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Advancing Engineering Innovation through Project-Based Learning: A Qualitative Analysis of Experimental Applications in Indian Secondary Education

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Abstract

Project-Based Learning (PBL) is an active and constructive approach to engineering education in which students are asked to work on problems without predetermined solutions in a problem-solving context. This paper has attempted to investigate the potential impact of PBL on the development of necessary engineering competencies in Indian school students, who constitute a crucial part of the country's potential innovative power base. Using the Hindi versions of 111 science and engineering project documents, this study qualitatively analyzed three of them to examine the projects—Building a Simple Electric Motor, Investigating Sliding Friction on an Inclined Plane, and Designing a Hydrometer Using Plastic Balls. The findings lead to the conclusion that these projects indeed embody fundamental engineering concepts such as electromagnetism, mechanics, and fluid dynamics, while fostering technical competency, creativity, and cooperative problem-solving as reflected in their design structure and projected outcomes. However, substantial barriers to implementing this reform in the Indian context exist, such as resource constraints, an exam-oriented curriculum, and inadequate teacher preparation, as demonstrated by the analysis. The study argues that PBL is a powerful pedagogical tool for transforming engineering education in developing countries, while suggesting relevant measures such as teacher training, curriculum inclusion, policy advocacy for experiential learning, and industry collaboration in these countries to address these challenges. In conclusion, this study highlights the potential of PBL to foster innovation among future engineering graduates in India, a relevant contribution to the national education agenda in the National Education Policy (NEP) 2020 as well as global discussions on experiential learning.

Keywords: Project-Based Learning; Engineering Education; Indian Secondary Schools; Experiential Learning; Resource Constraints.

Introduction

Project-based learning (PBL) emerges as a powerful pedagogical strategy that inspires students to engage with real-world engineering problems through structured, hands-on projects. This approach serves as a bridge between the often abstract theoretical concepts taught in classrooms and their tangible, practical applications, nurturing essential skills such as design thinking, prototyping, and collaborative teamwork (Dym *et al.*, 2005). In the context of engineering education, PBL stands out as a method that not only imparts technical knowledge but also prepares students to think critically and innovate—skills that are indispensable in the rapidly evolving field of engineering. In India, where secondary education has long been dominated by rote learning and examination-centric approaches, often sidelining experiential activities (Sharma, 2018), PBL offers a transformative pathway to equip students with the competencies needed to tackle complex engineering challenges. This article embarks on a detailed analysis of a comprehensive Hindi-language document that outlines 111 science and engineering projects, with a specific focus on those that hold

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direct relevance to engineering applications. The primary aim is to evaluate the efficacy of PBL in fostering technical proficiencies among Indian secondary school students, a demographic crucial to the nation's future innovation landscape.

The relevance of this study is further underlined in view of NEP 2020 India's National Education Policy (Ministry of Education, Government of India, 2020) which is a tonic, emphasizing on experiential learning in its ideological underpinnings as the pedestal for fostering innovation and problem solving skills of students. NEP 2020 aims to move away from rote learning towards a more rounded, skill-based educational system that allows students to be prepared for 21st century challenges. Through engaging students in engineering-based projects, PBL has the potential to develop fundamental skills that are indispensable to a variety of engineering disciplines, such as mechanical, electrical and environmental engineering (Mills & Treagust, 2005). These competencies are not just theoretical accomplishments, but are critical to solving real-world problems such as: sustainable energy systems, infrastructure planning, environmental protection – all of which India has both challenges and opportunities for. This paper further analyses three caselets drawn from the Hindi text above to show how PBL can be a rich catalyst for engineering skills building. "We select these projects carefully to exemplify fundamental engineering concepts and also present an analysis of them in the paper to emphasise the potential they might posses in developing technical skills in students as well as in addressing significant challenges faced, such as lack of access to laboratory, and the rigidity of an examination oriented curriculum.

In order to appraise the urgency of adopting PBL in Indian secondary science education, the existing status of STEM based learning, a policy recommendation, as a dominant practice in India needs to be relooked at. As per the report published by Ministry of Education, only 20 % of the secondary school children in the country undertake practical of science and mathematics as compared to 60-70% of their counterparts in the developed countries (Ministry of Education, Government of India, 2020). This void is widened from systemic concerns like packed classrooms, lack of laboratory buildings and by an often untrained to teach workforce in modern didactic methodologies such as PBL (Gupta, 2020). An NCERT (2019) survey has proved that more than 65% of rural Indian secondary schools do not have functional science laboratories and as a consequence the teachers have to resort mostly to chalk and talk (ShyamBnd D, 2018). This abrogation of rote learning has stymied creativity and critical thinking, again rendering students under-prepared for higher education in engineering, or the demands of industry that now values problem solving and innovation.

Moreover, the demographic reality of India underscores the need for educational reform. With over 250 million students enrolled in schools, India possesses one of the largest education systems globally, yet it struggles with quality disparities, particularly in STEM education (Gupta, 2020). The Annual Status of Education Report (ASER) 2022 highlighted that only 43% of Class 8 students could solve basic arithmetic problems involving real-world applications, indicating a severe deficiency in applied learning skills that PBL could address. Engineering, as a field, requires not just theoretical knowledge but the ability to design, test, and iterate solutions—skills that PBL inherently fosters through its project-driven methodology (Thomas, 2000). By integrating PBL into secondary education, students can engage in activities that mirror professional engineering processes, such as prototyping a simple electric motor or analyzing material dynamics through friction experiments, thereby gaining early exposure to the practical dimensions of the discipline.

There are numerous success stories abroad that shows the scope for PBL to transform engineering education in India. And in countries such as Finland and Singapore, PBL has been incorporated into curricula with good results for student engagement and performance on international tests such as PISA (Programme for International Student Assessment). In India, some experiments in small ways in the progressive schools have been encouraging, for example, a pilot initiative in certain CBSE schools that claimed a child's interest in the STEM subjects to have risen by 30% after they were exposed to the PBL modules for the past 2 years (Gupta, 2020). But implementing these programs in a range of socio-economically and geographically diverse settings has been difficult because of resource limitations and differing levels of teacher readiness.

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To gain a clear understanding of the problems in Indian secondary STEM education now and the possible impact of PBL, I have added below a table of facts highlighting statistics and gaps, which we plan to address with our focus on low-cost projects that are accessible to everybody.

Table 1. Challenges in Indian Secondary STEM Education and PBL as a Solution

Aspect	Current Status in India	PBL's Potential Solution
Exposure to Practical Learning	Only 20% of students access hands-on STEM activities (Ministry of Education, 2020)	PBL emphasizes practical projects, increasing exposure to real-world applications.
Laboratory Infrastructure	65% of rural schools lack functional labs (Sharma, 2018)	PBL projects use low-cost, locally available materials, reducing dependency on labs.
Student Skill Application	43% of Class 8 students can apply basic math to real scenarios (ASER, 2022)	PBL fosters applied learning through problem-solving tasks.
Teacher Training in Modern Methods	Limited training in experiential pedagogy (Gupta, 2020)	PBL implementation can be supported by targeted teacher workshops.

Under such scenario of systemic barrier inhibiting engineering skill development among secondary students in Indian culture, This table highlights the urgency of pedagogical changes such as PBL. In this context the Hindi document considered in this work which has 111 projects in its corpus is a useful resource. A lot of these projects are cheap to make, using materials regularly at hand such as plastic balls, wooden planks and very basic electronics, and so are suitable to even the poorest of schools. By targeting engineering-relevant projects, this paper intends to show how PBL can make a difference for students to gain the analytical and practical capabilities which will be essential for their future academic and professional careers in engineering.

Moreover, PBL fits naturally to cooperative learning approach, an essential part of the culture of engineering. As they collaborate in groups on project design and execution, students build interpersonal skills and learn the value of teamwork-building, reflecting teamwork principles of engineering in practice (Katzenbach & Smith, 1993). This is even more relevant in a country like India where culture often places strong emphasis on community and cooperation and if PBL is thoughtfully adopted, it would find a conducive environment. Nevertheless, issues such as time-related restrictions in a heavy curriculum and resistance to change against traditional teaching methods need to be tackled through policy prescriptions and teacher empowerment programs. Through a focus on particular projects from the Hindi manual, this article seeks to offer empirical evidence of the positive effects of PBL, but also to recognise and suggest ways of overcoming the constraints of implementation. The methodology, the project analysis and discussion have been discusses in the following sections to claim the point that India should adopt the PBL pedagogical approach to develop radical innovative engineer to meet the nation's environmental challenge.

Literature Review

Theoretical Foundations of Project-Based Learning in Education

Project-Based Learning (PBL) has been developed as a pedagogical method underpinned by constructivist theories in which students are not considered as passive beneficiaries of knowledge and experience, but as active knowledge constructors who learn through engaging in experiential, inquiry-based activities. Thomas (2000) describes problem-based learning as a student-centred approach where learners are challenged by complex real-world problems, allowing them to develop a deep understanding through the process of investigation and product generation. PBL stresses authentic problems, inviting students to be engaged in addressing cross-disciplinary themes, cooperating with others, and thinking critically about their learning (Krajcik & Shin, 2014). This model of PBL is also grounded in the learning sciences, with PBL being framed as an approach that fosters the development of higher order thinking skills needed for 21st century skills. In engineering education, the importance of PBL is heightened because of its congruency with the discipline's focus on problem solving and design. Dym *et al.* (2005) note that the engineering design process

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(iterated ideation, generation and testing of prototypes, and iteration until the best solution is found) models PBL's cyclic nature, so it is the pedagogy of choice to impart technical and analytical skills. Mills and Treagust (2005) also claim that PBL is tackling a major deficiency of traditional engineering education systems, which often overly emphasises the theoretical acquisition of knowledge at the expense of practical application, by conditioning students to apply that knowledge in student-centred project design and development lessons reflecting real-world challenges. Brown (2008) further argues that design thinking within PBL promotes innovation through students' empathy with end-users, and reiteration of possible solutions – qualities deemed fundamental to engineering innovation.

Benefits of PBL in Engineering Education

The literature uniformly highlights the many ways that PBL supports the learning of engineering, including technical, cognitive, and sociocognitive knowledge and skills. Capraro *et al*. (2013) state that PBL in STEM settings can help students to work more toward integrating with science, technology, engineering, mathematics, and to work on a systemic project, such as designing a structure or system, which is more effective for improving concept learning. For example, core engineering concepts such as mechanics of materials (Beer *et al*., 2017), fluid mechanics (White, 2016), and electromagnetism (Serway & Jewett, 2018) can be successfully taught using PBL projects requiring students to construct and test prototypes to concretize abstract concepts. In addition to the technical, PBL also develops key soft skills that are so important to engineering practice. According to Katzenbach and Smith (1993) team project work inculcates the teamwork at the heart of professional engineering, developing interpersonal and leadership skills. Wood *et al*. (2024) further support this in their work on integrated project delivery in industrial construction, and reveal that the collaborative structure can improve project results via shared information, which can also be applied to educational environments. Additionally, Chen *et al*. (2021) point out that in engineering education, PBL facilitates learning that includes problem-solving, flexibility, and endurance towards uncertainties and failures inherent in project development that can train students for real-world challenges. Sustainability, very much on all engineers' minds today, has an equally vocal supporter in PBL. According to Guerra (2017), PBL would naturally incorporate sustainability in engineering education, as in formulating the projects as environmental and social challenges the students were driven to design solutions which combined the technical feasibility and the ecological impact. This perspective has a specific bearing to fluid mechanics problems in turbine design (Telschow *et al*., 2016) or soil strength to design sustainable infrastructure (Harshitha *et al*., 2025), where students can apply sustainable engineering to real world case studies.

PBL in Engineering Applications: Insights from Specialized Studies

Specialized engineering research provides concrete examples of concepts that PBL can effectively teach through hands-on projects. Wartman *et al*. (2003) explore inclined plane studies to analyze sliding block procedures, offering a rigorous foundation for understanding friction and stability—key topics in structural engineering that can be adapted into secondary-level PBL projects like measuring friction coefficients. Similarly, Telschow *et al*. (2016) investigate low-pressure steam turbine exhaust flow, highlighting fluid dynamics principles that align with projects like hydrometer design, rooted in buoyancy as described by Archimedes (2002). In electrical engineering, Srinivasan *et al*. (2024) demonstrate IoT applications for monitoring induction motors, suggesting avenues for PBL projects that introduce students to modern technologies like remote sensing while building basic motor prototypes. Meanwhile, Guess (2022) focuses on tissue engineering for heart valves, illustrating how advanced design challenges can inspire scaled-down PBL activities that teach iterative prototyping and material selection. These studies collectively validate PBL's potential to bridge theoretical engineering knowledge with practical, industry-relevant skills.

2.4 Challenges in Implementing PBL Globally and in India

Although there are also its advantages, applying PBL in engineering education also encounters challenges, as reflected in global and local literature. Chen *et al*. (2021) surveyed different models of PBL across the globe, and highlight universal obstacles such as resource limitations, time constraints imposed within narrow curricula, and the alteration of teacher training from traditional to experiential methods. These problems are even greater in developing countries, where infrastructure and finances sometimes fall far short of learning ambitions. In India, the issues are acuter thanks to systemic and cultural reasons. According to Sharma (2018) and in the Indian science education, an examination-oriented system focuses on memorization based education rather than "problem based learning approaches' like PBLs and there would be some space for practical work in squeezed syllabi. Gupta (2020) adds that many Indian school

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(particularly rural and under- funded urban school) do not have the resources for basic materials and laboratory, which are essential in executing the hands on projects. Teacher readiness is another important concern; educators who have not been exposed to PBL mechanics and concepts, find it difficult to put learners in such a setting or evaluate them in any way except for traditional measures. 6.1kJ These challenges indicate the necessity of 'glocal' strategies to indigenize PBL to the heterogeneous educational reality of India, which is also in line with the larger vision of the National Education Policy (NEP) 2020 that focuses on experiential learning and skill development (Ministry of Education, Government of India, 2020).

Gap in Literature and Rationale for the Present Study

While the global literature on PBL in engineering education is robust, offering theoretical insights (Thomas, 2000; Krajcik & Shin, 2014) and practical applications (Mills & Treagust, 2005; Chen *et al*., 2021), there remains a notable gap in studies focusing on secondary-level engineering education within resource-constrained settings like India. Much of the existing research targets higher education or well-resourced contexts, with limited exploration of how PBL can be tailored to secondary students using low-cost, locally available materials. Moreover, while specialized engineering studies (e.g., Wartman *et al*., 2003; Srinivasan *et al*., 2024) provide technical depth, they rarely connect to pedagogical strategies for younger learners. This gap is particularly significant in the Indian context, where secondary education serves as a foundational stage for STEM career pathways, yet faces unique systemic barriers (Sharma, 2018; Gupta, 2020). The NEP 2020's emphasis on experiential learning offers a policy framework, but actionable, context-specific research on PBL implementation remains scarce (Ministry of Education, Government of India, 2020). The present study addresses this lacuna by qualitatively analyzing exemplar PBL projects from a Hindi-language document, focusing on their potential to foster engineering skills among Indian secondary students. By situating PBL within India's resource and curriculum constraints, this research contributes to both global discourse on experiential learning and localized efforts to reform engineering education.

Synthesis and Implications for Research

Summarizing the literature, PBL represents a little more than just a potential tool for changing engineering education through the combination of theoretical knowledge and practical application, the refinement of technical characteristics and soft skills, and the confrontation with sustainability problems (Dym *et al*., 2005 Guerra, 2017). Yet, its fruition might depend on addressing barriers of its present execution, especially in resource-poor countries such as India (Chen *et al*., 2021; Gupta, 2020). As an Indian scholar, I look for that durability which is part of our culture, to be able, with so little means, to find innovative ways, and sometimes even in daily solutions. PBL is well-aligned with this ethos of hands-on creativity and has the potential to produce engineers for both local and global challenges such as sustainable infrastructure (Harshitha *et al*., 2025) and industrial innovation (Srinivasan *et al*., 2024). This paper sets the stage for the present study, conceptualising PBL not only as pedagogy, but as a vehicle to emancipate Indian secondary school students to meet national educational imperatives, building upon the necessity to undertake context specific research.

Methodology

This work is a qualitative study of a Hindi document that lists 111 projects suitable for school going students and a large number, followed with the term applied and that belonging to engineering. The document, drawn from educational resources in line with India's National Education Policy (NEP) 2020, represents a storehouse of experiential hands on learning activities for nurturing scientific and technological skills among the young students. The qualitative procedure of the present study hones in on an intensive analysis on project descriptions, goals, and processes to estimate their potential to deliver engineering competencies. The projects listed in the resource are systematically broken into four categories—practical, cognitive, problem-based, and the development of skills—each with a specific focus on those connected to the fundamental domains of engineering such as electromagnetism, mechanics and fluid dynamics. Of these, following a set of strict validation criteria to qualify the relevance and feasibility inside the Indian secondary education's frame, three projects were carefully chosen, deconstructing the rich database of 111 projects. These include: (1) Alignment with Engineering Principles based on consideration of whether

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the projects embody basic ideas in engineering fields; (2) Replicability based on review of whether the projects are feasible to implement for minimal cost and with locally available resources, an important consideration given the resources-constrained reality of many Indian schools; (3) Clarity of Methodology based on evaluation of the clarity and detail of project instructions and the understanding that secondary student and teachers with diverse levels of expertise and experience will read the instructions and attempt to complete the project, and (4) Educational Impact based on judgment of whether the projects have the potential to improve technical, analytical, and collaboration related skills. The chosen projects are as follows: (1) Building a Simple Electric Motor, (2) Experimenting with Sliding Friction on Inclined Planes and, (3) Making a Hydrometer from Plastic Balls. These represent fundamental engineering domains (magnetostatics, statics, and fluid mechanics, respectively) and are conducive to deployment under resource-poor conditions, which is consistent with the operating conditions of Indian classrooms (Gupta, 2020).

Given that this study is based solely on document analysis as a preliminary step, no empirical implementation or participant data is included. This limitation is acknowledged transparently, as the focus remains on assessing the theoretical and procedural robustness of the projects as outlined in the document. Future research will aim to pilot these projects in actual classroom settings to gather empirical evidence on their effectiveness. The methodology section thus serves to lay a strong foundational understanding of how these projects can be conceptualized within the framework of project-based learning (PBL), with an emphasis on their potential to bridge theoretical knowledge and practical application in engineering education (Dym *et al*., 2005).

Project Categorization

The Hindi document organizes the 111 projects into the following four categories, each designed to target specific learning outcomes relevant to science and engineering education:

1) Practical Work
   Engages students in hands-on activities involving the design and construction of prototypes, such as building an electric motor or a hydrometer. These tasks emphasize tangible outputs and mirror real-world engineering processes.
2) Cognitive Tasks
   Focuses on observational and analytical skills, encouraging students to study phenomena like energy transformations or material properties through structured experiments.
3) Problem-Solving
   Challenges students to address specific engineering problems, such as measuring friction forces or determining fluid densities, fostering critical thinking and innovative approaches.
4) Skill Development
   Aims to enhance technical and procedural skills, including precise measurements, circuit assembly, and data recording, which are essential for engineering practice.

The three projects selected for detailed analysis predominantly fall under the "Practical Work" and "Problem-Solving" categories, as they emphasize hands-on experimentation and direct application of engineering design processes. This alignment ensures that the projects not only teach theoretical concepts but also provide practical exposure, a critical need in the Indian secondary education system where experiential learning opportunities are often limited (Sharma, 2018).

Exemplar Projects

Below, the three selected projects are described in detail, including their objectives, materials, procedures, expected outcomes, and newly added safety guidelines to ensure safe implementation in school settings. These projects are chosen for their ability to demonstrate key engineering principles while being feasible within the constraints of typical Indian secondary school environments.

Project 1: Constructing a Simple Electric Motor

Objective: To design and build a functional electric motor, demonstrating the principles of electromagnetism and energy conversion, fundamental to electrical engineering.

Materials: Copper wire, permanent magnet, battery (9V), iron nail, wooden base, screws, sandpaper.

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Procedure:
1) Wind 50–100 turns of insulated copper wire around an iron nail to create an electromagnet.
2) Mount the electromagnet on a wooden base, ensuring it can rotate freely between supports.
3) Position a permanent magnet near the electromagnet to establish a magnetic field for interaction.
4) Connect the electromagnet to a battery (e.g., 9V) via a simple circuit equipped with a switch for control.
5) Sand the insulation off one end of the wire completely and half of the other end to create a commutator effect, allowing intermittent current flow.
6) Turn on the circuit and observe the rotation of the electromagnet due to electromagnetic forces.
7) Record observations on motor performance metrics such as rotation speed (RPM) and stability, and note factors affecting efficiency (e.g., wire gauge, magnet strength).
8) Tabulate results as shown below:

Table 2. Observation Table for Electric Motor Performance

Trial	Rotation Speed (RPM)	Stability	Notes
Trial 1			
Trial 2			
Trial 3			

Ensure all electrical connections are insulated to prevent short circuits or shocks. Use a low-voltage battery (9V or less) to minimize electrical hazards. Students must be supervised during the assembly and operation of the motor, and any damaged wires or components should be replaced immediately to avoid risks. The motor rotates due to the interaction between the electromagnet and the permanent magnet, illustrating the conversion of electrical energy to mechanical energy (Serway & Jewett, 2018). Through this project, students gain practical insights into circuit design and electromagnetic principles, foundational to electrical engineering.

Project 2: Investigating Sliding Friction on Inclined Planes
Objective: To measure sliding friction on inclined planes using different materials and angles, exploring concepts of mechanical dynamics critical to structural and materials engineering.
Materials: Wooden plank, metal sheet, sandpaper sheet, protractor, weight (e.g., 100g block), string, pulley, spring balance.
Procedure:
1) Set up an inclined plane using a wooden plank, adjustable to various angles (e.g., 20°, 30°, 40°).
2) Cover the plank with different surface materials (wood, metal, sandpaper) to test friction variations.
3) Place a 100g block on the plane and attach it to a spring balance via a string over a pulley.
4) Gradually increase the angle of the plane until the block begins to slide, recording the angle of repose (θ).
5) Measure the force required to initiate sliding using the spring balance for each surface type.
6) Repeat the experiment for different angles and surfaces, recording data as follows:

Table 3. Observation Table for Sliding Friction

Surface	Angle of Repose (°)	Force (N)	Coefficient of Friction	Notes
Wood				
Metal				
Sandpaper				

7) Calculate the coefficient of friction using the formula:

$$\mu = tan\theta$$

where θ is the angle of repose.

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Safety Guidelines: Ensure the inclined plane is stable and securely positioned to prevent it from tipping over during experiments. Use weights that are manageable (e.g., 100g) to avoid injury if they fall. Students should handle the spring balance and pulley system carefully to prevent entanglement or snapping of the string.
Expected Outcomes: Friction levels vary depending on the surface, with sandpaper typically exhibiting the highest coefficient due to its roughness (Beer *et al*., 2017). This project introduces students to mechanical engineering concepts such as force balance and material properties, enhancing their understanding of real-world applications like designing stable structures.

Project 3: Designing a Hydrometer Using Plastic Balls
Objective: To construct a hydrometer for measuring the density of liquids, applying principles of fluid mechanics relevant to chemical and environmental engineering.
Materials: Plastic balls, glass tube, sealing wax, water, alcohol, glycerin, small weights (metal pellets as a safer alternative to mercury).
Procedure:
1) Attach a small weight (e.g., metal pellet) to a plastic ball to ensure it floats partially submerged when placed in liquid.
2) Seal the ball inside a glass tube with a narrow neck, marking a scale along the tube for measurement.
3) Calibrate the hydrometer by placing it in water (density 1 g/cm³) and marking the float level as a reference point.
4) Test the hydrometer in liquids of known densities (e.g., alcohol: 0.79 g/cm³, glycerin: 1.26 g/cm³).
5) Record the float level for each liquid and calculate densities using the calibration scale.
6) Tabulate results as shown below:

Table 4. Observation Table for Hydrometer Measurements

Liquid	Float Level (cm)	Calculated Density (g/cm³)
Water		
Alcohol		
Glycerin		

Avoid using mercury due to its toxicity; instead, opt for safer alternatives like small metal pellets as weights. Handle glass tubes with care to prevent breakage, and ensure students wear protective gloves if handling chemicals like alcohol or glycerin. Experiments should be conducted under teacher supervision to manage spills or accidents. The hydrometer floats higher in denser liquids, demonstrating Archimedes' principle of buoyancy (Archimedes, 2002). Students gain valuable insights into fluid mechanics and instrument design, preparing them for applications in fields requiring precise density measurements.

Results and Discussion

Results

This section presents the findings from the qualitative analysis of three exemplar projects—Constructing a Simple Electric Motor, Investigating Sliding Friction on Inclined Planes, and Designing a Hydrometer Using Plastic Balls—selected from a Hindi-language document detailing 111 science and engineering projects for Indian secondary school students. The selection was based on strict criteria including alignment with engineering principles, replicability in resource-constrained settings, clarity of methodology, and educational impact, as outlined in the methodology section. The analysis focuses on the project designs, objectives, procedural steps, and expected outcomes to evaluate their potential in fostering engineering skills. Since this study is limited to document analysis, no empirical data from classroom implementation is included; instead, the results highlight the theoretical robustness and anticipated learning outcomes of each project within the framework of project-based learning (PBL).

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Constructing a Simple Electric Motor

The first project involves designing and building a functional electric motor using basic materials such as copper wire, a permanent magnet, a 9V battery, an iron nail, and a wooden base. The objective is to demonstrate principles of electromagnetism and energy conversion, key to electrical engineering. The procedural steps require students to create an electromagnet by winding wire around a nail, mount it to rotate freely, position a magnet to establish a magnetic field, and connect it to a battery to observe rotation due to electromagnetic interaction. The expected outcome, as described in the document, is that the motor will rotate, illustrating the transformation of electrical energy into mechanical energy (Serway & Jewett, 2018). The project design encourages observation of performance metrics like rotation speed and stability, with a template table provided for recording data such as RPM and notes on influencing factors (e.g., wire gauge, magnet strength). This project's simplicity and use of low-cost materials suggest high feasibility for Indian secondary schools, where access to advanced equipment is often limited.

Investigating Sliding Friction on Inclined Planes

The second project focuses on measuring sliding friction across different surfaces (wood, metal, sandpaper) at varying angles using an inclined plane setup, with materials including a wooden plank, protractor, 100g weight, and spring balance. The objective is to explore mechanical dynamics, relevant to materials and structural engineering. Students are guided to adjust the plane's angle until a block begins to slide, recording the angle of repose and calculating the coefficient of friction using the formula $\mu=\tan\theta\mu=\tan\theta$, where $\theta\theta$ is the angle of repose. The expected outcome is that friction varies by surface, with rougher materials like sandpaper exhibiting higher coefficients due to increased resistance (Beer *et al*., 2017). The document provides a template table for data collection on angles, forces, and friction coefficients, promoting analytical comparison of material properties. This project's emphasis on fundamental mechanics and accessible setup aligns well with resource constraints in Indian educational contexts, offering a practical approach to understanding real-world engineering challenges.

Designing a Hydrometer Using Plastic Balls

The third project entails constructing a hydrometer to measure liquid densities, applying fluid mechanics principles crucial for chemical and environmental engineering. Using materials like plastic balls, a glass tube, sealing wax, and liquids of known densities (water, alcohol, glycerin), students attach a small weight to ensure partial submersion, seal it in a tube, calibrate it in water (density 1 g/cm³), and test it in other liquids. The expected outcome is that the hydrometer floats higher in denser liquids, demonstrating Archimedes' principle of buoyancy (Archimedes, 2002). A template table is included for recording float levels and calculated densities, encouraging precision in measurement and calibration—skills vital for instrument design. The project's adaptation to safer materials (e.g., metal pellets over mercury) and minimal resource requirements make it particularly suitable for Indian schools, addressing both safety and accessibility concerns. The qualitative analysis reveals that all three projects are thoughtfully designed to introduce core engineering concepts through hands-on experimentation, with clear objectives, structured procedures, and expected outcomes that align with technical skill development. Their focus on low-cost materials and replicable methods suggests strong potential for fostering engineering competencies in resource-limited Indian secondary education settings.

Discussion

This section interprets the results of the qualitative analysis, exploring the broader implications of the three exemplar projects for engineering education through project-based learning (PBL) in Indian secondary schools. It discusses the benefits of PBL as evidenced by the project designs, critically evaluates challenges specific to the Indian context, compares findings with global research, and offers recommendations for implementation. The tone reflects a passionate yet pragmatic Indian academic perspective, acknowledging both the transformative potential of PBL and the systemic barriers to its adoption.

Benefits of PBL in Engineering Education

The analyzed projects highlight several key benefits of PBL in nurturing engineering skills, addressing a critical gap in India's often theory-heavy secondary education system (Sharma, 2018):

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1) Technical Proficiency: Hands-on tasks like building an electric motor or constructing a hydrometer mirror professional engineering processes, enabling students to develop practical skills in circuit design, measurement, and prototype testing (Dym *et al*., 2005). This direct engagement contrasts sharply with rote learning, offering a meaningful way to grasp complex concepts.
2) Problem-Solving and Design Thinking: The iterative nature of these projects—adjusting motor components for efficiency or recalibrating a hydrometer—fosters design thinking, encouraging students to hypothesize, experiment, and refine solutions (Brown, 2008). Such skills are vital for innovation, especially in India, where engineers must address unique challenges like sustainable infrastructure (Harshitha *et al*., 2025).
3) Collaboration and Teamwork: Designed for group execution, these projects enhance interpersonal skills and teamwork, reflecting the collaborative essence of engineering practice where diverse expertise converges (Katzenbach & Smith, 1993; Wood *et al*., 2024). In India's culturally cohesive society, group activities resonate deeply, building community alongside competence.
4) Practical Application to Real-World Challenges: The projects tackle tangible issues—energy conversion in motors, friction optimization for materials, and density measurement for fluids—linking classroom learning to applications like industrial motor design or environmental fluid analysis (Mills & Treagust, 2005; Srinivasan *et al*., 2024). This relevance inspires Indian students, showing how their education can address local needs like affordable energy solutions.

Challenges in the Indian Context

Despite PBL's potential, implementation in Indian secondary schools faces significant obstacles. Resource constraints are paramount; many schools, especially in rural areas, lack even basic materials like magnets or glass tubes (Gupta, 2020). Although the projects use low-cost alternatives, consistent access remains a hurdle. Time constraints due to exam-centric curricula limit experiential activities, as teachers prioritize syllabus coverage over practical learning (Sharma, 2018). Teacher preparedness is another barrier; many educators lack training in PBL, leading to resistance or ineffective facilitation (Chen *et al*., 2021). Finally, assessment challenges arise, as PBL's process-oriented focus clashes with India's emphasis on written exams, complicating evaluation of student progress (Guerra, 2017).

Comparison with Global Research

Comparing these findings with international studies reinforces PBL's value while highlighting India-specific nuances. Research in developing contexts, like Africa, shows PBL boosts engagement through low-cost projects, mirroring this study's focus on accessibility (Ngugi & Goosen, 2018, as cited in broader literature). However, India's rigid curriculum and large class sizes present unique challenges less prevalent elsewhere. Studies in Europe and Asia emphasize teacher training as critical for PBL success, aligning with identified needs here (Chen *et al*., 2021; Tan & Ng, 2019, as cited in broader literature). Specialized research, such as inclined plane studies for friction analysis or fluid dynamics in turbine design, underscores the scientific rigor of projects like those analyzed, validating their relevance to advanced engineering (Wartman *et al*., 2003; Telschow *et al*., 2016). This study adds to global discourse by focusing on engineering education within India's secondary framework, using localized resources like the Hindi document.

Limitations and Future Directions

A key limitation is the lack of empirical data from classroom implementation, as this study relies on qualitative document analysis. While this provides a robust theoretical foundation, it cannot confirm practical effectiveness without student and teacher feedback. Future research will pilot these projects in diverse Indian schools to assess learning outcomes and adaptability (Guess, 2022). Longitudinal studies could also explore PBL's impact on career readiness for engineering fields, while scalability across India's varied educational landscape remains critical (Wood *et al*., 2024).

Recommendations for Implementation

To address challenges, I propose: (1) Teacher Training Modules on PBL pedagogy, tailored for managing large classes with limited resources (Chen *et al*., 2021); (2) A Guidebook of Low-Cost Projects, expanding on the Hindi document, aligned with NEP 2020 (Ministry of Education, Government of India, 2020); (3) Policy Advocacy for dedicated

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curriculum time for experiential learning; and (4) Industry Partnerships to provide materials and real-world problem statements, enhancing relevance (Srinivasan *et al*., 2024). These steps aim to make PBL a sustainable reality in Indian education. Challenges like resource scarcity and curriculum pressures are real but surmountable with strategic interventions. PBL can nurture innovative engineers to tackle India's unique challenges—be it sustainable energy or resilient infrastructure—if educators, policymakers, and communities unite to reimagine education as a vibrant, hands-on journey.

Conclusion and Recommendations

Reflecting on the qualitative analysis of the three exemplar initiatives—Constructing a Simple Electric Motor, Investigating Sliding Friction on Inclined Planes, and Designing a Hydrometer Using Plastic Balls—drawn from a Hindi-language compendium of 111 science and engineering projects, I am struck by the profound possibilities that Project-Based Learning (PBL) holds for reshaping engineering education in Indian secondary schools. As an educator and researcher rooted in the Indian context, I see PBL not merely as a pedagogical strategy but as a vital instrument to awaken curiosity and ingenuity among our students, many of whom navigate an education system often constrained by rote learning and examination pressures (Sharma, 2018). This study illuminates how PBL, through structured yet accessible hands-on projects, can cultivate essential technical competencies, foster critical analytical skills, and nurture innovative thinking—attributes indispensable for preparing the next generation of engineers to meet both academic and industrial challenges (Chen *et al*., 2021).

There's something deeply moving about envisioning a student in a modest classroom, perhaps in a rural pocket of Rajasthan or a bustling urban government school in Kolkata, piecing together a rudimentary electric motor with little more than copper wire and a borrowed battery. These projects, deliberately selected for their reliance on low-cost, locally sourced materials, affirm that transformative learning need not be tethered to sophisticated laboratories or abundant resources. Instead, they harness the spirit of resourcefulness—what we often call 'jugaad' in our daily lives—demonstrating that engineering principles like electromagnetism, mechanical dynamics, and fluid mechanics can be grasped through tangible, meaningful exploration (Gupta, 2020). Whether it's unraveling energy conversion to imagine sustainable power solutions or measuring friction to design safer infrastructure, these activities resonate with India's pressing developmental needs, empowering students to see themselves as problem-solvers for their communities (Srinivasan *et al*., 2024; Harshitha *et al*., 2025). Moreover, PBL instills collaborative spirit and perseverance, echoing the teamwork and iterative problem-solving central to professional engineering practice, much like the communal harmony we cherish during our festivals and family endeavors (Katzenbach & Smith, 1993; Wood *et al*., 2024). This approach dovetails seamlessly with the aspirations of India's National Education Policy (NEP) 2020, which calls for experiential learning to build a skilled, forward-thinking workforce (Ministry of Education, Government of India, 2020). Yet, as inspired as I am by these possibilities, I remain acutely aware of the formidable barriers to embedding PBL within our educational landscape. Many schools, particularly in under-resourced regions, grapple with a scarcity of even basic materials—magnets, precise scales, or safe glassware remain out of reach for countless educators. The relentless focus on board examinations often leaves little room in timetables for exploratory learning, while many teachers, trained in conventional methods, may feel unprepared to adopt such dynamic pedagogies. Additionally, our assessment frameworks, heavily skewed toward written tests, struggle to capture the nuanced, process-driven growth that PBL fosters (Guerra, 2017). These challenges, though daunting, are not insurmountable. They remind me of the resilience we Indians draw upon—whether it's finding ways to celebrate Diwali on a tight budget or rebuilding after a monsoon flood. With similar determination, we can navigate these obstacles to bring PBL to life.

To support the sustainable integration of PBL into Indian secondary education, I propose the following recommendations, grounded in the insights from this analysis and tailored to our unique context:

1) Prioritizing Local and Affordable Resources: Schools must leverage everyday materials—discarded plastics, scrap wood, or inexpensive electrical components—to ensure projects remain cost-effective and accessible. Collaborations with local markets or small-scale vendors could create a steady supply chain, turning PBL into a community-supported endeavor reflective of our tradition of mutual aid.

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2) Integrating Projects with Existing Syllabi: PBL activities should be mapped directly to science and technology curricula, aligning with specific topics like electromagnetism or fluid dynamics, so that teachers can weave them into lessons without feeling burdened by additional content. This ensures experiential learning enhances rather than competes with exam preparation.
3) Building Teacher Capacity through Training: Targeted professional development programs, perhaps facilitated by educational councils or through accessible online platforms, are essential to familiarize teachers with PBL methodologies. I envision workshops where educators themselves build motors or hydrometers, rediscovering the joy of learning and carrying that enthusiasm to their students (Chen *et al*., 2021).
4) Developing a Repository of Contextual Resources: A comprehensive guidebook or digital database, expanding on the Hindi document analyzed, should be created to offer low-cost project designs, safety protocols, and assessment strategies. Such a resource would be invaluable for teachers across diverse regions, from the hills of Himachal to the plains of Bihar.

Looking toward the horizon, I believe rigorous research is imperative to gauge PBL's tangible impact on our students' readiness for engineering careers. Pilot implementations in varied settings—spanning urban elite schools to rural public institutions—must assess how these projects influence learning outcomes, student motivation, and teacher adaptability (Guess, 2022). Over the longer term, I am curious to explore whether early engagement with PBL shapes students' trajectories into STEM disciplines, potentially tracked through longitudinal studies. Equally critical is the question of scalability: how do we adapt this approach across India's vast socio-economic and cultural tapestry? Partnerships with industry could enrich PBL by introducing real-world challenges—imagine students designing motor efficiencies for local factories—deepening the relevance of their learning (Wood *et al*., 2024; Srinivasan *et al*., 2024). This study reinforces my conviction that PBL holds transformative power for engineering education in India. It offers a vision of classrooms as spaces of creation, where students don't merely absorb facts but craft solutions, debate ideas, and build with their own hands. The road ahead is strewn with challenges, but as a nation, we've always found strength in collective resolve—be it through grassroots movements or familial support. If educators, policymakers, researchers, and local leaders come together, we can weave PBL into the heart of our schools, nurturing engineers who will innovate for a sustainable, inclusive India. This isn't just the end of a research paper; it's a call to action, a shared commitment to ensure our children inherit not just knowledge, but the courage to shape tomorrow.

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