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Applying Project-Based Learning to Course System Analysis and Design: Bridging Theory and Practice

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ABSTRACT

CONTEXT

Traditional teaching methods in education often use lecture-based instruction, limiting opportunities for active student engagement. Problem-Based Learning (PBL) has emerged as an effective pedagogical approach that encourages active learning, critical thinking, and hands-on experience. This research explores the successful implementation of PBL in the teaching of System Analysis and Design (SAD).

PURPOSE OR GOAL

The primary purpose of this research is to evaluate the effectiveness of Project-Based Learning (PBL) as a pedagogical approach in teaching System Analysis and Design (SAD). It aims to shift from traditional lecture-based methods to an active learning approach that enhances students' problem-solving, analytical thinking, and teamwork skills.

APPROACH OR METHODOLOGY.

PBL approach involved 12 student teams, each working on a distinct case study. Each team consisted of 4-6 students, ensuring collaborative learning and jelled teamwork. Implementation of PBL: Each team was assigned a real-world problem to analyse system requirements and design solutions. Students applied Unified Modeling Language (UML) using STAR UML to design various system diagrams to develop their problem-solving and analytical skills.

ACTUAL OR ANTICIPATED OUTCOMES

Understanding of system requirements, completeness of UML diagrams, Teamwork and communication skills, Analytical and problem-solving abilities were improved. Regular assessments were conducted every two weeks to track student progress. Feedback was provided to help refine their work.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Students actively participated in team-based learning, leading to better retention of concepts compared to traditional lecture-based methods. The application of UML diagrams in real-world scenarios helped students bridge the gap between theoretical knowledge and practical implementation.

KEYWORDS

Problem based learning, System Analysis and Design, Unified Modeling Language, Assessment, Evaluation.

Introduction

System Analysis and Design (SAD) is the core course of undergraduate program of Computer Engineering. This course develops the ability to view real world problems, integrate multidisciplinary knowledge, and systematically plan solutions. Before software is developed, Software development life cycle (SDLC) to be followed which requires communication with stakeholders, Requirement gathering, planning, designing, analysis, coding and deployment (Xu, 2011).

Thus, strong 'system analysis and design' skills are essential for preparing students to solve complex, ill structured, real-world problems in industries namely IT, aerospace, healthcare ,environmental, sustainable energy., etc.

Object-Oriented Programming and Design serves as a prerequisite for the System Analysis and Design course. In the prerequisite course, students learn the fundamentals of algorithm design and implementing solutions using object-oriented programming. Building on this foundation, the System Analysis and Design course takes students to the next level, encouraging them to shift their perspective from writing individual programs to conceptualizing and designing complete software systems. This transition helps students develop a system-level thinking approach, essential for analyzing, modeling, and constructing real-world applications (Silva et al., 2021).

PBL originated in the 1950s and 1960s in medical education at Case Western Reserve University and McMaster University, and has since gained attraction in various disciplines, including engineering. Its adoption has expanded globally across countries like the U.S., Canada, the Netherlands, Denmark, Germany, Sweden, Australia, Spain, and Mexico. Notably, Aalborg University in Denmark pioneered the integration of PBL into engineering curricula during the 1970s, making it one of the first institutions to formally implement this approach in engineering education(Maladzhi et al., 2024).

Project-Based Learning (PBL) has emerged as a prominent pedagogical approach in engineering education, promoting active learning, problem-solving abilities, and the practical application of theoretical knowledge. By engaging students in hands-on projects that reflect real-world engineering challenges, PBL enables them to bridge classroom learning with industry-relevant experiences. Rooted in constructivist philosophy, PBL places learners at the centre of the educational process, encouraging them to integrate conceptual and technical knowledge to solve practical problems (Maladzhi et al., 2024).

Criticism about undergraduate engineering education not focusing on problem solving, real-world contexts which most often deviate from ill-structured problem statement. Instead, UG courses focus mostly on well structured, known and correct solutions. Practically speaking, real world problems are ill structured. (Olusegun, 2015)(Alcaraz et al., 2020)

To enhance students' analytical and design thinking skills in '*System Analysis and Design*' course, a team-based, experiential learning activity focused on solving ill-structured, real-world problem statements is conducted. A total of 12 teams, each comprising of 4 students, were formed. These teams were tasked with identifying and analysing open-ended problems and translating them into structured system models. Teaching plan for the entire course is designed and the appropriate rubric for the assessment is framed. Student's were required to design a complete set of UML diagrams, use case diagrams to deployment diagrams keeping real-world system development processes in mind. The activity was assessed using clearly defined rubrics to ensure consistency and transparency in evaluation.

Problem based learning enhances creativity, problem solving skills, curiosity, critical thinking, collaboration, and self-confidence(Ismail et al., 2023)

Literature Review

The students found that project-based learning approach is a motivational pedagogical model (Ismail et al., 2023). Participation of industry in the project was seen as a great motivation for the students. As a result, it was therefore concluded that the idea of allowing students to do real-life projects should be encouraged further in higher education curricula. The students' positive attitude towards integrated project-based learning inspired higher education institutions to apply this framework (Maladzhi et al., 2024) in their courses or program.

There are challenges faced by faculty members while teaching design courses. Students lack to visualise the scenarios, students loose interest as the complexity of the course increase. Text book and lecture-based teaching lacks the design thinking ability (Ismail et al., 2023). Insufficient hands-on or collaborative activities obstruct the practical understanding of SDA principles. Thus, Problem and Project based learning resolves this issue, encourage student's deep dive into the problem statement.

Project and problem-based learning are different methods of learning. Project based learning takes longer time compared to problem-based learning. The steps of Project based learning are not certain; the steps in Problem based learning are traditionally-defined steps (Akarsu et al., 2016). Studying within a group encourages the active participation of students into the education process, enables them to solve their doubts on their own, reduces the rate of students' dropping out of school, makes them gain the ability to think critically, encourages them to take pleasure in the educational process and a more positive attitude towards the subject of the study, provides increase in academic performance in mathematics, science and technology, and supports them in preparing for the future life, provides them with the opportunity to obtain different perspectives in achieving educational goals, encourages self-learning, increases their communication skills, supports different learning styles(Akarsu et al., 2016).

Rubrics are an excellent way to establish communication between the student and the teacher about the evaluation criteria and what the quality standard demanded by the teacher is. They allow the student to know, right from the start, how to do their work individually and in groups(Martínez et al., 2011).

Setting up the following research questions after reviewing the existing literature is as follows:
RQ1 : What are the effective Learning Activities of PBL for system Analysis and Design?

RQ2 How is the educational effectiveness of PBL for system Analysis and Design is measured?

Methodology

During the academic year 2023-2024, in 4th semester similar course called "System design using UML" was taught and received the following comments from students. Conventional lectures were conducted . Course outcome attainment of that semester was not so great, while comparing their midterm marks.

Table 1: Comments received for Previous year's Traditional Teaching of SDUML course

S.No	Comments received	Solution designed
1	Assignments can be guided, and given a real time examples instead of just giving questions	PBL approach, with ill structured problem statements selected by the student teams itself, but approved by Faculty members
2	Faculty members race against the completion of syllabus, to cover the portion for the syllabus	PBL is not syllabus centric, it is problem centric. Covering all the aspects of the syllabus is planned, resources are uploaded on MSTeams class group, every fortnight grading took place.
3	Below average students anticipate / excel in the practical/ hands-on based topics	Student's Team will collaborate in the classroom and perform. The challenges faced will be addressed by the faculty member and similar problems faced by other teams is addressed in the class room for better understanding.

Table 1 , assessments showed that the average student could not achieve the outcomes in their midterm exams. Previous years' assessments revealed low attainment levels, with below-average students consistently avoiding questions related to class diagrams, state diagrams, activity diagrams, and component diagrams. Instead, they tend to attempt theory-based questions, which generally yielded lower scores. Data collection is done from this course, by the course Faculty.

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Course Design of System analysis and Design using Constructive Alignment Theory:

Student centred learning is the contribution of Constructive Alignment learning (Olusegun, 2015). The Active Learning (AL) activities are designed to support students to reach the outcome of the course and assess them accordingly. In PBL teaching we have considered only in-class activities.

AL activities were selected to engage learning in the class according to the course outcomes, while having a hands-on design that correspond to the topics being taught in class. AL was implemented during class time to support students in constructing understanding before moving on to the next design. In PBL classroom, students must think, create, and solve problems rather than passively listen to lectures; Faculty members must allow them to construct their knowledge and skills (Alcaraz et al., 2020; Calderon et al., 2025; Martínez et al., 2011).

In a PBL classroom, discussions are driven by student-raised questions. When a doubt arises on a particular topic, it is often addressed collaboratively, with other student groups actively contributing to the resolution.

The objective of PBL method is to contribute on student learning with an experience on how to think critically to gather requirements, design, and validate software systems by focusing on challenges faced in the software industry (Gupta, 2022)

Course Outcomes and Content of the Course:

The course 'System Analysis and Design' has mainly four course outcomes.

CO1. Describe Unified process and elicit requirements using Use case diagram (Level-2).

CO2. Analyse the problem using interaction, structural, and dynamic model (Level-3).

CO3. Design Package, Component and Deployment model for the given problem (Level-4).

CO4. Design test cases, infrastructure design and installation of the product (Level-4).

Content of the course is divided in to stages 1 to 5. Also CO's are mapped with these stages.

Table 2: 15 week's task is divided into 5 stages, stage 1 to stage 5

PBL Stages/CO's	Week	Tasks	Outcome
Stage 1 CO1	1-2	Team formation	Problem statement with list of team members, Validating the Problem statement by Faculty Member
Stage 2 CO2	3-6	Requirement gathering	Requirement specification Requirement Document (SRS)- Functional and non functional requirement specification Feasibility- Cost estimation, Process Model identification: Waterfall, incremental, Prototype, Spiral , Agile , Functional Model: Usecase Diagram, Sequence Diagram, Collaboration Diagram, Structural Model: Class Diagram
Stage 3 CO2	7-11	Design Specification	Software design document in IEEE format Behavioural Model :State chart diagram, Activity diagram, Swimlane diagram Updated diagrams -Usecase Diagram, Sequence Diagram, Collaboration Diagram, Class Diagram
Stage 4 CO4	12-14	Risk analysis and test specification	Designing Test cases , Test Plan on Unit and System testing
Stage 5 CO3	15	Final documentation	Infrastructure Design, Package Diagram

Table 1 and Figure 1, depicts the all five stages implemented in Problem based learning activity conducted in classroom.

Stage 1: In stage1, team formation and topic identification is done. Students are grouped into teams of 3–5 members. Teams are encouraged to ensure diversity in skills, interest areas and try to simulate industry. Then, the Problem statement Identification is done. Each team identifies a relevant and practical problem, preferably from domains such as education, healthcare, environment, social welfare, or business. The problem should be specific, feasible within the semester, and solvable with a software-based solution. Faculty validates it. Faculty validates the scope, relevance, and complexity of the problem. Feedback is provided for refinement to ensure alignment with course objectives and technical feasibility.

Stage 2:

Student's Team interact with potential stakeholders, or they simulate as a potential stakeholder to gather detailed software requirements. Requirements are Documented using the Software Requirement Specification (SRS) format.

Feasibility analysis is done using rough estimation of development time, effort, and cost using models like COCOMO is done. Technical feasibility assess availability of technology, skills,

and tools required. Identification of the Process Model based on the project complexity and requirements.

Process Model Identification is done based on the project complexity and requirements, teams choose an appropriate process model namely Waterfall Model, Incremental Model, Prototype model, Spiral model, Rapid Application Development (RAD) model and agile model.

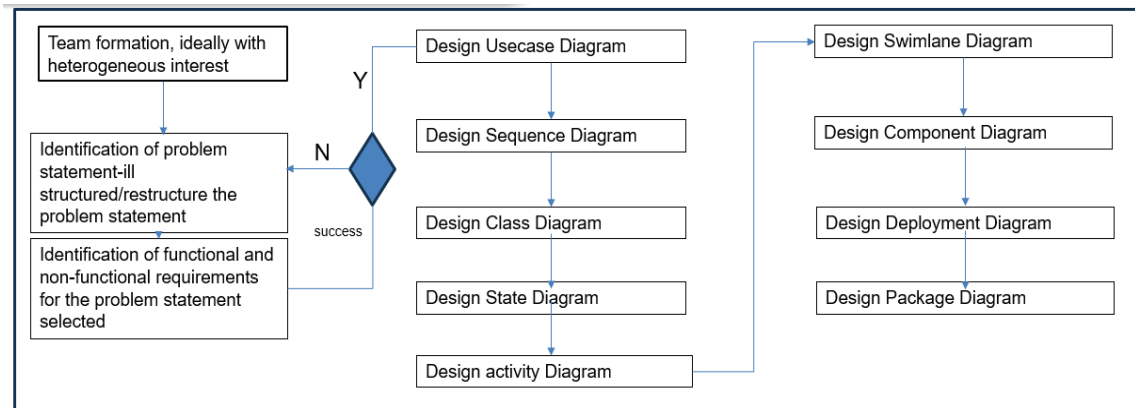


Figure 1: Flow diagram for the Stage1 to Stage 5

Stage 3: Design Specification

To translate the requirements into required UML diagrams. Usecase Diagram: it depicts the functional requirements of the system, also shows the interaction between Actors and the Use Cases. Sequence Diagram: It shows the interactions between the objects and detailed object lifelines are shown. Class Diagram shows the system architecture, it shows how data is structured and how the objects interact in the system. State diagram shows the dynamic behaviour of a system or an object based on its states and transitions. Activity Diagram shows the activity of the system. An Activity Diagram shows the sequence of activities and their transitions based on conditions or events. It is similar to a flowchart but specifically tailored for modelling system behaviour. Swimlane diagram shows the role wise responsibility in workflows. Component diagram is a structural diagram in UML that shows how a software system is split into components and how those components are interconnected via interfaces. From the component diagram one can easily understand how components depend on each other, provided and required interfaces explicitly shown in UML diagrams. This helps coders while implementing the system. Deployment diagram provides a clear view of infrastructure. Helps to plan the physical configuration of the system.

Stage 4: Designing effective test cases, performing Unit Testing, and analysing risk factors that may affect system quality.

Stage 5: Package diagram shows the modularity of large systems. It supports namespace management and code reusability. It makes the system navigation easier for developers.

Outcomes of the Implementation

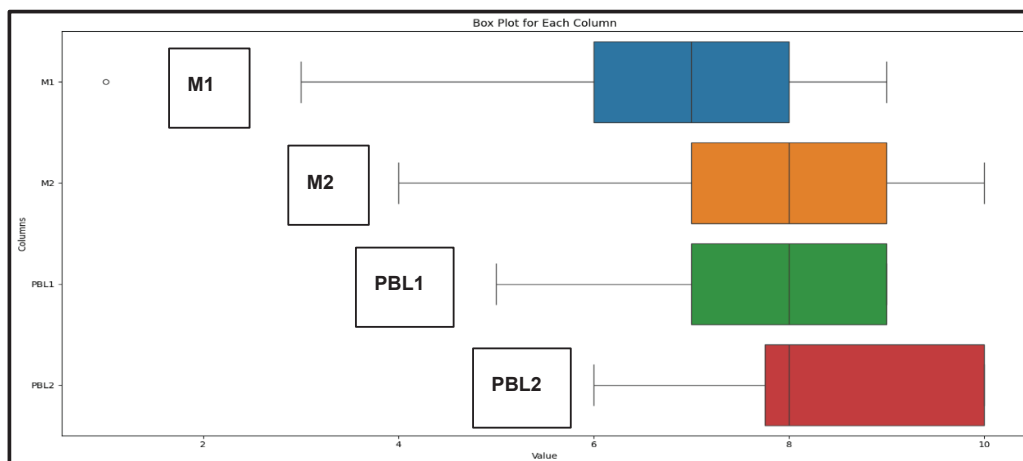


Figure 2: Box Plot mentioning X axis as 'Marks' and Y axis as assessment component

The box plot in Figure 2, shows that PBL1 and PBL2 activity gained higher Median than M1 and M2. The data spread is relatively tighter, indicating more consistency in student performance. No Extreme Outliers in the figure for PBL1 and PBL2 suggests overall balanced performance among students.

M1 has a significantly lower median compared to PBL1 and PBL2. The presence of a low outlier suggests some students performed poorly in M1. Wider Spread Indicates more variability in student scores, especially in M1.

PBL1 and PBL2 performance is better than M1 and M2 in terms of both central tendency (higher medians) and consistency (tighter IQR).

The data implies that students are engaging more effectively and possibly performing better in project-based learning (PBL) components compared to traditional module assessments (M1, M2).

Student Surveys:

Surveys measure student satisfaction about the course carried out during the Semester. They were asked about the positive and negative aspects of the course in an open-ended manner. The survey results for the year 2024 – 2025 are presented in Figure 3. and answers shows that most often Students feel very positively about the contents and the teamwork.

Table 3: Outcome of the Student feedback after the course completion using PBL

Feedback type/ Students feedback (%)	General Perception				Collaboration and Teamwork			
	Project Objectives were clearly communicated	The project aligned well with the course learning outcomes	The topic of the project was relevant to real-world applications	The project increased my interest in the subject	The project helped deepen my understanding of the subject.	The activity improved my critical thinking and problem-solving skills.	I had sufficient resources and guidance throughout the project	The timeline and expectations were clear and achievable.
Strongly Agree	52.4	55	52.4	47.6	47.6	47.6	52.4	47.6
Agree	38.1	35	38.1	33.3	28.6	23.8	28.6	33.3
Disagree	4.8	5	4.8	4.8	9.5	9.5	9.5	9.5
Strongly Disagree	4.8	5	4.8	4.8	9.5	9.5	9.5	9.5

Table 3 and Figure 3 depicts the student feedback on a Project Based Learning (PBL) activity conducted in the "System Analysis and Design" course. The aim was to evaluate the effectiveness of the PBL method in enhancing student engagement, understanding, and skill development. Using both quantitative and qualitative responses from the participants, the feedback provides insights into the strengths and areas for improvement in the implementation of PBL pedagogy.

The questionnaire included Likert scale questions covering various dimensions such as clarity of objectives, relevance, peer learning and communication skills.

Clarity and Alignment: Over 90% of students agreed or strongly agreed that project objectives were clearly communicated and aligned with course outcomes.

Relevance and Engagement: More than 85% felt the project was relevant to real-world applications and enhanced their interest in the subject.

Skill Development: While most students reported improvement in communication, research, and analytical skills, a small percentage (around 10%) disagreed, indicating a need for more structured handholding.

Peer Learning and Teamwork: Strong agreement was observed in peer learning and collaborative experience.

Students appreciated creative learning, hands-on learning, and the enthusiastic delivery by faculty.

Few Suggestions given by the students were more time for execution, clearer rubrics, and inclusion of examples during instruction. Improvement on this feedback will be considered in the next semester.

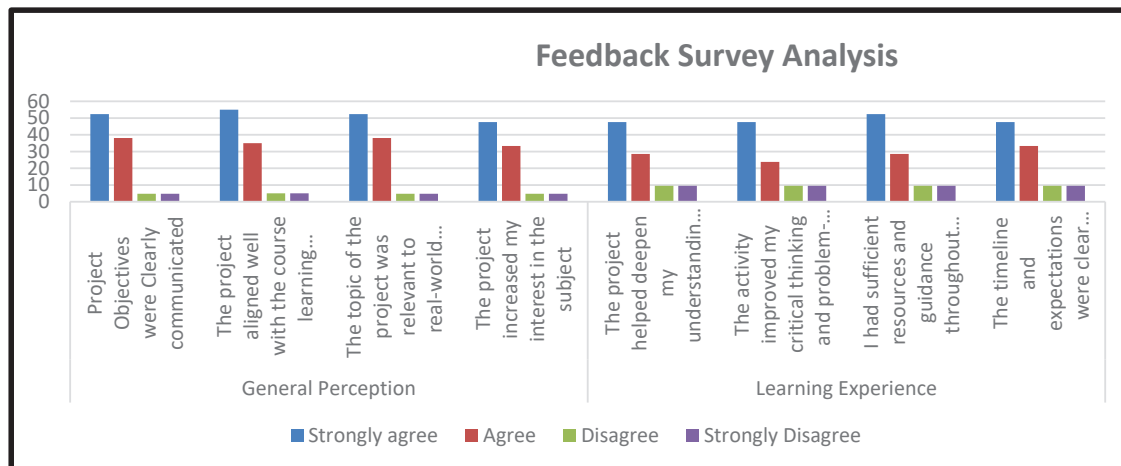


Figure 3: Feedback survey conducted for students

Conclusions and Future work

RQ1 has been effectively addressed, as the implementation of active learning techniques such as design-based tasks, debates, discussions, and teamwork significantly enhanced students' understanding. This improvement is evident in the median marks observed in both PBL1 and PBL2 activities conducted in the class room which included designing of all 9 diagrams. Positive outcome in helping students in attaining the knowledge, and understanding of both theoretical and practical concepts. These findings are based on academic results, PBL activities, and the survey.

The findings of statistical analysis suggest a positive influence PBL in 'System Analysis and Design' course to meet industry expectations and overall course outcomes.

RQ2 is also comprehensively answered, with the results of the PBL implementation supporting its effectiveness. Additionally, feedback collected through surveys further corroborates the positive impact. Overall, the PBL activity conducted in the *System Analysis and Design* course proved to be largely successful in meeting its intended learning outcomes. Students found it engaging and educational, with tangible benefits to their understanding and skills. However, enhancements such as clearer evaluation rubrics, structured feedback, and additional examples during project briefing can further improve the experience.

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