challenge	Frequency (n=32)
Resource limitations	24
Teacher preparation	19
Assessment standardization	23
Student resistance	8
Administrative support	11

DISCUSSION

The findings of this systematic review indicate that Project-Based Learning (PBL) is a promising pedagogical approach for developing problem-solving competencies among STEM students in higher education. Across the 32 studies included in the review, the dominant pattern was a positive association between participation in PBL and students' abilities to analyse problems, apply disciplinary knowledge, generate solutions, collaborate with others, and evaluate the effectiveness of proposed solutions. This finding supports the broader argument that contemporary STEM education should move beyond the transmission of factual knowledge towards learning environments in which students can apply knowledge to authentic and complex situations (National Academies of Sciences, Engineering, and Medicine, 2020; Odhiambo, 2026). The findings also suggest, however, that PBL does not automatically produce improved problem-solving competence. Rather, its effectiveness appears to depend on the quality of project design, the nature of the problems presented to students, instructor facilitation, assessment practices, student engagement, availability of resources, and institutional support.

A major finding of the review is that PBL provides students with repeated opportunities to engage in different stages of the problem-solving process. Students participating in project-based activities are commonly required to identify or formulate a problem, investigate relevant information, analyse evidence, develop possible solutions, apply disciplinary knowledge, test alternatives, evaluate outcomes, and revise their approaches. These activities are particularly relevant to STEM education because professional STEM problems are frequently characterized by uncertainty, incomplete information, competing constraints, and multiple possible solutions. Unlike highly structured classroom exercises in which the problem, procedure, and expected answer may already be known, project-based tasks require students to make decisions about both the problem-solving process and the eventual solution. This supports the view that PBL can provide an authentic environment for developing higher-order cognitive competencies (Kokotsaki et al., 2016; Larmer et al., 2019).

The relationship between PBL and problem-solving can be understood as an iterative process involving problem identification, inquiry, analysis, solution generation, experimentation, evaluation, and reflection. This process is important because problem-solving competence is multidimensional rather than a single cognitive skill. A student may be able to identify a problem but have difficulty generating alternative solutions, or may develop a technically sound solution without adequately evaluating the evidence supporting it. PBL can provide opportunities for students to practise these different dimensions within a single learning experience. The project environment therefore makes it possible to assess not only whether students arrive at an appropriate solution but also how they reasoned, what evidence they considered, how they responded to failure, and how they modified their strategies.

The findings further demonstrate that PBL strengthens the relationship between theoretical knowledge and practical application. This is particularly important in STEM higher education, where students may acquire substantial amounts of disciplinary knowledge without always developing sufficient opportunities to apply that knowledge to unfamiliar situations. Project-based learning addresses this potential theory-practice gap by embedding concepts within purposeful tasks. Engineering students, for example, can apply mathematics, physics and engineering principles when designing and testing a prototype. Computer science students can apply programming, systems analysis and database knowledge when developing a technological solution. Similarly, students in environmental science can combine scientific investigation, statistics and data analysis to address an environmental problem. In these situations, knowledge becomes a practical resource for solving problems rather than information that students are expected merely to remember.

This finding has important implications for STEM graduate preparedness. Professional STEM practice rarely involves simply reproducing procedures learned in university courses. Graduates are expected to identify problems, determine what information is required, select appropriate methods, work with other professionals, interpret evidence and make decisions under conditions of uncertainty. PBL can provide opportunities to rehearse these professional practices before students enter the workplace. The emphasis on authentic tasks and knowledge application may therefore contribute to the development of graduates who are better prepared to transfer disciplinary knowledge to complex professional situations. This interpretation is consistent with the broader emphasis on integrating technical knowledge with transferable competencies such as critical thinking, collaboration and problem-solving in contemporary STEM education (National Academies of Sciences, Engineering, and Medicine, 2020).

Another important finding concerns the contribution of PBL to analytical reasoning and higher-order thinking. The reviewed studies generally indicated that students involved in project-based environments had opportunities to interpret information, distinguish relevant evidence from irrelevant information, compare alternative explanations, identify relationships among variables, and justify decisions. These processes are central to sophisticated STEM problem-solving. The finding also supports constructivist perspectives of learning, according to which learners develop understanding through active engagement with problems, experiences and social interaction rather than through passive reception of information.

However, the evidence indicates that the cognitive benefits of PBL depend substantially on the level of complexity and structure incorporated into projects. Projects that are excessively structured may provide limited opportunities for independent reasoning because students simply follow predetermined procedures. Conversely, projects that are insufficiently structured may create cognitive overload, particularly among students who have limited experience with independent inquiry. Effective PBL therefore requires an appropriate balance between autonomy and scaffolding. Instructors need to provide clear learning outcomes, project milestones, guiding questions, feedback and assessment criteria while still allowing students meaningful control over how they investigate and solve problems. This balance is particularly important in higher education, where students are expected to develop increasing independence but may still require structured academic support.

Student engagement emerged as another important finding in the review. Students involved in PBL frequently demonstrated greater interest in learning, stronger participation, increased motivation and greater ownership of learning activities. Authentic projects can make STEM learning more meaningful because students can recognize the relationship between academic content and real-world challenges. Rather than completing isolated exercises, students are able to see how their knowledge can be used to produce an outcome, solve a practical problem, or respond to a community or professional need. Such relevance may increase students' willingness to invest effort in difficult learning tasks.

Engagement is particularly significant for problem-solving because complex problems require persistence. Students engaged in authentic projects are likely to encounter unsuccessful experiments, incorrect assumptions, technical difficulties, incomplete information and failed prototypes. PBL can create a learning environment in which such difficulties become part of the learning process rather than simply being treated as failure. Through iteration and feedback, students can revise their approaches and develop greater tolerance for uncertainty. This process can strengthen adaptive problem-solving because students learn that an unsuccessful strategy does not necessarily represent the end of the problem-solving process but may provide information for developing a better approach.

Collaboration represents another mechanism through which PBL can contribute to problem-solving competence. Many of the reviewed studies involved students working in teams in which they were required to divide responsibilities, exchange information, negotiate disagreements and jointly develop solutions. Collaboration exposes students to different perspectives and approaches to the same problem. When students explain and defend their reasoning to peers, they are required to make their assumptions explicit and consider alternative interpretations. Consequently, teamwork should not be viewed merely as a social feature of PBL; it can also function as a cognitive process that promotes deeper reasoning.

The interdisciplinary nature of many STEM projects further strengthens this potential. Contemporary problems such as climate change, renewable energy, environmental sustainability, digital transformation, food security and public health frequently require knowledge from multiple disciplines. PBL can provide a practical structure for integrating such knowledge. Students may need to combine mathematical modelling, scientific analysis, computing, engineering design, economic considerations and communication skills to develop a viable solution. The reviewed evidence therefore suggests that interdisciplinary PBL can help students understand that complex problems cannot always be solved using knowledge from a single disciplinary perspective.

Personalized learning and learner autonomy also emerged as important dimensions of PBL. Project-based environments can provide students with opportunities to make decisions about project topics, research questions, methods, tools, responsibilities and forms of presentation. Such flexibility can accommodate differences in students' interests, prior knowledge and professional aspirations. Students can contribute according to their strengths while also developing competencies outside their existing areas of expertise. For example, a student with strong programming skills may contribute to computational modelling while another student focuses on scientific investigation or communication. Through collaboration, both students can potentially expand their competency profiles.

Nevertheless, the review suggests that personalization should not be interpreted as complete independence from instructional guidance. Student autonomy is most effective when accompanied by appropriate scaffolding. Students need clear expectations, milestones, feedback and assessment criteria to guide their project work. Excessive freedom can create uncertainty and may disproportionately disadvantage students with limited prior experience of self-directed learning. Consequently, effective PBL appears to involve guided autonomy, whereby students exercise meaningful choice within a structured pedagogical framework.

Assessment emerged as one of the most significant challenges affecting PBL implementation. Conventional examinations often focus on individual recall, procedural knowledge and structured problem-solving, whereas PBL involves complex processes such as problem formulation, collaboration, experimentation, iteration and reflection. Consequently, conventional examinations alone may fail to capture important competencies developed through project work. The findings indicate a need for more authentic assessment approaches that evaluate both the processes and products of learning.

Project reports, portfolios, presentations, demonstrations, performance tasks, structured rubrics, peer assessment, self-assessment and reflective reports can provide complementary evidence of problem-solving competence. Such approaches can enable instructors to evaluate whether students understood the problem, selected appropriate evidence, generated alternative solutions, justified their decisions and reflected on the effectiveness of their strategies. However, the use of multiple assessment approaches can increase instructor workload and may create challenges concerning reliability and standardization. Higher education institutions therefore need assessment frameworks that provide common competency criteria while allowing disciplinary flexibility in the way students demonstrate those competencies.

The review also identified resource availability as a major factor influencing the implementation of PBL. STEM projects may require laboratories, specialist equipment, software, computing facilities, internet connectivity, digital platforms and consumable materials. Where these resources are limited or unequally distributed, students may experience different opportunities to participate in project activities. Resource constraints therefore represent not only an implementation challenge but also an equity concern. Institutions need to consider how PBL can be designed around locally available resources while simultaneously investing in essential infrastructure.

This issue is particularly important for African higher education institutions, where financial and infrastructural constraints may affect the implementation of resource-intensive pedagogical approaches. The findings suggest that PBL should not be conceptualized exclusively around expensive technologies or highly specialized laboratory environments. Universities can develop locally relevant projects that use available materials, open-source software, community resources and real-world institutional or environmental problems. Such approaches may make PBL more sustainable while ensuring that students develop problem-solving competencies through authentic experiences. Evidence from Kenya is particularly relevant because it demonstrates the importance of examining PBL within local institutional and socioeconomic conditions rather than assuming that models developed in highly resourced universities can be transferred without modification (Odhiambo, 2026).

Instructor preparedness was another important implementation factor. PBL changes the role of the lecturer from primarily transmitting information to facilitating inquiry, supporting student decision-making, managing collaboration, providing feedback and assessing complex outcomes. These responsibilities require pedagogical competencies that may differ from those associated with traditional lecture-based teaching. Instructors therefore require professional development in project design, facilitation, collaborative learning, formative assessment, digital technologies and interdisciplinary teaching.

The findings suggest that professional development should be continuous rather than limited to one-off training sessions. Faculty members need opportunities to collaborate in developing projects, share experiences, examine student work and refine assessment strategies. Institutional leaders also need to recognize that PBL can initially increase instructor workload because projects require extensive preparation, monitoring and assessment. Without appropriate workload arrangements and administrative support, instructors may find it difficult to sustain high-quality project-based teaching.

The role of technology represents an emerging dimension of PBL. Digital learning platforms, simulations, programming environments, collaborative applications, data-analysis tools and digital fabrication technologies can expand the range of projects that students can undertake. These technologies can facilitate communication, modelling, experimentation, data analysis and presentation. They may also make it possible to support project work beyond the physical classroom and laboratory.

Artificial intelligence presents additional opportunities and challenges. AI-supported tools can assist students with brainstorming, coding, data analysis, information organization and feedback. However, excessive reliance on AI may undermine the very cognitive processes that PBL seeks to develop. If students use AI systems to define problems, generate solutions and produce final outputs without independent evaluation, they may complete projects successfully while developing limited problem-solving competence. Consequently, AI should be positioned as a support for inquiry rather than a substitute for reasoning. Students should be required to explain their decisions, verify information, evaluate AI-generated suggestions and demonstrate their own understanding of the project process.

The geographical distribution of the reviewed literature also deserves attention. The evidence base was internationally diverse, but research from North America, Europe and Asia was more prominent than research from Africa. This uneven distribution limits the extent to which international findings can be generalized to African higher education. Universities differ in class sizes, technological infrastructure, curriculum structures, funding, instructor preparation and student characteristics. Therefore, contextual adaptation is essential.

For Kenya and other African countries, PBL could be particularly valuable when connected to locally relevant STEM challenges. Projects could focus on renewable energy, agricultural productivity, water management, environmental conservation, digital services, sustainable urban development, public health technologies and climate resilience. Such projects can simultaneously develop problem-solving competencies and connect university education with national and community priorities. Increased empirical research in African universities would also contribute to a more geographically balanced evidence base and provide evidence concerning scalable and resource-sensitive models of PBL.

The findings can therefore be interpreted through an integrated conceptual relationship in which PBL design features influence learning processes, which subsequently contribute to problem-solving competencies. Authentic problems, student autonomy, sustained inquiry, collaboration, interdisciplinary learning, feedback and reflection create the conditions for students to engage in analytical reasoning, knowledge application, solution generation, experimentation, evaluation and decision-making. These learning processes can then contribute to broader outcomes such as innovation, adaptability, employability and evidence-informed decision-making.

Importantly, this relationship is moderated by contextual factors. Instructor preparedness, institutional resources, curriculum flexibility, assessment systems, class size, technological access and administrative support can strengthen or weaken the relationship between PBL and problem-solving. This explains why studies examining PBL may report different levels of effectiveness even when they use similar terminology. PBL is not a single standardized intervention; projects vary considerably in duration, complexity, authenticity, student autonomy, disciplinary integration and assessment.

The findings therefore support a shift away from simply asking whether PBL is better than traditional teaching towards asking under what conditions PBL is most effective for developing problem-solving competence. This is an important theoretical and practical distinction. A well-designed project that requires students to investigate an authentic problem, apply disciplinary knowledge, collaborate, test alternatives and reflect on outcomes is fundamentally different from a project that simply requires students to produce an assigned product. The quality of the learning process is therefore more important than the presence of a project label.

The findings have several implications for STEM curriculum development. PBL should be progressively integrated throughout STEM programmes. (Figure 2 and Figure 3)

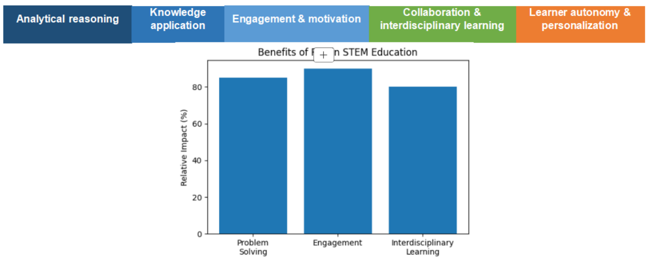

Figure 2. Benefits of PBL in STEM Education

Region	North America	Europe	Asia	Africa	Other/Not specified
Evidence base	Reported	Reported	Reported	Reported	Not quantified in manuscript

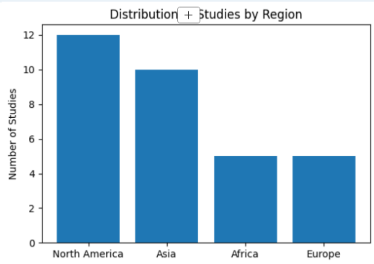

Figure 3. Distribution of Studies by Region

IMPLICATIONS FOR STEM EDUCATION

The findings of this systematic review have important implications for the development, delivery, assessment, and governance of STEM education in higher education. The evidence synthesized from the reviewed studies indicates that Project-Based Learning (PBL) can make a meaningful contribution to the development of problem-solving competencies when it is deliberately designed around authentic problems, sustained inquiry, collaboration, reflection, and application of disciplinary knowledge. The implications extend beyond the classroom because the successful implementation of PBL requires changes in curriculum structures, lecturer roles, assessment practices, institutional resources, technological infrastructure, and educational policy. The findings therefore suggest that PBL should not be treated simply as an alternative classroom activity but as a pedagogical strategy that can contribute to a broader transformation of STEM education.

One of the most important implications concerns STEM curriculum design. The evidence suggests that curricula should provide students with regular opportunities to engage with authentic and complex problems rather than relying predominantly on highly structured exercises with predetermined answers. Problem-solving competence develops when students are required to identify problems, investigate relevant information, formulate possible explanations or solutions, test alternatives, interpret evidence, and revise their approaches. STEM curricula should therefore incorporate projects that require students to integrate knowledge from several areas of their programmes. For example, an engineering project may require the integration of mathematics, physics, computing, materials science, environmental considerations, and economic analysis. Similarly, a computer science project may require students to combine programming, systems analysis, user-centred design, communication, and ethical reasoning. Such curriculum integration can help students understand that professional STEM problems are rarely confined to one disciplinary area.

The findings further imply that PBL should be embedded systematically across programmes rather than introduced as an occasional enrichment activity. A curriculum that includes isolated projects without alignment with programme learning outcomes may provide limited opportunities for sustained development of problem-solving competencies. Institutions should instead establish progressive project experiences in which the complexity of tasks increases as students advance through their programmes. Early projects could emphasize problem identification, information gathering, and basic solution development, while later projects could involve open-ended challenges requiring interdisciplinary collaboration, independent inquiry, experimentation, modelling, and evaluation. Such progression would enable students to develop problem-solving competencies cumulatively and connect classroom learning with increasingly authentic professional situations.

The review also has significant implications for instructional practice. PBL changes the role of the lecturer from primarily transmitting information to facilitating inquiry, guiding students, providing feedback, and creating conditions in which learners can take responsibility for their learning. This does not mean that direct instruction becomes unnecessary. Rather, direct teaching should be strategically integrated into project activities when students require particular concepts, procedures, or technical knowledge to progress. Effective lecturers should therefore identify points at which students need conceptual explanations, demonstrations, scaffolding, or corrective feedback while maintaining sufficient autonomy for students to make decisions and develop their own solutions. This balance between guidance and independence is particularly important because excessive lecturer direction can undermine the student-centred nature of PBL, whereas insufficient support can leave students unable to manage complex tasks effectively.

The findings also emphasize the importance of scaffolding in PBL. Although authentic problems can stimulate higher-order thinking, students may not automatically possess the cognitive, metacognitive, collaborative, and organizational skills necessary to solve them successfully. Lecturers should consequently provide structured support for problem definition, planning, information evaluation, decision-making, experimentation, reflection, and revision. Scaffolding may take the form of guiding questions, problem-solving frameworks, project milestones, exemplars, formative feedback, research skills instruction, peer discussion, and reflective activities. As students become more competent, the level of scaffolding can gradually be reduced to promote independence and self-regulated learning. This approach can ensure that PBL develops genuine problem-solving competence rather than simply transferring responsibility for learning from the lecturer to the student.

Another important implication concerns the preparation of STEM lecturers. The implementation challenges identified in the review indicate that PBL requires pedagogical competencies that may differ from those associated with traditional lecture-centred teaching. Lecturers need to understand how to formulate authentic project problems, manage student teams, facilitate inquiry, provide formative feedback, integrate technology, supervise extended projects, and assess complex learning outcomes. Institutions should therefore incorporate PBL pedagogy into academic staff development programmes. Professional development should not be limited to theoretical workshops; it should provide lecturers with opportunities to design projects, develop assessment rubrics, use digital project-management tools, examine examples of successful PBL implementation, and reflect on their own instructional practice. Continuous professional learning may be particularly important where lecturers have extensive disciplinary expertise but limited preparation in student-centred and experiential pedagogies.

Assessment represents another major implication of the review. Conventional examinations alone may not adequately capture the problem-solving competencies developed through PBL because such competencies involve processes as well as final answers. Assessment should therefore consider students' abilities to define problems, identify and evaluate information, generate alternatives, apply disciplinary knowledge, justify decisions, collaborate effectively, test solutions, respond to feedback, and reflect on outcomes. Authentic assessment approaches such as project reports, portfolios, demonstrations, presentations, design artefacts, reflective journals, performance tasks, peer assessment, and self-assessment can complement conventional examinations. Assessment criteria should be communicated clearly to students through detailed rubrics that distinguish between the quality of the final product and the quality of the problem-solving process.

The review further indicates the importance of assessment validity and reliability. One challenge associated with PBL is that projects may involve group work, making it difficult to determine individual contributions and learning outcomes. Institutions should therefore develop assessment systems that combine group-level and individual-level evidence. Peer evaluation, individual reflections, oral presentations, project diaries, individual reports, and structured interviews can help determine students' individual contributions and understanding. Standardized competency-based rubrics may also improve consistency across lecturers and courses while preserving the flexibility required by project-based learning. Such approaches can help address concerns that PBL assessment may be subjective or overly focused on the appearance of the final product.

The findings have important implications for interdisciplinary STEM education. Many of the problems confronting contemporary societies involve environmental sustainability, public health, energy, artificial intelligence, climate change, infrastructure, food security, and digital transformation. These challenges require knowledge from multiple disciplines and cannot be adequately addressed through isolated disciplinary perspectives. PBL can provide a practical mechanism through which students from different STEM fields collaborate around shared problems. Universities should therefore consider interdisciplinary projects that bring together students from engineering, computing, mathematics, natural sciences, health sciences, and other relevant fields. Such experiences can strengthen systems thinking, communication, teamwork, negotiation, and the ability to integrate different forms of expertise.

Technology integration represents another important implication. Digital technologies can expand the possibilities of PBL by providing students with access to simulations, virtual laboratories, collaborative platforms, data-analysis tools, modelling environments, programming environments, digital fabrication technologies, and online information resources. Technology can also support communication and project management when students work across geographical or institutional boundaries. However, the review suggests that technology should be integrated according to clear pedagogical objectives rather than used simply because it is available. The educational value of digital tools depends on whether they enable students to investigate problems more deeply, test solutions, collaborate more effectively, and receive meaningful feedback. Technology integration can therefore complement PBL, but it should remain subordinate to the development of learning and problem-solving objectives (Odhiambo, 2026).

The emergence of generative artificial intelligence creates additional implications for PBL in STEM education. AI tools can support brainstorming, coding, data analysis, simulation, information organization, and feedback, potentially allowing students to explore complex problems more efficiently. At the same time, unrestricted reliance on AI may reduce opportunities for independent reasoning and make it difficult for lecturers to determine whether students genuinely possess the competencies being assessed. Institutions should therefore establish responsible AI-use guidelines within project-based learning. Students should be expected to disclose significant uses of AI, critically evaluate AI-generated information, verify outputs against credible evidence, and demonstrate their own reasoning and decision-making. Assessment should increasingly emphasize processes, justification, reflection, oral defence, and application rather than relying exclusively on submitted written products. In this way, AI can become a tool that extends students' problem-solving capabilities rather than replacing them.

The review also has implications for institutional infrastructure and resource allocation. Effective STEM projects may require laboratories, equipment, software, internet connectivity, technical materials, maker spaces, fieldwork opportunities, and access to relevant digital resources. Resource limitations can therefore influence both the quality and equity of PBL implementation. Universities should consider the infrastructure requirements of PBL when developing institutional strategic plans and allocating teaching and learning resources. Where resources are limited, institutions can explore low-cost projects based on locally available materials, community problems, open-source software, virtual simulations, and partnerships with industry and other educational institutions. Such approaches can demonstrate that meaningful PBL does not necessarily depend on expensive technologies, provided that projects are appropriately designed and connected to authentic learning objectives.

Equity and inclusion are also important considerations. If PBL depends heavily on students' access to personal computers, high-speed internet, specialist software, laboratory equipment, or other resources outside the university, students from disadvantaged backgrounds may experience unequal opportunities to participate. Institutions should therefore ensure that essential resources are available through university facilities or other supported mechanisms. Project groups should also be structured carefully to ensure that students have meaningful opportunities to contribute rather than allowing technical expertise, socioeconomic status, or access to personal resources to determine participation. Inclusive project design is particularly important in expanding STEM participation and ensuring that the benefits of problem-based and project-based learning are distributed equitably.

The findings have particular significance for Kenyan and African higher education. Although the international literature provides substantial evidence concerning the potential benefits of PBL, implementation conditions differ considerably across educational systems. African universities may face large student populations, constrained laboratory facilities, inadequate digital infrastructure, limited funding, and varying levels of lecturer preparation. These circumstances should not necessarily be interpreted as barriers that make PBL unsuitable. Instead, they highlight the need for context-sensitive models of implementation. Kenyan universities, for example, can develop projects around locally relevant challenges such as water management, renewable energy, agricultural productivity, digital financial services, sustainable urban development, environmental conservation, public health technologies, and climate resilience. Locally grounded projects can make STEM learning more meaningful while enabling students to apply disciplinary knowledge to problems affecting their communities.

The review also suggests that partnerships between universities, industry, government agencies, communities, and professional organizations could strengthen PBL implementation. Industry and community partners can provide authentic problems, technical expertise, data, mentorship, and opportunities for students to test solutions in real-world settings. Such partnerships can also strengthen the alignment between university curricula and labour-market expectations. For Kenyan higher education, this approach may contribute to graduate employability by exposing students to the collaborative, interdisciplinary, technological, and problem-solving demands encountered in professional environments. It can also provide universities with opportunities to contribute directly to national development priorities.

At the policy level, the findings suggest that higher education policies should recognize problem-solving, innovation, collaboration, digital competence, and interdisciplinary learning as important outcomes of STEM education. Quality assurance and curriculum frameworks should provide sufficient flexibility for universities to incorporate authentic and experiential pedagogies while maintaining appropriate academic standards. Policies that emphasize only examination performance may unintentionally discourage institutions from adopting learning approaches that require extended inquiry and performance-based assessment. A broader conception of educational quality should therefore recognize students' ability to apply knowledge, solve unfamiliar problems, work collaboratively, communicate solutions, and adapt to changing circumstances.

Finally, the findings have implications for future research. Although the reviewed literature provides encouraging evidence concerning PBL and problem-solving competence, differences in intervention design, assessment methods, disciplinary contexts, sample characteristics, and geographical settings make direct comparisons difficult. Future studies should employ more rigorous and longitudinal research designs to determine whether improvements in problem-solving skills are sustained beyond the immediate project experience. Researchers should also develop and validate common measures of problem-solving competence that can facilitate comparisons across disciplines and institutions. More evidence is particularly needed from African higher education contexts, including Kenya, because much of the existing literature reflects educational environments with different levels of infrastructure and institutional capacity. Future research should also investigate how PBL interacts with emerging technologies, including generative AI, virtual laboratories, simulation, learning analytics, and collaborative digital platforms.

Overall, the implications of this review indicate that the educational value of PBL depends less on the simple presence of projects and more on the quality of their pedagogical design and institutional implementation. PBL has the potential to reposition STEM education around authentic inquiry, application, collaboration, creativity, and reflective problem-solving. However, realizing this potential requires curriculum alignment, adequately prepared lecturers, appropriate assessment systems, sufficient institutional resources, responsible technology integration, and policies that support active and experiential learning. For higher education institutions seeking to prepare STEM graduates for increasingly complex professional and societal challenges, PBL provides a promising framework for connecting disciplinary knowledge with the capacity to think critically, work collaboratively, adapt to uncertainty, and develop innovative solutions. In this respect, the findings reinforce the broader argument that effective STEM education should move beyond knowledge transmission toward the development of graduates who can mobilize knowledge purposefully in addressing authentic problems (National Academies of Sciences, Engineering, and Medicine, 2020; Odhiambo, 2026). (Table 4)

Table 4: Recommendations for Stakeholders

Stakeholder	Recommendation
Teachers	Continuous PBL and AI-focused professional development
Schools	Invest in digital and PBL infrastructure
Policymakers	Flexible assessment frameworks
Curriculum designers	Interdisciplinary authentic projects
EdTech providers	AI tools for personalized PBL

CONCLUSION

This systematic review of 32 studies published between 2019 and 2026 highlights the significant potential of Project-Based Learning (PBL) in enhancing problem-solving skills among higher education STEM students. The evidence indicates that PBL fosters improved analytical reasoning, application of theoretical knowledge, engagement, collaboration, interdisciplinary understanding, learner autonomy, and performance on problem-solving tasks. Its core value lies in connecting theory with practice, as students engage in well-designed projects that require mobilizing concepts, methods, and skills to tackle complex, authentic problems without predetermined answers. The process of defining issues, gathering information, developing and testing solutions, and reflecting on outcomes cultivates higher-order cognitive abilities, positioning PBL not merely as an alternative activity but as an essential instructional environment that embeds problem-solving into the learning experience.

The findings further indicate that PBL can help develop competencies that extend beyond narrow, cognitive problem-solving. Students frequently collaborate, communicate ideas, divide responsibilities, manage project activities, negotiate alternative viewpoints, and present solutions to authentic audiences. These experiences can strengthen communication, teamwork, leadership, creativity, critical thinking, and self-directed learning. Such competencies are particularly relevant to contemporary STEM workplaces, where professional problems increasingly require interdisciplinary collaboration rather than isolated disciplinary expertise. PBL can therefore contribute to a broader conception of STEM graduate preparedness in which technical knowledge is combined with transferable professional competencies.

The review nevertheless demonstrates that the effectiveness of PBL should not be interpreted as automatic or universal. The implementation of PBL is strongly influenced by the quality of project design and the conditions in which learning occurs. Authenticity of the problem, appropriate levels of student autonomy, instructor scaffolding, formative feedback, opportunities for reflection, meaningful collaboration, adequate time, and alignment between learning objectives and assessment all appear to influence the quality of project-based experiences. Consequently, simply introducing projects into an existing curriculum is unlikely to produce the full range of benefits associated with PBL. Institutions should instead approach PBL as a pedagogical and curricular transformation requiring careful planning, instructor preparation, appropriate resources, and sustained institutional support.

Resource availability is crucial for successful PBL implementation, as STEM projects require labs, equipment, software, internet connectivity, materials, and specialized environments. Financial and infrastructural constraints can limit access, raising concerns about equitable student participation. Institutions should consider low-cost, locally relevant project designs alongside investments in digital infrastructure, open educational resources, simulation technologies, and collaborative tools to prevent resource disparities from widening educational inequalities. Instructor preparedness is equally vital; teachers shift from content delivery to facilitation, requiring ongoing professional development in project design, interdisciplinary teaching, assessment, digital tools, and emerging technologies. Recognizing instructor capacity as a core element is essential for effective PBL adoption.

Assessment also requires particular attention. The development of problem-solving competence cannot always be captured adequately through conventional examinations that focus primarily on individual recall or structured problem solving. PBL requires assessment approaches capable of recognizing the processes as well as the products of learning. Institutions should therefore consider using authentic assessment strategies such as project portfolios, performance tasks, presentations, demonstrations, reflective reports, structured rubrics, peer assessment, and individual learning reflections. Such approaches can provide richer evidence of students' abilities to formulate problems, evaluate alternatives, apply knowledge, collaborate, revise solutions, and justify decisions. At the same time, assessment systems should maintain clear and transparent criteria so that increased flexibility does not compromise reliability or fairness.

The review also highlights the importance of contextualizing PBL within different geographical and institutional environments. Although the international evidence generally supports PBL, much of the available research originates from North America, Europe, and Asia, while evidence from African higher education remains comparatively limited. The inclusion of Kenyan evidence is therefore significant because it demonstrates the relevance of PBL within an African university context while also drawing attention to the importance of infrastructure, institutional capacity, and contextual adaptation (Odhiambo, 2026). PBL should not be implemented through simple replication of models developed in other educational systems. Instead, projects should be adapted to local resources, societal priorities, disciplinary requirements, student characteristics, and institutional realities. Locally relevant projects addressing environmental, technological, health, agricultural, energy, economic, and community challenges may be particularly valuable for connecting STEM education with national development priorities.

The growing use of digital technologies and artificial intelligence presents both opportunities and challenges for the future of PBL. Digital tools can support collaboration, simulation, modeling, data analysis, prototyping, communication, and access to information, while AI-supported systems can provide personalized feedback and assist students at different stages of project development. However, these technologies should complement rather than replace students' cognitive engagement. If students rely excessively on automated systems to define problems, generate solutions, analyze information, or produce final outputs, the very problem-solving competencies that PBL seeks to develop may be weakened. Institutions should therefore establish clear guidelines for responsible technology and AI use and design assessments that require students to demonstrate their reasoning, decision-making, reflection, and ability to justify project outcomes.

From a curriculum perspective, the findings support integrating PBL across STEM programs rather than restricting it to isolated courses or occasional projects. A progressive approach may be particularly appropriate, with students encountering increasingly complex projects as they move through their programs. Early projects can emphasize foundational collaboration and problem identification, while advanced projects can require interdisciplinary inquiry, independent decision-making, prototyping, evaluation, and engagement with external stakeholders. Such curricular progression can help students develop problem-solving competence systematically rather than treating it as an incidental outcome of individual courses.

For policymakers and higher education leaders, the findings suggest that investment in PBL should extend beyond the purchase of equipment or the introduction of new teaching policies. Successful implementation requires alignment among curriculum policy, institutional resources, instructor development, assessment systems, digital infrastructure, and quality assurance mechanisms. Policies should provide sufficient flexibility for instructors to design authentic learning experiences while maintaining clear graduate competency expectations. Funding mechanisms should also recognize the resource requirements associated with experiential STEM education and prioritize equitable access for institutions and students that may otherwise be disadvantaged.

The findings should nevertheless be interpreted in light of several limitations. The review was restricted to English-language studies and therefore may not represent relevant evidence published in other languages. The selected publication period from 2019 to 2026 also means that potentially valuable earlier empirical research was not included in the main evidence base. Considerable methodological heterogeneity existed among the included studies, particularly in relation to research design, sample size, PBL duration, outcome measures, and definitions of problem-solving competence. These differences limited the extent to which findings could be statistically combined and required the use of narrative and thematic synthesis. In addition, the evidence base was geographically uneven, which limits the generalizability of conclusions to underrepresented regions.

Future research should therefore prioritize longitudinal investigations that examine whether problem-solving competencies developed through PBL are retained and transferred into professional and workplace contexts after graduation. Researchers should also conduct larger multi-institutional studies using more consistent measures of problem-solving competence. Comparative research across different STEM disciplines and geographical settings would provide stronger evidence concerning the contextual factors that shape PBL outcomes. There is also a need for research examining cost-effective and scalable approaches to PBL in institutions with limited resources, particularly in African and other developing higher education contexts. Further investigation is warranted into the responsible integration of AI, virtual laboratories, simulation, digital fabrication, and other emerging technologies within project-based STEM education.

In conclusion, the evidence synthesized in this review supports PBL as a promising pedagogical approach for developing problem-solving competencies among STEM students in higher education. Its principal strength is creating authentic learning environments where students apply knowledge, investigate complex problems, collaborate with others, evaluate alternatives, develop solutions, and reflect on their decisions. However, PBL's effectiveness depends substantially on implementation quality and contextual conditions. Adequate resources, prepared instructors, appropriate assessment systems, meaningful project design, technological support, and equitable student participation are essential to realizing its potential. PBL should therefore be understood not merely as a teaching technique but as a broader approach to STEM curriculum design that can connect academic learning with the complex problems graduates are expected to address in professional and societal settings. When supported by appropriate institutional and policy conditions, PBL can make a substantial contribution to preparing STEM graduates who are analytical, adaptable, collaborative, innovative, and capable of developing evidence-informed solutions to complex real-world challenges.

DECLARATION

Author contributions

TO conceptualized the review, developed the review questions and methodology, conducted the literature synthesis and interpretation, and drafted, revised, and approved the final manuscript.

Source of funding

The author declares that no specific external funding was received for this study.

Conflict of interest

The authors declare no competing interest.

Data availability statement

No new primary dataset was generated for this systematic review. The review synthesized findings from published literature identified through the databases and search procedures described in the manuscript.

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