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Problem-Based Learning Experience in Civil Engineering

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Abstract : The activity-based learning (ABL) is essential to be incorporated in teaching-learning process to attain graduate attributes in engineering education. Problem-based leaning (PBL) is one of such activities. This paper demonstrates the crafting of authentic PBL problems in Civil Engineering discipline. The problems can be of different durations and can be segregated in to various phases based on the knowledge acquired by the students and problem requirements. The experience of one phase of a PBL problem carried out is promising in exhibiting the improvement of skills of the students in solving the problems in the real-world scenario. PBL activity if incorporated in engineering curriculum will definitely result in enhanced Teaching-Learning process.

Keywords: Accreditation; Activity Based Learning; Problem-Based Learning; Civil Engineering.

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1. Introduction

The improvement in academic quality in the present state of the art Engineering Education, not only plays a vital role in producing employable graduates but also equip the graduates with blend of entrepreneurial skills, social responsibility and accountability along with professionalism. To accomplish such a goal, the accrediting bodies are established to check the quality of higher education. The National Board of Accreditation (NBA), in India an independent autonomous body with the objectives of assurance of quality and relevant technical education, brought a mechanism of accrediting the programs offered by technical institutions. After being the permanent signatory of the Washing Accord on 13th June 2014, the NBA accreditation process follows Outcome Based Education (OBE) whose philosophy is "Keep the Goal in Mind and Work to Achieve it". That is to set the clear education goals (outcomes) and then Design Educational Process that enables the students to meet those goals.

The outcomes of such an education system makes the Graduate Engineers well-equipped with Knowledge, Skills and Attitudes which forms the basis for OBE. These outcomes or objectives are defined at different levels of educational process right from course levels (Course Outcomes - Cos), program levels (Program Outcomes – POs and Program Specific Outcomes - PSOs) up to and after completion

of 4 to 5 years of program (Program Educational Objectives – PEOs).

The accreditation process of NBA involves four phases: (1) Defining the objectives and outcomes at the institute and program levels, (2) Designing a well-structured Curriculum to meet all the defined objectives/outcomes, (3) Development of a well-designed and effective Teaching-Learning Process and (4) Framing Suitable Assessment Methods and Tools to check the learning of graduates and monitor them through a continuous improvement process. Revised Bloom's Taxonomy is employed to measure the skillsets attained by the graduates.

In this regard, the Teaching-Learning phase as well as assessment methods look for an apt professionalism in the faculty members. There are two categories of professionalism, namely Restricted and Extended Professionalisms. The restricted professionalism emphasizes only on high level of classroom competence such as teaching skills and good relationships with students. On the other hand, the extended professionalism demands additional attitudes in the teachers such as their work in the wider context of community and society, substantiated by theory, research, and current exemplars of good practice. Hence, it is utmost important for a teacher to exhibit extended professionalism to support greater learning capabilities in the students. The extended professionalism of teachers helps in meeting the well-crafted Graduate Attributes or Program Outcomes (POs) of NBA, which encompass all the needs of the present-day educational requirements.

To address these POs, the incorporation of Activity Based Learning (ABL) in Teaching-Learning process becomes essential. The history of ABL is sketched back during 1944 around World War II. Mr. David Horsburgh, British man, who came to India and settle down here, is considered as pioneer of ABL. ABL is a pedagogical approach wherein the various modes of activities are incorporated. The various activities of ABL (not limited to) are: Quizzes, Group Discussions, Educational Games, Brainstorming, Problem Solving, Debates, Discovery Learning, Projects, Field Works, Experimentation, Concept Mapping and many more. In this pedagogy, students learn by performing activities in the simulated work environment. In addition, they also explore themselves to take on the real-world task. In this pedagogy, both student and teacher become active participant. The core objective encompasses that learning should be based on doing some hands-on experiments and activities. ABL not only helps in maintaining the learning curve nearly constant but also enhances abilities of the students in participation, analyzing ability, critical thinking, knowledge sharing, communication, team-work, problem solving, self-driven learning, concerns about environment and society and many more. The present study focusses on the implementation of PBL in Civil Engineering stream to support in enhancing the attainment of graduate attributes of the students. Amongst many PBL problems crafted, the details of one problem on Planning and Designing of Residential Building is presented.

2. Problem-based Learning

Problem-Based Learning is a type of ABL in which learners define a process in finding the solution to the complex problem (frequently real world) by using one or more concepts or principles along with the required information processed during their learning. PBL is a methodological Teaching-Learning process wherein the teacher creates nearly a real world and unfamiliar situation to the learners, in which they are expected to solve the problem using the acquired knowledge, skills, attitudes and application of the same in the context of the unfamiliar situation. Further, the learner shall possess the additional required knowledge to solve the problem, thus becoming self-directed learner.

The pioneering work on this novel approach in Teaching-Learning was done by Barrows and Tamblyn (1980), who define the approach as the learning that results from the process of working towards an understanding or resolution of a problem. Even though, the PBL has its origin in the Education of Law wherein the situation of court of law is created in the classroom for simulating the legal practice, Barrows and Tamblyn (1980) devised it in the School of Medicine at McMaster University in Canada in the 60s and 70s with its first application to the sciences. Since then, PBL has made its signature in different areas of study, including the various branches of engineering and architecture (Mahendru and Mahindru, 2011; Jamaludin et al., 2012; Rodriguez and Fernández, 2016; Holmes and Beagon, 2015; Larson et al., 2018; Thakur et al., 2018b; Barg et al.,2000 and many more).

Thakur et al. (2018a) presented a detailed review on the effect of PBL in developing various skills such as critical thinking, problem solving, self-directed and

self-regulated learning skills, reasoning skills, leadership skills, team skills and cognitive skills considering different layers of learning from schools to workplace. They further presented (Thakur et al., 2018b) the implementation of PBL in learning biology by 9th class students. They reported the enjoyable experience of the students in learning biology at their own pace along with finding new things besides the syllabus prescribed in the textbook. Kuvac and Koc (2019) found that PBL is more effective than the traditional teaching approach in the development of environmental attitudes in preservice science teachers. The study was undertaken with an experimental design having pre-test and post-test control group consisting of 51 junior preservice science teachers.

According to John Dewey (1916), the first approach in any institute is that the teacher shall create and present an empirical situation replicating the real-world outside the school, which demands the students, their experience in handling the situation, the sort of occupations that interest and engage activity in ordinary life. They give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking, or the intentional noting of connections; learning naturally results. According to Boud, the principal idea behind PBL is that the starting point for learning should be a problem, a query, or a puzzle that the learner wishes to solve (Boud and Feletti, 1991). The common features involved in PBL approach are:

1. Learning is initiated by a problem,

2. Problems are based on complex and real-world situations,

3. Information needed to solve problem is not given initially, however students identify, and

4. Find and use appropriate resources and work in permanent groups.

More importantly, in this approach, the teacher becomes a dynamic facilitator who might change his role as group member, dialogue-based facilitator or consultant as per the demand of the situation.

3. Crafting Pbl Problems

An effective problem is the heart of PBL and crafting an engineering problem is a challenging task. In general, problems can be classified into three different types: fictional, authentic and real. Though, real engineering problems are hard to find, and if any, they cannot be directly adopted for academic perspectives as the actual working environment cannot be easily modelled and simulated. Further, the real field engineering problems are highly technical for students to visualize, and difficult for educators to transform into written format. Hence, often modification and simplification are necessary for real problems to be used for classroom benefits. One way to deal with this issue is by crafting the problems that cover the intended learning outcomes and customized to the industrial standards which promote higher-order thinking, lifelong learning and team working skills. Therefore, crafting the authentic PBL problems is always a good alternative and is the most preferred by PBL practitioners.

The crafting of a PBL problem is both an art and science. PBL needs to create interest in students, motivate them to apply the fundamentals of the theory and practical learnt, induce zeal for higher self-learning and ensure successful implementation of solutions. Studies have revealed that the application of the scientific principles in PBL have promoted effective learning and implementation. Apart from creativity, the crafting engineering problems in PBL curriculum requires a lot of effort that includes a study of practical knowledge related to the course and also communication with the expert personnel from industries. The problems have to be industrial-based and never subject-driven. The PBL problems shall incorporate five main principles such as: Authentic and Realistic (if not real) [P1], Constructive and Integrated [P2], Offer Suitable Complexity [P3], Promote Self-directed and Lifelong Learning [P4], and Stimulate Critical Thinking and Metacognitive Skills [P5] and to cover the intended learning outcomes (Jamaludin et al., 2012).

Designing a PBL problem in engineering consists of several steps that may require iteration, as described below (Jamaludin et al., 2012):

Step-1: Identification of the intended learning outcomes. Here, the gap between knowledge and skills in a problem should not be too large, which otherwise make the students to give up. However, if the gap is large, it is advisable to fragment the problem into parts/phases with certain outcomes at each phase before the final solution.

Step-2: Identification of the real problem, work setting and demand at the workplace where the learning outcomes fit. This requires inputs and opinion from industrial experts.

Step-3: Writing the first draft of problem that indicate the learning outcomes achieved through the problem and the demand at the workplace. The problem can be presented in the same format as experienced in the professional practices. However, best way is creating a similar situation as that in the field. If possible, the required resources may be indicated and the possible approaches may be recommended. Problems can be presented in different forms such as word document, presentation, letter or e-mail and written in present tense. The problem must contain objectives and expectations from the students instead of procedures and methods.

Step-4: The guidelines in the form of expected possible findings and learning issues that could arise are prepared to avoid students' learning going off-track. In addition, grading rubric prepared for a particular problem shall be shared with the students to show them the outcomes and expectations of the problem.

Step-5: Packaging the problem for presentation is an added-value that will aid in engagement and immersion. The work sheets with fictitious company headings can give a feel of more realistic situation.

Step-6: Once the problem is crafted, it requires to be reviewed, revised and refined to ensure that it is solvable and can be solved by the students in the given timeframe. The feedback from colleagues teaching the same course is necessary before the problem to be distributed. Steps 1 to 6 are iterative in nature before delivering the problem to students (Step-7).

4. Pbl Problems in Civil Engineering – An Insight

Crafting of PBL problem for engineering courses is challenging and fascinating. PBL is practiced in all the disciplines of Engineering. Mahendru and Mahindru (2011) employed PBL concept for students of Electronics and Communication Engineering in SRM Group of Professional Colleges, Lucknow and found that the students' learning with PBL is much better than the traditional teaching. A PBL problem was crafted to Chemical Engineering students by Jamaludin et al. (2012) in Universiti Teknologi, Malaysia. The problem was crafted for Process Control and Dynamics. They observed that the PBL studies motivated the learning in students along with skill development and engineering perspectives. Barg et al. (2000) designed a PBL course to address the challenges in foundation course in Computer Science. PBL concept is also experienced in Civil Engineering field. Holmes and Beagon (2015) crafted two PBL scenarios for third year students at School of Civil and Structural Engineering in Technological University, Dublin. Larson et al. (2018) used PBL in understanding the foundation knowledge in real-world problem at Arizona State University, USA. Butan (2007) reported that the hybrid model of PBL and Traditional teaching learning increase the knowledge base of the students along with problem solving, independent and critical thinking, which are the essential features of the future engineers.

Table 1: Pbl Problems in Civil Engineering - Examples

Sl. No.	Problem Statement
1	Planning and Designing of Residential Building
2	Proposal for Integrated Township with a Pre-Engineering Building
3	Energy Efficient Design of Buildings
4	Data Base for Cadastrial Maps Using Co -Ordinates Systems
5	Design of Water Distribution System for a village
6	Rainwater Harvesting
7	Water Quality Analysis and Remediation
8	Lake Eutrophication: Causes and Remediation
9	Instrumental and Analytical Tools for Material Characterization
10	Preparation of Fly Ash Coarse Aggregates and its Effective Utilization in Concrete
11	Concrete Distresses and Repair
12	Quantification of Severity of Damage in Structures
13	Analysis of Bridge cum Barrage
14	Design of Industrial Structure
15	Seismic Evaluation and Strengthening of Buildings
16	Earthquake Resistant Design of Building Structure by Selecting a Suitable Lateral Load Resisting Structural System
17	Effective Use of Construction Management Tools in Moderating Delay in Projects
18	Foundation Design on Expansive Soils
19	Strategies for Road Safety
20	Pavement Management System, Effective Tool for Government Agencies
21	Design and Economical Analysis of Canal Network
22	Planning and Designing of check dam
23	Quantitative Analysis of Salinized Soil and Its Remediation

The previous studies demonstrate the implementation of PBL on a specific topic of an Engineering stream. However, in this article the experiences of PBL practice crafting number of problems in authors institute is presented. Some of the typical PBL problems crafted in Civil Engineering

stream are listed in Table-I. It is to be noted that the list is not limited. All the PBL problems are of four cycles with total duration of 16 to 20 weeks. The duration of each cycle depends on the specific problem. The details of one of the problems "Planning and Designing of Residential Building" is presented in the next section.

5. Problem: Planning and Designing of Residential Building

This PBL problem is crafted for 16 weeks duration having four cycles as detailed in Table-II. It is a special PBL problem designed for the students to undergo for three successive years from second year to fourth year based on the acquired knowledge. The problem is crafted in such a manner that the learning outcomes of successive cycle are built over the previous cycles, hence addressing the principle P2. The workflow in each cycle follows the phases as indicated in Figure 1.

Table 2 : Details of Pbl Problem

Cycle	Problem Statement	Duration	Principles of PBL	Year
1	Preparation of plan of residential building	2 weeks	P1 to P5	II year
2	Preparing the 3D soft model and architectural model along with use of green building concept and documentation for approval process from the concerned authority	3 weeks	P1 to P5	III year
3	Structural design of various components using STAAD.pro software	5 weeks	P1 to P5	III year
4	Estimation of total cost, preparation of inventory (material, labour and machinery) schedule, preparation of working drawings	6 weeks	P1 to P5	IV year

Note : Principles of PBL - P1: Authentic and Realistic, P2: Constructive and Integrated, P3: Offer Suitable Complexity, P4: Promote Self-Directed and Lifelong Learning, P5: Stimulate Critical Thinking and Metacognitive Skills.

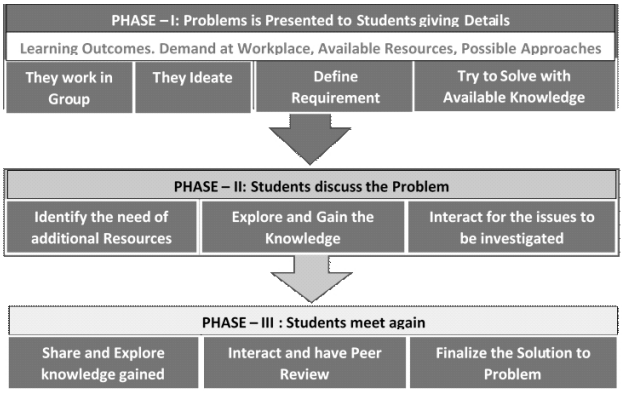

Fig. 1 : Workflow diagram

Table 3 : Presentation Steps of Cycle-i

Steps	Particulars	Details
1	Learning outcomes	• To prepare the plan of a residential building for a client as per the site condition and requirements **[P1]**
2	Problem and Appropriate Demand	• Interaction with the client and collect the information regarding the site (plot size, location, site map etc) and their requirements and limitations
3	Resources to be collected	• Site Map
	Prior Knowledge	• Building Materials and Construction • Building Planning and Design • AutoCAD concepts
4	Solution Guidelines	• Each team members shall prepare minimum 2 alternate plans • Select minimum 3 alternative plans (amongst 8) meeting the requirements of clients and guidelines [**P2**] • Preparation of AutoCAD plans along with interior details of 3 selected plans for discussion with client [**P5**] • After finalization of the plan, the submission drawing shall be prepared that include underground drainage, water supply, electricity plans [**P4**]

Cycle-1: Preparation of Plan of Residential Building

This cycle is designed for second year undergraduate students of Civil Engineering particularly for even semester (IV Semester). It is designed for short duration (2 weeks) so as to create interest in students and make them to enjoy solving the problem. Four students in a group are considered. The details of various stages of this cycle are furnished in Table-III.

Cycle-2: Preparation of 3D and Architectural Plan

Cycle-2 is crafted for third year students who will take it up in odd semester (V Semester). It is of 3 weeks duration involving certain self-driven learnings such as 3D architectural drawing and detailing and greenhouse concepts. This cycle is built on cycle-1 wherein the students will work on their finalized plan in previous cycle. The details of steps involved are given in Table-IV.

Cycle-3: Structural Design of Components using STAAD.pro

This cycle is taken up at third year in the even semester (VI Semester) after acquiring prior knowledge. It is of 5 weeks duration. This cycle requires the students to learn STAAD.pro software and prepare structural drawings. Table-V gives the learning outcome, problem and demand of the problem, requirement of resources and prior knowledge along with solution guidelines.

Cycle-4: Cost Estimation and Preparation of Inventory

This is the last cycle of this PBL designed for fourth year (VII and VIII Semesters) students for 6 weeks duration. The learning outcome, problem and demand of the problem, requirement of resources and prior knowledge and solution guidelines are furnished in Table-VI

Table 4 : Presentation Steps of Cycle-ii

Steps	Particulars	Details
1	Learning outcomes	• To prepare 3D Model of finalized plan • To create an architectural model • To identify locally available greenhouse materials • To create documents for approval from the concerned authority
2	Problem and Appropriate Demand	• Preparation of a 3D soft and architectural scaled model • Alternative locally available materials leading to green building concept are to be implemented after discussion with client
3	Resources to be collected	• Knowledge of locally available alternative materials and their suitability • Guidelines of approval authority • Document list required for submission to approving authority
	Prior Knowledge	• 3D software [**P4**] • Alternate building materials [**P4**] • Study on documentation process for approval [**P4**]
4	Solution Guidelines	• 3D Model shall be prepared as a team [**P3**] • Using card boards, an architectural model shall be prepared [**P2**] • Survey for locally available material to find their suitability • Discussion on the available alternate materials and finalize them before presenting to the client. • Presentation of the model to the client along with recommendation to use locally available to incorporate greenhouse effect. [**P5**] • Documentation shall be done for getting approval from approving authority.

6. Implementation

The concept of PBL was introduced to the students of second year (IV Semester) along with the advantages of the same. The problem was presented in the form of presentation explaining the learning objectives of the problem and the expected outcomes of the activity along with timeline of 2 weeks. Initially, the students show dis-interest in the activity. However, with the explanation of learning outcomes as required in the professional practices, the students shown their curiosity to carry out the PBL activity and worked in group of 4 members. The students were asked to interact with fictious clients, who gave their site details along with their requirements as detailed in Table-VII. The site size was 30 feet × 40 feet with 40 feet side parallel to north-south direction and 30 feet side adjoining the road.

In the first week, each member of the team prepared two residential plans. They are being asked to deliberate in the team side parallel to north-south direction and 30 feet side adjoining the road.

Table 5 : Presentation Steps of Cycle-iii

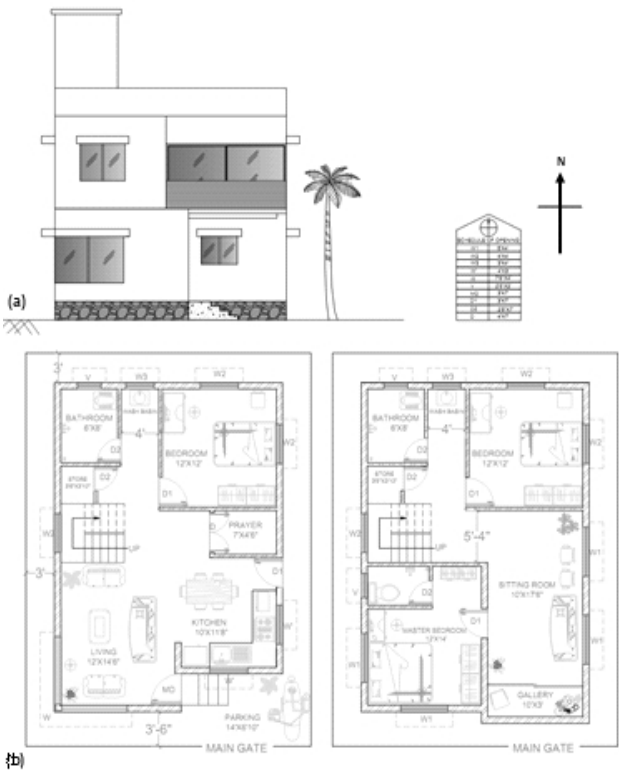

Fig. 2 : (a) Front elevation, (b) Floor plans (Left: Ground Floor, Right: First Floor) of residential building

In the first week, each member of the team prepared two residential plans. They are being asked to deliberate in the team regarding their individual plans and the activity was facilitated by the faculty mentor. The students selected three best plans amongst the total 8 plans. In the second week, for the selected three plans, the AutoCAD drawings were prepared combinedly by the team along with interior details. The team presented their plan and elevation that include underground drainage, water supply, electricity plans. During the entire activity faculty mentor facilitated the process. The finalized typical plan of the residential building of one group is presented in Figures 2 to 4.

Table 6: Presentation Steps of Cycle-iv

Steps	Particulars	Details
1	Learning outcomes	• To prepare measurement sheet of various quantities of all components. • Prepare abstract table and estimate the total cost of building. • To calculate the materials and labour required. • Prepare the Schedule of work and estimate the probable completion period using Network analysis (CPM/PERT) • Prepare the working drawings for construction
2	Problem and Appropriate Demand	• It is required to compute the material quantities • Estimate the total cost of the building • The labour required is to be estimated • Schedule of work is to be prepared • Working drawing shall be prepared
3	Resources to be collected	• Schedule of rates from the Public Works Department • MS Project software
	Prior Knowledge	• Quantity Surveying • Network Analysis • Knowledge of MS Project [**P4**]
4	Solution Guidelines	• Each team member shall calculate the quantities and compute total cost of building [**P3**] • Computation of labour requirement. • Schedule of work shall be prepared by the whole team [**P5**] • Working drawings shall be prepared by the whole team

Table 7: Requirements and Limitations of Client

Requirements:
- Three Bed Rooms out of which One shall be Master Bed Room
- Kitchen – Open Type
- Dining Hall
- Hall
- Verandah
- Pooja Hall
- Common Toilet
- Internal Staircase

Limitations:
- Facilities can be taken to First Floor, if required Circulation/Passage area shall be minimum

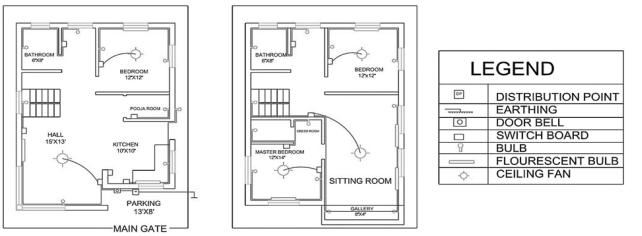

Fig. 3 : Plan indicating electrical layout

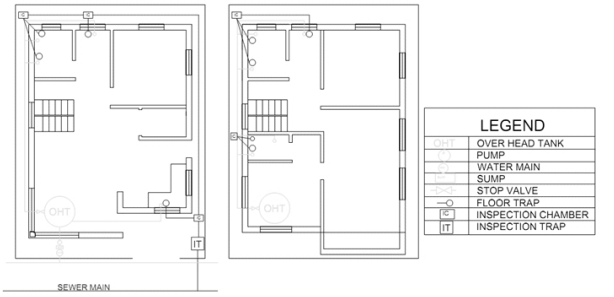

Fig. 4 : Plan indicating underground drainage and water supply lines

The learning outcome of cycle-1 "To prepare the plan of a residential building for a client as per the site condition and requirements" was measured through the feedback from the clients. The clients expressed their satisfaction of students' learning and understanding from the drawings. They also appreciated the implementation of PBL activity.

7. Students Feedback

The feedback was collected from the students on the 12 questions matrix consisting of closed (Yes/No type – 8 numbers) and open ended (brief descriptive – 4 numbers) questions and given in Table-VIII. Initially, students did not show interest in the PBL concept, however, when the problem was presented in the same format as experienced in the professional practices, the students get motivated to work on the problem. The overall experience of the students was very satisfactory. The PBL activated is motivating the students towards self-driven learning, team interactions, exposure to practical situations and solving the problems.

8. Faculty Experience

The faculty members experienced the challenges of convincing the students, however, with the advantages of PBL and the attainment of various attributes they could motivate the students in taking up the activity. Further, the mentors also enjoyed working with students.

Table 8 : Feedback Questions and Responses

Q. No.	Question	Type of question	Response
1	Were you aware about PBL earlier to this activity?	Closed ended (Yes/No)	Yes – 10% No – 90%
2	Whether your facilitators equipped you about the PBL activity and its advantages?	Closed ended (Yes/No)	Yes – 100% No – 0
3	Did you get opportunity to apply your gathered knowledge (earlier semesters) or skills to the problem given to you which is very close to the Real world?	Closed ended (Yes/No)	Yes – 100% No – 0
4	Did you able to spend extra time on this PBL activity?	Closed ended (Yes/No)	Yes – 100% No – 0
5	If answer to Question 4 is yes, total how many hours?	Open ended	Average of 3 hours per day
6	Did you enjoy working on the problem? If so alone or team.	Open ended	Enjoyed individually as well as in teams
7	Did this PBL helped in improvement of Teamwork and Interpersonal Skills?	Closed ended (Yes/No)	Yes – 100% No – 0
8	Did you experience challenges that made you to work or study on your own? Were you able to find the solution to the challenge faced by you?	Open ended	Yes, I found solution on my own. (general)
9	Do you feel the PBL activity keeps your knowledge for a Long-Term that you can use in your future endeavors?	Closed ended (Yes/No)	Yes – 100% No – 0
10	Did this PBL activity helped you in sharing your knowledge or Skills?	Closed ended (Yes/No)	Yes – 100% No – 0
11	Did your experience of in this PBL motivated you for lifelong learning skills?	Closed ended (Yes/No)	Yes – 100% No – 0
12	Write about your Experience during the PBL activity and suggestions if any in a line or two.	Open ended	• It was a very nice experience. • Practical knowledge increased due to this activity. • It helped to overcome the drawbacks by putting efforts to improve on own. • PBL activity did help in sharing our thoughts and ideas and also learn some new skills. • Same activity can be extended to public buildings. • Ready to take next cycles.

9. Conclusions

Nevertheless, the crafting of PBL problem for engineering courses is challenging but it is fascinating. It is experienced that numerous authentic as well as realistic (few) problems can be framed. Further, the problems can be crafted of different durations and worked into number of phases. The students can take up the PBL activities and their experience is encouraging. The outcome of the activity is promising in addressing many graduate attributes, which otherwise difficult to address in conventional method of teaching. The student's reflections demonstrated the learning and skill improvements in them and giving overall development. The experience of the present study is similar to the other researchers those have implemented PBL on different scenarios.

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