3.1 DESIGN OF THE STUDY

The study was aimed at determining the effectiveness of Problem Based Learning instructions on knowledge and skills of students of undergraduate program in Electronics and Communication Engineering at Chitkara Institute of Engineering and technology, Punjab, India, in three subjects – Analog Electronics (AE), Digital Electronics (DE) and Pulse, Digital and Switching Circuits (PDSC). The Institute is affiliated to Punjab Technical University, Punjab. The experiment was carried out in above three subjects over a period of five semesters, as described in the layout of sample base in Table 3.1 and Table 3.2.

The factorial design of 2x2x2 was used because it permits to evaluate the combined effect of two or more independent variables simultaneously. The layout of the factorial design is given in figure 3.1.
<table>
<thead>
<tr>
<th>Subject</th>
<th>Facilitator</th>
<th>Duration</th>
<th>Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>Teacher 1</td>
<td>Jan – May 2006</td>
<td>Batch 2004 – Y section</td>
</tr>
<tr>
<td></td>
<td>Teacher 2</td>
<td>Jan – May 2007</td>
<td>Batch 2005 – Y section</td>
</tr>
<tr>
<td>DE</td>
<td>Teacher 1</td>
<td>Jan – May 2007</td>
<td>Batch 2005 – X section</td>
</tr>
<tr>
<td></td>
<td>Teacher 2</td>
<td>Jan – May 2008</td>
<td>Batch 2006 – X section</td>
</tr>
<tr>
<td>PDSC</td>
<td>Teacher 1</td>
<td>July – Dec 2006</td>
<td>Batch 2003</td>
</tr>
<tr>
<td></td>
<td>Teacher 2</td>
<td>July – Dec 2007</td>
<td>Batch 2004 – X Section</td>
</tr>
</tbody>
</table>

Table 3.1 : Subject wise, teacher wise conduct of experiment

<table>
<thead>
<tr>
<th>Semester</th>
<th>Batch</th>
<th>Teacher</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan – May 2006</td>
<td>Batch 2004 – Y Section</td>
<td>Teacher 1</td>
<td>AE</td>
</tr>
<tr>
<td>July – Dec 2006</td>
<td>Batch 2003</td>
<td>Teacher 1</td>
<td>PDSC</td>
</tr>
<tr>
<td>Jan – May 2007</td>
<td>Batch 2005 – X Section</td>
<td>Teacher 1</td>
<td>DE</td>
</tr>
<tr>
<td>Jan – May 2007</td>
<td>Batch 2005 – Y Section</td>
<td>Teacher 2</td>
<td>AE</td>
</tr>
<tr>
<td>July – Dec 2007</td>
<td>Batch 2004 – X Section</td>
<td>Teacher 2</td>
<td>PDSC</td>
</tr>
<tr>
<td>Jan – May 2008</td>
<td>Batch 2006 – X Section</td>
<td>Teacher 2</td>
<td>DE</td>
</tr>
</tbody>
</table>

Table 3.2 : Semester-wise, batch wise conduct of experiment

3.2 SAMPLE

Since the total of engineering students across India is too large to experiment with, a representative of the population is drawn for this study. Sampling refers to selecting relatively small number of individuals, called subjects, to find out something about entire population that the subjects represents.

In this study, sample were chosen from different batches of students. Each batch contained approximately 67 students. Each time the class was divided into two threads – PBL Thread (known as Treatment Group) and the Traditional Thread (known as Control Group). Each time the random table procedure was used to select students for PBL thread. The same teacher handled both the threads each time. “Teacher 1” in tables 3.1 and 3.2 refers to the researcher herself and the next time the experiment was repeated with a fresh batch of students, with a different senior teacher (Teacher 2).

The Group Embedded Figures Test - GEFT (Appendix A) was administered on each batch and the students were classified into Field independent and Field Dependent cognitive styles. The attitudes of the students for finding their level of satisfaction were measured on attitude scale form (Appendix B). The end semester knowledge test and end semester skill test were conducted at the end of each semester for all the students.
The result so obtained was then analyzed using Three Way ANOVA to find the effect of pedagogy on knowledge and skill of the students.

3.3 OPERATIONAL DEFINITIONS:

- **Control Group (CG):** The students in this group were imparted instructions using Direct or Traditional method as described in section 3.5.3.
- **Treatment Group (TG):** The students in this group were imparted instructions using PBL method as described in 3.5.3.
- **Lecture Plan and Lab Plan:** They are the lecture wise, lab wise schedule, in which the instructions were imparted to TG. The Lecture plans and Lab Plans of the three subjects are given in sections 4.1.2, 4.2.2 and 4.3.2.
- **Subjects:** The three subjects in scheme of Electronics and Communication Engineering at Punjab Technical University (PTU), in which this particular study and was conducted are – Analog Electronics (AE), Digital Electronics (DE) and Pulse and Switching Circuits (PDSC).

3.4 TOOLS USED

For the present study, the researcher required various data gathering tools which varied in their design, complexity, administration and interpretation. Following tools were used to impart the instructions and collect the data:

- **Lecture Plan and Lab Plan** for guiding the Instruction in a time bound manner to Direct instruction group (Traditional method or Control Group)
- **Technical Problems (TPs)** for imparting instructions to PBL instruction group (Treatment Group)
- **Group Embedded Figures Test** to classify the selected sample of students into Field Dependent and Field Independent groups.
- **Assignment cum Tutorial Sheets (ATSs)** as practice sheets for aiding the teacher and students in both Direct and PBL instruction groups
- **Mid Semester Tests (MSTs)** as assessment tool for evaluating the knowledge of the students during the course of imparting instructions in a particular subject.
- **End Semester Knowledge Test** as assessment tool for evaluating the knowledge of students after imparting instructions is complete in a particular subject.
- **End Semester Project Test** as assessment tool for evaluating the skill of students.
• Peer Evaluation Form to evaluate the team work of the students in a team in the PBL Group (Table 3.3).

• Attitude Scale Form to measure the attitude of students in TG and CG (Appendix B).

3.4.1 LECTURE PLAN AND LAB PLAN: For each experiment in a subject (such three experiments were conducted), this document was prepared by the researcher to impart Direct instruction to the CG in a time bound manner. Refer to tables 4.1, 4.2, 4.4, 4.5, 4.8 and 4.9 in chapter 4.

3.4.2 TECHNICAL PROBLEMS (TPS) are Quasi–open-ended technical problems, framed from within the scope of the subjects and were the first points of triggers to simulate knowledge construction in CG (PBL group). TPs for each subject are given separately in sections 4.1.3.1, 4.2.3.1 and 4.3.3.1.

3.4.3 GROUP EMBEDDED FIGURES TEST (GEFT) is a psychometric test [101a]. It was used to classify the sample of students into Field independent and Field dependent Groups. In this test a student is required to find a simple form when it is hidden in complex pattern. The test has seven simple forms (A, B, C, D, E, F, G, and H) that have to be located. In this test, there are 3 time sections of 2, 2, and 5 minutes respectively. Section A consists of seven items practice set which serves the purpose of providing practice to the students and is not to be scored while section B and Section C consists of nine figures each which are arranged in ascending order of difficulty within each section. Thus, the test has a scored set of 18 items administered in two equal parts.

The total number of simple forms correctly traced in the sections B and C contribute the total score of an individual student. The forms correctly traced in Section A are not scored, but merely scanned to ensure that the instruction have been understood properly by the students. Omitted items are scored incorrect. In order to receive credit for an item, all lines of the simple forms must be traced. All incorrect lines must be crossed. No extra lines are added (Appendix A).

3.4.4 ASSIGNMENTS CUM TUTORIAL SHEETS (ATSS) were developed by the researcher to aid and supplement the teachers and the students so that they do a lot of practice on the analytical problems in the subject area. These ATSs mostly comprised of straight questions on reasoning, derivation, design, synthesis, analysis
and application problems on various topics in the subject areas. The ATSs were
given for practice to both TG and CG, in various sessions spanned throughout the
semester.

**3.4.5 MID SEMESTER TESTS (MSTS)** were assessment tools developed by the
researcher to test the knowledge of the students in subject areas. MST I was used in
the 6th week of the semester and MST II was administered in 12th Week of the
semester. Each MST was of 24 marks each and contributed to internal assessment component of knowledge score (table 3.6). It has the following break up:

SECTION A: consists of 4 questions on reasoning, understanding, recalling and
reproducing. All the questions are compulsory. Out of four questions, one would be
very easy, two would be of medium difficulty level and the fourth one would be of
high difficulty level.

SECTION B: Consists of 3 questions of 4 marks each on analytical reasoning. This
section would test the derivations, design and synthesis knowledge of students. The
students are given a choice to attempt only two questions out of three. The difficulty level of all the three questions would be high.

SECTION C: Consists of 2 questions of 8 marks each. This would test the students
on explanation and application levels. The student is given a choice to attempt one
question out of two. The difficulty level of both the questions would be medium.

**3.4.6 END SEMESTER KNOWLEDGE TEST** is the assessment tool used to
evaluate the knowledge of the students on 60 marks scale. This is the external
evaluation component in the table 3.6. This tool is developed by the affiliating
University and is administered to the students in this experiment simultaneously with
the universal population of students under the University. This tool tests the students
on all level of Bloom’s taxonomy. The organization of this test is:

SECTION A: consists of 10 questions on reasoning, understanding, recalling and
reproducing. There are 10 questions of 2 marks each and all of them are compulsory
to attempt.

SECTION B: consists of 5 questions on derivation, design, synthesis and analysis
levels. Each question would be of five marks each and the students are required to
attempt any four questions out of five.
SECTION C: consists of 3 questions on synthesis, analysis, creation and description levels. Each question is of 10 marks each and the students are required to attempt any two questions out of three.

3.4.7 END SEMESTER SKILL TEST is the assessment tool to evaluate the skill of the students. Invariably, in all the three subjects, the skill test was in the form a hardwired complicated circuit on the bread board, with specified input and output parameters, but with three faults introduced in the wired circuit board. The students, in a team of four, are required to find the faults and rectify the circuit. The students are then evaluated on their performance, team work and success in finding the faults and rectifying the circuit. The Skill test for the three subjects are given in the appendices F, J and N.

3.4.8 PEER EVALUATION FORM is a simple form, used to evaluate the peer performance in a team in the PBL group. Each team member evaluated the other fellow team members on their contributions to solving the TPs in a team. A student did not have to evaluate himself. Each team member had to give one of the 6 evaluation levels, shown in Table 3.4, to every other member of his or her team. As an example consider that a team comprises of five students – A, B, C, D, and E. The student A evaluates his other team members on the Table 3.3 giving each one of them some marks in the range +2 to -5 according to the table. The sum of the marks given to his fellow team members should sum up to a number ≤2. All the marks scored by a team member are added up and divided by (number of team members – 1). The number so obtained is the score of that member.

<table>
<thead>
<tr>
<th>Team Number:</th>
<th>Self Name: A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student B</td>
<td>Student C</td>
</tr>
<tr>
<td>Student D</td>
<td>Student E</td>
</tr>
</tbody>
</table>

Table 3.3 : Peer Evaluation Form
| ---- | Self                                      |
| +2   | Contribution well above team norm        |
| +1   | Contribution above team norm             |
| 0    | Contribution at team norm                |
| -1   | Contribution below team norm             |
| -2   | Contribution well below team norm        |
| -5   | No contribution, doesn’t deserve to be a team member |

Table 3.4 : Peer Evaluation Guide

3.4.9 ATTITUDE SCALE FORM was used to measure the attitude of students in the sample. It has six items (statements), to which the students have to respond on a 10 point scale and one item, to which the students have to respond on a 5 point scale. The form is given in Appendix B.

3.5 PROCEDURE

3.5.1 FLOW CHART A pictorial representation of the step by step procedure is shown in the figure 3.2
Preparation of Learning Objectives, Outcomes, technical nodes, practice tools – ATSs, Assessment tools – Mid semester tests, End semester theory paper, End semester project test

Preparation of technical open-ended-problems (TPs)

Team of Professors vet TPs

Changes required?

No

Using random table students are divided into two groups – TG (PBL method) and CG (Traditional method)

Cognitive Style test conducted on the students

Students are enrolled in TG (PBL method)

Introduction to PBL is given. Assessment and evaluation strategy and Peer evaluation are discussed.

Does any student want to leave TG and join CG?

Yes

Students are enrolled in CG (Traditional Method)

Subject content is delivered in traditional classroom setup and according to the Lecture and lab plans.

No

Classroom with circular tables, internet facility, lab equipments and a small library is created; the students make their teams, with 3-4 students in each team.
Technical Problems TP1 – TPm are given to the students, one after the other; students grapple through them, to traverse the conceptual space & reach at the solution, while the teacher acts as guide by side – as facilitator. The students discuss issues amongst themselves & with the facilitator. They authenticate their solutions practically & by using the simulation tools. The PBL sessions are interlaced with practice sessions on Assignment cum tutorial sheets (ATSs). The students submit a solution to each TP.

Conceptual delivery takes place in well structured lecture sessions. The students work on well structures experiments in lab sessions. The students practice analytical problems in tutorial sessions interlaced with lecture session.

Mid semester evaluation is done using Mid semester Test I

Mid semester evaluation is done using Mid semester Test II

Knowledge test at the end of the semester using “End Semester Theory paper”; Skill Test at the end of the semester using a Trouble shooting project.

Tabulation of results of all the students, use of SPSS and ANNOVA tool to analyze the result.

Fig 3.2 : Flow chart of the procedure adopted for conduct of experiment
### 3.5.2 FORMATION OF THE TWO THREADS

In order to contrast the pedagogies and results, in each semester the students of each class having 67 students was divided into two threads – The PBL thread (TG) and the Traditional thread (CG).

The formation of the Traditional thread was quite traditional with the students sitting in the classroom in rows, facing the teacher. The demarcation of Lecture, Tutorial and Practical classes was quite clear. The teacher gave lecture in lecture classes, made the students practice closed-ended problems in tutorial classes and made the students do experiments in the practical classes, in a typical laboratory set up.

The students in PBL thread were first asked to form their groups with minimum 4 and maximum 5 students in each group. The class had circular tables, with chairs around them and a scribble board placed in the centre. The set-up thus facilitated interaction and discussion amongst groups [67] [29]. A small library was also built in the classroom. The students were free to use internet on their laptops and search for any data and information required. They could use simulation software and laboratory equipment in the class itself for achieving any practical learning objectives.

### 3.5.3 TEACHING PEDAGOGY

The teaching pedagogy for the Traditional thread continued to be “traditional” using Lecture, Tutorial and Practical classes, with the teacher as “Sage on Stage” [4]. The teacher made the Lecture plan and Lab Plan – an hour wise, lecture wise, lab wise schedule, for delivery of whole syllabus, right from knowledge level to the application level. She also delivered the course in accordance to the same. The quasi-open-ended-problems, as given in the sections 4.1.3.1, 4.2.3.1 and 4.3.3.1, were changed into more closed-ended-ones and given to the traditional group for practice, in the tutorial classes. These problems were in addition to many other analytical questions, which the students practiced in tutorial classes. The lecture and tutorial sessions were interlaced throughout the semester. The content delivery in the Lecture classes was one way - from teacher to students. However the students were allowed to work in groups, practice analytical problems and discuss the issues in Tutorial classes. The practice session for a particular topic was always after the concept was
delivered and understood by the students in the Lecture classes. The practical sessions in the Lab classes had objectives, again, determined by the prescribed study scheme and syllabus of the affiliating University and the teacher. All in all, there was a clear demarcation in the Lecture, Tutorial and Lab classes in terms of the delivery of content, what the students performed and the learning objectives.

For the PBL thread, there was no structured plan in terms of delivery of content. However the teacher – here, termed as Facilitator - prepared a complete set of Technical Nodes and Learning Objectives. Examples of Technical Nodes and Learning Objectives can be found in Sections 4.1.3.2, 4.2.3.2 and 4.3.3.2.

The facilitator designed open – ended Technical Problems (TPs) as given in sections 4.1.3.1, 4.2.3.1 and 4.3.3.1 and got them authenticated by a group of senior teachers. While designing TPs, care was taken that the scope was broad enough so that the students could achieve all the Technical Nodes and Learning Objectives in the conceptual space, while attempting to solve them.

Students grappled with these fuzzy Technical Problems (TPs) – one at a time, and tried to understand the scope, issues and concepts stemming from or inherent in the TP before attempting to identify the learning points that would guide them towards the formulation of an eventual response [100] (in the form of a theory, hypothesis, solution or argument).

There was no demarcation of Lecture, Tutorial or Practical classes and the total time available for the course was divided into several two hour PBL-sessions. The students developed an understanding and also found the solution to the TP while traversing the conceptual space, covering the technical nodes and also learned to work in teams. The role of the teacher was changed from the “content-delivery-person” to a “facilitator”. The students worked on their Technical Problems, trying to find out one of the many possible solutions, determining and achieving their own theoretical and practical Learning Objectives. The teacher remained and worked as “guide-by-side”, truly taking up the role of a facilitator. She carefully monitored each and every step of the groups and remained aware of the progress made by the groups. At times, when the facilitator felt that all the students encountered the same kind of bottleneck at some point, the facilitator even delivered a structured lecture or
called upon all the students to perform the same experiment, so that they all could proceed further.

Moodle™ software was used for online submission of assignments and presentations for both the threads and also to extend the discussion among students even beyond the class room.

### 3.5.4 TIME ALLOTMENT AND EVALUATION PARAMETERS

The total hours per week, allotted to each subject were fixed and were predefined by the university, the time allotments for the PBL thread and the Traditional thread were made parallel as given in Table 3.5. In the PBL sessions, the demarcation of lecture, tutorial and practical was removed and the students not only decided their strategy, but also managed their time to achieve their theoretical and practical Learning Objectives.

<table>
<thead>
<tr>
<th>Traditional thread</th>
<th>PBL thread</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 lecture hours per week</td>
<td>2 hour PBL class * 4 classes per week</td>
</tr>
<tr>
<td>2 tutorial Hours per week</td>
<td></td>
</tr>
<tr>
<td>2 practical hours per week</td>
<td></td>
</tr>
<tr>
<td>Total = 8 hours per week</td>
<td>Total = 8 hours per week</td>
</tr>
</tbody>
</table>

**Table 3.5**: Time Allotment for PBL & Traditional threads

The selection of students for the PBL thread was truly random. Since the PBL class cannot support large strength, the number was limited to 25. However, in some of the experiments, after initial intake, a few students left the class - and rejoined the traditional group and the PBL thread was run with lesser than 25 students.

The evaluation criteria of both the threads were matched as given in Table 3.6.

The external theory paper is set by the University and is a combination of subjective and objective type questions. The questions are incorporated, such that all the levels of Bloom’s Taxonomy are tested in the paper.

Once the teaching pedagogy and time distribution were paralleled for both the threads, the course was delivered to both the groups, by the same teacher.
### Table 3.6: Evaluation Parameters of Traditional and PBL Groups

<table>
<thead>
<tr>
<th><strong>Internal Evaluation</strong> = 70</th>
<th><strong>External Evaluation</strong> = 80</th>
</tr>
</thead>
<tbody>
<tr>
<td>As done by the affiliated college (CIET, in this case)</td>
<td>As done by the University (PTU, in this case)</td>
</tr>
<tr>
<td><strong>Traditional thread (CG)</strong></td>
<td><strong>PBL thread (TG)</strong></td>
</tr>
<tr>
<td><strong>Attendance in Lecture and Tutorial classes (6)</strong></td>
<td>One-to-one Oral examination on the solution of the problem submitted: can be taken anytime during the class. (6)*</td>
</tr>
<tr>
<td>Assignments (10)</td>
<td>Assignments(10)**</td>
</tr>
<tr>
<td>Mid semester tests (24)</td>
<td>Mid semester test (24)**</td>
</tr>
<tr>
<td>Attendance in Labs (5)</td>
<td>Peer evaluation (-5 to +2)**</td>
</tr>
<tr>
<td>Lab / file work (15)</td>
<td>Practical Work Done by the group (10)*</td>
</tr>
<tr>
<td>Internal viva voce (10)</td>
<td>Presentation by the group (5)**</td>
</tr>
<tr>
<td>Attendance (5)</td>
<td>Solution to the problem (10) *</td>
</tr>
</tbody>
</table>

*Weekly  **Thrice in a semester

#### 3.5.5 FACILITATING THE PBL THREAD

Students, who enrolled for the PBL thread, were asked to frame their teams. They were given introductory presentations on collaborative learning, in order to prepare them for the new learning experience. Technical-Problem 1 was given as the starting point of the PBL class. The teams were then asked to frame the Learning Objectives on their own. The students could decide only some of the Learning Objectives very vaguely (they were never aware of all the issues involved in solving a problem) [12]. The facilitator, then, supplemented their Learning Objectives by adding the remaining ones, so as to make it a complete set. Having a complete set of Learning Objectives was a very important step to determine the direction of work. These Learning Objectives, in turn, were important driving forces and acted as triggers.
towards desired outcome(s), while working towards the solution. At times, the Learning Objectives got added in the due course, while the search for information was still on. The group members then distributed various tasks amongst themselves e.g. search for information from various resources, compile the data, do calculations, perform experiments and finally write down about the work done and prepare presentation. The group members were encouraged to rotate all above tasks amongst themselves for each Technical Problem at hand. For each Technical Problem, the group members were asked to elect a team leader, who would streamline the things and would take necessary decisions on work distribution. The group members were also encouraged to discuss the issues, decide their own theoretical, practical and software aims and explore through their own learning and mistakes. This was done by continuous monitoring and instructing them to record each relevant finding, any mistakes committed and the corrective action taken. Once they had reached the solution, they were also asked to frame similar kind of problems and identify application areas. All in all, they were guided and corrected by the wandering facilitator who would optimize the time and learning and also helped them to draw conclusions so as to find the desired solution. Learning happened as the students encountered successes and failures while exploring. The facilitator emphasized on this “exploration” voyage as much as reaching the correct solution.

**Cognitive and Pedagogical Issues:**

From a constructivist’s perspective, discourse is a central mechanism for learning [71]. For ages, educationalists have been working on making the ‘theory’ as practical as possible and making the ‘practice’ as theoretically interesting as possible. This effort is the guiding force to relate constructivism as theory of learning to the practice of instruction [84]. Constructivism is a philosophical view on how we come to understand or know and the instructional principles guide us the practice of teaching and the design of learning environments. Orchestrating constructive discourse is a complex process whether in a classroom or otherwise [52]. Over a period of time, ever since the need to introduce PBL was understood and practiced in engineering courses world over, its positive effects have been discussed and published time and again [19][10][1]. While the knowledge construction is
structured but limited in a teacher centered classroom, the same is much more complicated but elaborate in the student centered approach. In PBL, thus, when the teachers and students co-construct the instructional agenda in a student centered classroom, the role of the facilitator becomes very critical as he has to juggle with many simultaneous goals and has to coordinate pedagogical actions with semantic knowledge.

The knowledge, in technical fields and subjects should not be limited to the system defined by the teacher and limited to the experiences of the teacher. Thus, within those disciplines which are systematic and experience based, such as management of construction, there is always a need for an approach which is not reliant on the particular knowledge base of the teacher. “Educationalists are often inadequately equipped to provide much of the useful knowledge and skills needed by practitioners” [93], so it is understandable that there has been a move to include elements of PBL within traditional courses without changing the underlying structure of the program.

In place of traditional learning materials where content notes, topical or subject descriptors and textbooks are given, students instead grapple with a fuzzy problem and try to understand the scope, issues and concepts stemming from or inherent in the problem before attempting to identify learning points that will guide them towards the formulation of an eventual response (be it in the form of a theory, hypothesis, solution or argument).

There are many cognitive activities involved in teaching and different strategies to actively engage students. There is teacher centered approach and there is student centered approach. In traditional classrooms, usually teachers ask 95% of the questions which mostly require short answers [37]. Thus many teachers’ goal is to make students learn facts. However in technical education, the goal should be to make students learn theories, and how are they derived. This includes having students learn what questions to ask, how to make predictions and how to test theories. In other words, teachers should be enquiry teachers, who use questioning techniques to promote deep thinking among students. In problem based learning the teacher is enquiry teacher or a facilitator, and makes the class room environment
conducive for the students to be more active. However he has to still lead the discussion, working towards the global goals but choosing strategies on the fly [18].

Technical Issues
Apart from the role of facilitator, the designing of problems and then gauging their effectiveness in conducting the course is also critical. In order to gauge the effectiveness of the PBL program and of the problems, in each topic a number of learning outcomes or technical nodes were defined which were required to be achieved, in order to achieve as many learning objectives as possible. This was done by listing the set of technical nodes under each topic and getting it authenticated by senior teachers. Although, no set of technical nodes and learning objectives can be complete, an effort was made to have all relevant ones listed. Sections 4.1.3.2, 4.2.3.2 and 4.3.3.2 list all the number of technical nodes and learning objectives to be achieved during PBL sessions.

Decoding of transcripts:
The entire transcripts of all the teams for some of the PBL sessions of Analog Electronics were individually recorded and decoded for the types of questions and statements in the discourse. These were coded using taxonomy of questions types and several additional categories that were developed to capture monitoring, clarification and group dynamics questioning. The major categories of questions were short answer type, long answer type and meta. Similarly, statement types were recorded according to new ideas, agreements, disagreements, conclusions, inferences, wrong interpretations or meta-cognitive statements. This analysis gave an insight into the PBL class. Section 5.4 gives an example of analysis of some of the PBL sessions and relates how the learning achieved can be quantized related to the discussion that took place in the class

Triggers:
The triggers in the PBL Sessions were required to guide, direct and redirect the students and team members to achieve learning objectives and touch through all the technical nodes. These triggers are various short answer type statements and questions, touching various cognitive domains and posed by facilitator and the team members. Examples of various triggers in the three subjects are given in Sections
4.1.3.3, 4.2.3.3 and 4.3.3.3.

The pictorial representation of Technical nodes, Learning Objectives, Conceptual Space and Triggers is given in Fig 3.3.

Fig 3.3: How students in PBL class traverse through conceptual space

During the conduct of PBL course, the students under the guidance of facilitator tried to cover, but did not limit themselves to, as many technical nodes and learning objectives as possible. The facilitator also asked the students to mention all learning, technical issues, failures, findings, sources, interpretations and explanations in the problem solutions. While the TPs were meant to infuse inquisitiveness, build the concept, learn about the theories, the practice part was taken care by making the students practice assignments and tutorial sheets. After the receipt of solutions by the groups, these were analyzed in terms of technical nodes covered and learning objectives achieved.

3.6 CHALLENGES ASSOCIATED WITH THE PBL CLASS

In PBL, the students do a substantial amount of question asking and subsequent
discussion supported by meta-cognitive triggers from facilitator aid the students to move through complex conceptual space and achieve the learning objectives.

The role of the facilitator in the face-to-face discussion has several aspects. Not only the facilitator needed to manage time, but also keep in mind that maximum technical nodes were covered and learning objectives were achieved. The flow of ideas should touch the deep conceptual level and at the same time move to presentation levels. The most difficult role of the facilitator was to keep the groups moving and make sure that everyone participated. At the same point of time in the PBL class, one team would be diverging appearing to be out of sync with the time frame and another group might be converging too fast, so that the learning objectives might not be achieved. The types of triggers would then have to be different for the two groups at the same time.

The designing of Technical problems is a difficult and meticulous task, with a group of teachers involved. The TPs should be open-ended and carefully designed and words carefully selected, so as to ensure that the teams traverse the whole conceptual space, in order to reach at the solution. If the TPs are not open ended or are not broad enough, the students would any way find a short cut to a solution, without achieving all the learning objectives and covering all the technical nodes. The purpose of knowledge construction would then be lost.

In the PBL class, the facilitator has to deal not only with technical issues, but also with psychological issues. He has to work in the teams as one of the team members and closely traverse the individual learning curves of all the teams. The work distribution of teams also needs to be closely monitored, lest each team member keeps doing the same task one after the other TP.

The PBL way of teaching is an expensive preposition, as larger floor space is consumed (with circular tables, with scrabble board, in contrast of desk chair rows) for the same number of students.

The faculty training to handle PBL classes is another very big challenge.

It was assumed that the all the students remain motivated throughout the PBL sessions. As a research study, in this case the students were debarred from changing their groups after an initial period of one week.
The tools developed as supplementary practice material was again developed by a group of experienced teachers, so that the PBL students did not lack in their practice part and written work.

PBL provides a well described and discussed approach to constructivist learning. However, it is labor intensive and requires trained facilitator for each group of students. Facilitation is quite difficult for novices [24]. Not only technical but also psychological issues of teams are also to be tackled by the facilitator. Some of the difficulties, the author faced, while working with this particular PBL class were:

(a) At the point of time that the students were introduced about the peer evaluation factor, they became apprehensive about the fact that their own peers might not give them good points and their overall score would suffer. But as they progressed, and they understood group dynamics, they could understand the importance of this factor and soon came to terms with it. They could realize that the only way to grapple with so many simultaneous goals is only to distribute the work amongst group members, pool in the data and information and work to full honesty, lest a group member is left behind and he gives negative marking to all other team members affecting the scores.

(b) At times, the competition amongst various teams took killing proportions and the groups worked lesser to traverse the conceptual space and more to make their presentations more effective. The facilitator would then have to counsel the students so as to strike out a balance.

(c) The use of simulation tool viz. MULTISIM™ software would take undesirable proportions and students would use the simulation tools as a substitute for essential calculations, which should be done, to design and analyze a circuit.

(d) The most frequent problem encountered was that of team members worrying about following a particular approach. The facilitator had to continuously align and misalign the groups from finding the answers to the problem. The misalignment was required so that while trying to find out the correct solution to the problem, maximum learning objectives are achieved. The alignment was required so that the learning curve did not diverge much from the ideal curve of learning within the set time frame.

(e) Though still in the transition phase from L/T/P to PBL, and because of the limitation on the class size a PBL class could handle, the two-threaded approach was to be used.
The students in PBL, initially, would always see the short-term achievements of the L/T/P class and would keep questioning the facilitator about the learning being achieved in the two sections. But as the time passed on, PBL students could understand the pedagogy and cognition differences of the two sections and could parallel the learning objectives.