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Optimizing problem-based learning in civil and electrical engineering: An in-depth study

A.M.N. Kashyap*
Godavari Institute of Engineering & Technology, INDIA

S.V. Sailaja
Godavari Institute of Engineering & Technology, INDIA

B. Murali Krishna
VNR Vignan Jyothi Institute of Engineering & Technology, INDIA

T. Vamseekiran
Jawaharlal Nehru Technological University Hyderabad, INDIA

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Abstract

Problem-Based Learning (PBL) has become a crucial method in engineering education, specifically in the fields of civil and electrical engineering, supporting the desired understanding. This research aims to optimize problem-based learning methods in civil and electrical engineering to enhance the understanding and skills of students in these two disciplines. The type of research conducted is action research with 64 student subjects in the fields of civil and electrical engineering. Quantitative data obtained from the survey will be examined using both descriptive and inferential statistics, depending on the data distribution, and qualitative data from interviews and observations will be analyzed through content analysis. During the problem formulation process, many real issues were identified that could be framed, and these problems can be formulated over various time periods and with multiple sub-cycles. Students also found that PBL activities were highly engaging and motivating. The outcomes of PBL have been very encouraging in achieving the designed graduate attributes, which are rather challenging to accomplish with traditional teaching and learning processes. With the implementation of these activities, teamwork and team-building skills have improved, allowing for holistic growth. The application of PBL has proven to enhance team collaboration and team-building skills, essential components in the students' professional development. This can motivate students and make the learning process more appealing, thus supporting overall growth in the concerned disciplines. This study affirms the effectiveness of PBL in improving student understanding and skills. It indicates a need to further integrate and optimize this method within the engineering curriculum.

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INTRODUCTION

Enhancing academic excellence in the contemporary epoch of Engineering education not only bears a significant impact on generating proficient graduates primed for employment, but also endows such graduates with a confluence of entrepreneurial prowess, accountability, societal responsibility, and professionalism (Loyalka et al., 2014). In order to realize this objective, accreditation entities are established to ensure the standard of education in Higher Education Institutions (HEI's). The NBA, recognized as the National Board of Accreditation in India, operates as an independent entity striving to assure the quality and relevance within the sphere of engineering education, and it has orchestrated a mechanism for the accreditation of programs proffered by

* **Corresponding author:**
A.M.N. Kashyap, Godavari Institute of Engineering & Technology, INDIA. kashyap.civil@giet.ac.in

Engineering institutions (Kulkarni, 2017). By acquiring a permanent signatory status to the Washington Accord in 2014, the NBA's accreditation procedure adheres strictly to Outcome Based Education (OBE) under the philosophy of "Establish Goals with Foresight and Endeavor to Accomplish Them". This philosophy dictates the articulation of educational objectives (outcomes) and subsequently, the orchestration of an educational design that enables students to realize the set objectives.

Such an educational framework yields graduates who are enriched with KSA (Knowledge, Skills, and Attitudes), which constitute the cornerstone of Outcome Based Education (OBE) (Karim & Yin, 2013). These specific objectives are delineated at various junctures of the educational journey, ranging from course levels (Course Outcomes - CO's), Program levels (Program Outcomes - PO's and Program Specific Outcomes - PSO's), to the completion and post-completion phases of the 4-5 years program (Program Educational Objectives - PEO's) (Milligan, 2015; Vasudevan & Sudalaimuthu, 2020). The NBA accreditation procedure encompasses four stages: (a) Articulating objectives and outcomes at the institutional and program levels (b) Crafting a well-structured curriculum to meet all outlined outcomes/objectives, (c) Evolution of a meticulously designed and efficient Teaching-Learning (TL) Process (d) Formulating robust methods of assessment and tools to validate the learning process of graduates and supervise them through a system of continuous improvement processes (Gray & Patil, 2009). The Revised Bloom's Taxonomy is employed to gauge the skill sets amassed by the Engineering Graduates (Krathwohl, 2022).

Within this context, both the Teaching-Learning (TL) process and the assessment methodologies strive to pinpoint an appropriate aspect of professionalism within the teaching community. This professionalism is bifurcated into two subcategories, namely Restricted and Extended professionalism. The former focuses solely on advanced competence within the classroom, encompassing effective teaching skills and the nurturing of strong relationships with learners. Conversely, Extended professionalism targets additional attitudes within educators, such as their societal and community work competence, all underpinned by theoretical substantiation, research, and good practice. Consequently, it is paramount for an educator to discern and demonstrate professionalism to bolster the advanced learning capabilities of students. This heightened professionalism among educator aids in procuring well-designed graduate attributes or PO's as stipulated by the NBA, thereby embracing all the requisites of contemporary educational demands.

The educational methodologies of Activity-Oriented Learning (AOL) and Problem-Based Learning (PBL) have garnered significant attention within engineering education recently. As per Masek & Yamin (2011), these two techniques harbor the potential to enrich students' conceptual understanding and practical skills, especially within the sphere of civil and electrical engineering. To address the PO's, it is essential to incorporate Activity-Oriented Learning (AOL) within the Teaching-Learning process. AOL's inception can be traced back to the era of World War II, pioneered by a British gentleman, Mr. David H., who is recognized as an innovator in the AOL concept (Tarnoff et al., 2022). AOL is a pedagogical strategy that entails diverse activity modes such as quizzes, group discussions, brainstorming, educational games, debates, problem-solving methods, field works, projects, and mind mapping during the TL process. Activity-oriented learning techniques offer a superior level of cognitive engagement compared to passive learning techniques, potentially leading to deeper and more significant learning experiences (Magana et al., 2017). Within this methodology, students learn by engaging in activities within a simulated work environment and are also prompted to tackle real-time issues. In this specific pedagogical approach, both the students and the educator act as active participants. The core objective involves anchoring the learning process in subject-related activities and hands-on experiments. AOL not only ensures a near-constant learning trajectory for students but also bolsters their abilities in active participation, analytical thinking, critical reasoning, knowledge sharing, teamwork, problem-solving skills, self-paced learning, and social and environmental consciousness (Tarnoff et al., 2022). AOL's flexibility is particularly beneficial when integrated with problem-based learning.

Problem-Based Learning (PBL), in particular, situates students within a challenging and realistic context, necessitating them to employ their acquired knowledge and skills to solve tangible problems (Adenan, 2022). Existing literature on problem-based learning within engineering education highlights numerous educational and professional advantages derived from this approach. Specifically, PBL has proven effective in the sphere of biomedical engineering education, notably in spurring student motivation, enhancing knowledge retention, and honing problem-solving, communication, and teamwork skills (Clyne & Billiar, 2016). Problem-based and project-organized learning (PBL) are often perceived as paragons of the future curriculum, embodying elements such as problem orientation, communication, teamwork, interdisciplinarity, participant-directed learning, critical thinking, and creativity (Guerra & Rodriguez, 2021). Despite this method's enormous potential, several challenges persist. A paramount challenge resides in formulating and implementing an efficacious PBL problem. The chosen problem should be pertinent to the course material while being complex enough to stimulate critical thinking and problem-solving. Simultaneously, sufficient support must be available for students to prevent them from feeling overwhelmed.

Although PBL has been extensively employed and acknowledged as an efficacious learning method across various disciplines, its application within civil and electrical engineering education continues to face hurdles, and the research landscape remains uncharted. As per recent research conducted by Katageri & Raikar (2022), establishing and executing effective PBL issues pertinent to the civil and electrical engineering context remains an unresolved matter. Constructing PBL problems that apply to real-world situations while catering to civil and electrical engineering demands an in-depth comprehension of both disciplines and formidable pedagogical skills from educators. This aligns with Yadav et al. (2011), who found that many educators still grapple with this aspect. Furthermore, despite Katageri & Raikar (2022) evaluation of PBL's effectiveness within an engineering context, empirical evidence explicitly focused on civil and electrical engineering remains scarce. This leaves a knowledge gap regarding how well-designed PBL problems can impact the learning capabilities of both students and educators within this field. This void necessitates further research given the rapid technological advancements and evolving industry demands. The skills anticipated from today's civil and electrical engineering graduates may diverge from those of the past, and effective PBL methods must be designed to equip learners for these emerging challenges. Hence, this study aims to bolster PBL within civil and electrical engineering education to enhance the attainment of graduate attributes. Of the numerous PBL problems applied, one particular problem regarding the mechanical strength characteristics of concrete for civil engineering students and the predetermination of various performance characteristics of single-phase transformers for electrical engineering students is analyzed and discussed in detail.

METHOD

This research will employ an Action Research design, a methodology well-suited for practical change and enhanced comprehension (Coghlan, 2019). Within the educational setting, Action Research permits educators to design and administer changes in the teaching-learning process, while concurrently gauging the impact of these alterations. This study will utilize Action Research to scrutinize the efficacy of Problem-Based Learning (PBL) in civil and electrical engineering.

Participants

The participants for this study included 64 students in civil and electrical engineering. Their participation is pivotal in assessing the processes and outcomes of PBL, and providing feedback on the quality and applicability of the tasks conceived within the PBL framework. As part of the Action Research design, participants will participate in cyclical phases of planning, action, and observation (Lewin, 1946).

Instruments

Multiple research instruments will be employed to gather data in this study. For quantitative measurements, a survey is developed to evaluate participants' perceptions of PBL and its influence on their learning. For qualitative data, in-depth interviews and class observations will be utilized. Class observations will provide researchers with an understanding of how PBL is implemented and how participants engage with this method. On the other hand, interviews will offer further insights into participants' perceptions, experiences, and responses towards PBL (Creswell & Creswell, 2017).

Data Analysis

In the analysis phase, the quantitative data derived from the survey will be examined using both descriptive and inferential statistics, contingent on the data's nature and distribution. The qualitative data from interviews and observations will be analyzed through content or thematic analysis (Cooper et al., 2012). The researchers will seek patterns or themes in the data, which can contribute to a more profound understanding of participants' experiences and the PBL process. This process will include coding the data, identifying themes, and interpreting the results. This comprehensive procedure will be conducted with a critical and reflective attitude, with the ultimate goal of comprehending the execution of PBL within engineering education.

RESULTS AND DISCUSSION

PBL Problems in Engineering

In developing an effective Problem-Based Learning (PBL) approach, it is vital to comprehend its underlying foundation. This is not merely about presenting a problem, but also about how the applied structure and principles can support the student learning process. The PBL issues encompass five fundamental principles, as follows.

a. Realistic and Authentic [Pr1]
b. Integrated and Constructive [Pr2]
c. Extend appropriate complexity [Pr3]
d. Promoting self-paced and lifelong learning [Pr4]
e. Stimulate critical thinking and meta-cognitive skills[Pr5]

Designing PBL problems with technical references encompassing several stages that require literacy represents an innovative approach in education and teaching. Based on research conducted by Simanjuntak et al. (2021), this method is crafted to enhance problem-solving skills. The study underscores the urgent implementation of PBL within civil and electrical engineering at two distinct institutions. The primary focus is on 24-hour problems over four monthly cycles, divided into three sub-cycles with three hours of learning per activity. This research is tailored for third-year students and involves daily lab practices in Advanced Concrete Technology and Civil and Electrical Machinery. Two specific issues identified, namely "Normal Grade Concrete Mechanical Strength Characteristics" and "Preliminary Determination of Various Single-Phase Transformer Performance Characteristics," are presented with the aim to achieve the anticipated outcomes by learners and educators. Details related to PBL problems for the civil engineering domain are provided in Table 1.

Table 1. PBL Problem Details for Civil Engineering Domain

Cycle	Problem Statement: Mechanical Strength Characteristic of normal grade concrete	Time Duration	PBL Principles
I	Sub-cycle: 1 Identification of ingredients required to prepare normal strength concrete	15 Minutes	Pr1-Pr5
	Sub-cycle:2 Mix design processby using Indian Standard Code of practice IS:10262-2009	45 Minutes	Pr1-Pr5
	Sub-cycle:3 Batchingof requiredmaterials and initial tests like specific gravity, water absorption, fineness modulus for ingredients and queries and discussions in cycle:1	120 Minutes	Pr1-Pr5
II	Sub-cycle:4 Mixing of ingredientsto prepare desiredconcrete mix in concrete mixer	20 Minutes	Pr1-Pr5
	Sub-cycle:5 Testing of freshproperties of concrete like workability and placing the concrete mix in cubes, cylinders and prismsmoulds	90 Minutes	Pr1-Pr5
	Sub-cycle:6 Compaction and finishing of concretefilled moulds and queries and discussions in cycle:2	70 Minutes	Pr1-Pr5
III	Sub-cycle:7 Demolding of specimens after 24 hours of curing	120 Minutes	Pr1-Pr5
	Sub-cycle:8 Exposing to roomtemperature	20 Minutes	Pr1-Pr5
	Sub-cycle:9 Placing the specimens in waterfor curing process, queries and discussions in cycle:3	40 Minutes Cycle:3 is resumed for28 days for curing process	Pr1-Pr5
IV	Sub-cycle:10 Specimens taken outfrom curing and exposed to room temperature	30 Minutes	Pr1-Pr5
	Sub-cycle:11 Testingof specimens for their corresponding test results	60 Minutes	Pr1-Pr5
	Sub-cycle:12 Discussions related with the total process,Experiences of Learners and Evaluation of Outcomes	90 Minutes	Pr1-Pr5

Table 1 shows the details of the PBL problems for the civil engineering domain in order to understand the process of creating standard-quality concrete, and the research has been designed using twelve sub-cycles. The first sub-cycle focuses on the identification and selection of required materials, a crucial step emphasized by Singh and Bhardwaj (2020) as key in achieving the desired concrete quality. The second sub-cycle involves mix design using the Indian Standard Practice Code, while the third sub-cycle outlines the process of material grouping and preliminary testing. This process, according to Alexander and Beushausen (2019), is vital in controlling the quality of concrete. The fourth to sixth sub-cycles handle the mixing of materials, testing fresh concrete properties, and compaction and completion of molds, with emphasis on quality and structural integrity. The seventh to tenth sub-cycles deal with the stages of specimen demolding, room temperature exposure, curing process, and specimen retrieval from curing. Akca and Özyurt (2018) highlight the importance of proper control in these stages. The eleventh sub-cycle is specimen testing, which, according to Mehta and Monteiro (2014), must be carried out rigorously for accurate results. The final sub-cycle is a discussion and reflection on the overall process, a key aspect of the experimental learning process.

In the field of electrical engineering, the Problem-Based Learning (PBL) approach becomes an invaluable tool in teaching and learning. PBL not only aids in building a strong conceptual understanding but also stimulates the development of critical analytical and problem-solving skills essential in engineering practice. Specifically, in electrical engineering, PBL can be used to explore and delve into various complex technical problems representing real challenges in the industry. In this context, Table 2 will present specific details of a PBL problem specially formulated for electrical engineering, highlighting the key aspects of the problem and how it can be integrated into learning.

Table 2. PBL Problem details for Electrical Engineering

Cycle	Problem Statement: Predetermination of various performance characteristics of a single phase transformer	Time Duration	PBL principles
I	Sub-cycle: 1 Identification ofequipment (transformer,measuring meters, rheostats, variac)	15 Minutes	Pr1-Pr5
	Sub-cycle:2 Defining a transformer, working principles	45 Minutes	Pr1-Pr5
	Sub-cycle:3 Operation of transformer and queries and discussionsin cycle:1	120 Minutes	Pr1-Pr5
II	Sub-cycle:4 Study on design of a transformer	120 Minutes	Pr1-Pr5
	Sub-cycle:5 Identification ofcooling methods of a transformer	30 Minutes	Pr1-Pr5
	Sub-cycle:6 Queries and discussions in cycle:2	30 Minutes	Pr1-Pr5
III	Sub-cycle:7 Mathematical modelling for E.M.Fequation of a transformer	120 Minutes	Pr1-Pr5
	Sub-cycle:8 Identification of leakages in a transformer	40 Minutes	Pr1-Pr5
	Sub-cycle:9 Queries and discussions in cycle:3	20 Minutes	Pr1-Pr5

IV	Sub-cycle:10 Open Circuit test andShort Circuit Test	90 Minutes	Pr1-Pr5
	Sub-cycle:11 Calculation of various parameters from the theoretical and practical study	60 Minutes	Pr1-Pr5
	Sub-cycle:12 Discussions related	30 Minutes	Pr1-Pr5

A comprehensive study on transformers, various sub-cycles are defined to address key aspects. The first sub-cycle emphasizes the identification of equipment such as transformers, measuring meters, rheostats, and variacs, which, according to the research findings, form the foundation of efficient and safe operation. The second and third sub-cycles delve deeper into the definition and operation of transformers, opening insights into common problems and potential solutions. Design studies, as explored in the fourth sub-cycle, reveal crucial factors in effective design, while the fifth and sixth sub-cycles discuss transformer cooling and further working principles. Mathematical modeling in the seventh sub-cycle and leakage identification in the eighth provide further information about the parameters influencing transformer performance. The ninth to eleventh sub-cycles handle practical aspects such as open and short circuit testing, and cooling methods, while the twelfth sub-cycle concludes with an integrated discussion that synthesizes all findings. Through this phased approach, the study successfully provides an in-depth framework for understanding and evaluating transformers, paving the way for further research in this field.

Workflow Process

The PBL concept is introduced to the III B. Tech Civil and Electrical Engineering students by considering two different concepts within their respective domain. The problem is given in the form of presentation explaining the learning objectives of the problem and the expected outcomes of the study along with the given time period. As this problem is based upon laboratory activity, the learners showed keen interest to carry out the problem. The learners are divided into a group of 4 members and the total number of groups is 15 for strength 60 in each domain. They were asked to carry out their problem in three phases and the work flow process is furnished as under. They were asked to solve their problem in three stages and the workflow process was completed as presented in Table 3.

Table 3. Workflow Process Phase

Phase	Implementation PBL
1	The learners initially work in group in order to resolve the given problem in which they emphasize and ideate the problem, define the requirements that are needed to resolve the problem and they try to resolve the problem with the help of acquired knowledge.
2	The learners discuss the problem, identify the requirement for additional and suitable resources, they explore and gain suitable and relevant knowledge and interact with each other to resolve the given problem.
3	The learners meet again and share the acquired knowledge with one another and have a peer review and they finalize the solution for the given set of problem.

The results of this study emphasize the importance of a collaborative approach in problem-solving, starting from problem identification, resource exploration, to the discovery of solutions through group work, in-depth discussions, and peer review. This research underscores how interaction and collaboration among learners allow the exchange of ideas leading to more accurate solutions and provide guidance for designing more effective and meaningful learning experiences.

Student Response on PBL Learning

After getting the desired and expected solution by the learners to the given problem, the students are asked to share their views and feedback on this activity. The feedback is taken from all the learners within the classroom. The feedback from the learners is furnished in Table 4.

Table 4. Feedback and Responses of The Learnes

No	Qustion	QuestionType	Response and Feedback
1.	Do you know about PBL prior to this activity?	Closed Ended (Yes/No)	5%, Yes, we have undergone with this activity earlier i.e., in schooling level
2.	Did the teachers helped during the process of PBL, if there is any dead lock?	Closed Ended (Yes/No)	100%, yes, the teachers helped us in the processof PBL
3.	Do you experience that the given problems are associated with realtime applications?	Closed Ended (Yes/No)	100%, yes, as the given problem isahybrid model of laboratory experiment and theory part, we experienced practicality by this activity
4.	Did you enjoy working individually or group to resolve thegiven problem?	Closed Ended (Yes/No)	100%, yes, In the early stages of activity, some ofthe students did not show interesttowards workingingroups, but as the time passes by, they collaborated with one another to resolve the problem.
5.	Did the PBL enabled in enhancement ofteam work and interpersonal skills?	Closed Ended (Yes/No)	100%, yes
6.	Please provide your feedback ofPBL activity?	Open Ended(Yes/No)	a. With the help of sub-cycles, we are able tounderstand clearly the process to resolve a problem b. It was a goodexperience c. It can be utilizedfor other subjects also

The findings of this study demonstrate significant effectiveness in the implementation of Problem-Based Learning (PBL) within education. A total of 5% of respondents acknowledged being familiar with this activity since their school level, while unanimously, that is, 100%, agreed that the teachers assisted them in the PBL process. Furthermore, all respondents conceded that the hybrid model of laboratory experimentation and theory provided valuable practical experience. Though there were initial challenges with some students being reluctant to work in groups, the research shows that over time, collaboration grew and problems were resolved. Indeed, the universal agreement on this PBL method revealed three main findings: the sub-cycles aided in clear understanding to solve problems, the experience was rated positively, and the method was considered applicable to other subjects. The results of this study underline the value of structured and focused learning, and support the further integration of the PBL method across various academic disciplines.

In the PBL process that has been described, there are several important stages that show how students collaborate and use their knowledge to solve problems. As stated by Thakuri (2023) and Wiznia et al. (2012), collaboration and ideas are important components in the PBL approach. This is shown in the first stage where students work in groups to determine and formulate problems, and try to find solutions using the knowledge they already have. This concept reflects the theory of social constructivism, in which knowledge is constructed through interaction and discussion between individuals (Burr & Dick, 2017).

In the second and third phases, the learning process becomes more in-depth, in line with what was stated by Ehrenberg & Häggblom (2007) that PBL facilitates research-based learning where students actively seek and learn new information needed to solve problems. The third phase, which involves meeting again and sharing the knowledge that has been acquired, also shows the importance of peer-review in the PBL process. This emphasizes the reflective aspect of learning, in which students discuss and evaluate their solutions prior to finalization (Ge & Land, 2013).

CONCLUSIONS

Though the formulation of PBL (Problem-Based Learning) problems for engineering streams is quite challenging, it is also highly engaging. During the problem formulation process, numerous real-world issues were discovered that could be framed, and these problems could be articulated over various time periods and through multiple sub-cycles. The students also found that PBL-based activities were highly appealing and motivating. The outcomes of PBL were very encouraging in achieving the intended graduate attributes, something quite challenging to attain with traditional teaching and learning processes. The results indicate that through the implementation of these activities, teamwork and team-building skills were enhanced, allowing them to grow holistically.

The importance of implementing the PBL (Problem-Based Learning) approach in engineering education, specifically in civil and electrical engineering, cannot be overstated. Formulating and applying effective PBL problems requires careful consideration, time, and adequate support for students. Consequently, this calls for strong institutional backing, both in terms of resources and teacher training. For further research, it is recommended to delve deeper into how to formulate effective PBL problems, as well as how to support students in this learning process. Specifically, it would be highly intriguing to evaluate how variations in PBL problem formulation and learning approaches can influence student learning outcomes.

AUTHOR CONTRIBUTION STATEMENT

AMN : Idea, desain, and conceptualizon, analysis, and editing
SVS : Drafting the manuscript, correction, directing, and final approval
BMK : Analysis, reviewing, correction
TV : Editing, reviewing, and proofreading.

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