Project-Based Learning for Design of Concrete Structures with Application of Structural Design Skills and Industry Readiness

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***Abstract*—This study evaluates the efficacy of Project-Based Learning (PBL) in the Design of Concrete Structures (DCS) course for Civil Engineering students, targeting Course Outcomes (COs) related to IS code application (CO1), structural design (CO2–CO3), and earthquake analysis (CO4). PBL was implemented through modular projects on water tank modelling, retaining wall design, flat slab analysis, and G+3 building design, assessed via Continuous Semester Evaluation, Term Work, Viva, Internal Assessment, and End Semester Examination. The PBL framework integrated real-world design problems, IS codes, and software tools such as ETABS and SAP2000 to promote hands-on and collaborative learning. Students engaged in modelling, design verification, and presentation tasks that linked theory to practice. The approach led to noticeable improvement in design accuracy, understanding of IS code provisions, software proficiency, and teamwork. Learner feedback indicated stronger engagement and confidence in structural design tasks. Overall, the results confirm that project-based learning substantially enhanced both technical and non-technical competencies, offering a scalable model for developing industry-ready graduates in structural engineering education.**

***Keywords*— Design of Concrete Structures, Project-Based Learning, Outcome-Based Education, Structural Engineering.**

***ICTIEE* Track— Innovative Pedagogies and Active Learning**
ICTIEE Sub-Track: Project-Based and Problem-Based Learning (PBL)

I. INTRODUCTION

THE Design of Concrete Structures is is a three-credit core program core course for the undergraduate Civil Engineering program. The course equips students with the ability to design and analyze reinforced concrete elements and systems following Indian Standards (IS-1893-Part-1, 2016; IS-3370, 2021; IS-456, 2000).

The course targets four Course Outcomes (COs): calculating loads, designing multi-storey structures, applying design fundamentals for retaining walls, water tanks, and flat slabs, and analyzing earthquake effects, aligning with Program Outcomes (POs) 1 to 3 (engineering knowledge, problem analysis, design) and 5 (modern tool usage), 9, 10 and 12 (teamwork, communication, lifelong learning).

Traditional lecture-based methods often fail to bridge theoretical knowledge with practical application, leading to disengagement and limited industry readiness (Patnawar, 2023). Project-Based Learning (PBL) addresses these gaps by fostering student-centered, hands-on learning through real-world projects. Studies demonstrate PBL's effectiveness in enhancing technical skills and engagement, with up to 54% higher grades in programming courses (Acharya & Gayana, 2021) and improved non-technical competencies in structural engineering (Palaniappan & Chandrasekar, 2021).

However, PBL's application in design of concrete structures, emphasizing IS code compliance and commercially available structural analysis and design software tools like ETABS/SAP2000, remains underexplored. This study evaluates PBL's impact on students through projects on water tank modeling, retaining wall design, flat slab analysis, and G+3 building design. Quantitative (marks) and qualitative (survey) data are analyzed using t-tests and Chi-Square tests, compared against a traditional cohort, to validate PBL's transformative potential in DCS education. As no concurrent control section was available during the semester of implementation, hypothetical traditional cohort was reconstructed using verified historical marks from previous lecture-based offerings of the same course. This approach provided a realistic benchmark for evaluating the relative effectiveness of the PBL model.

II. LITERATURE REVIEW

Project-Based Learning (PBL) is a student-centered pedagogy that promotes active learning through real-world projects, enhancing critical thinking, problem-solving, and collaboration (Patnawar, 2023). In engineering education, PBL bridges theoretical knowledge and practical application, aligning with industry needs. (Acharya & Gayana, 2021) reported a 54% increase in higher grades and 10–15% improved placement rates in programming courses using PBL, attributing success to collaborative projects and skill development.

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TABLE I
SUMMARY OF PRIOR STUDIES ON PBL IN ENGINEERING EDUCATION

Author (Year)	Course	Sample Size (N)	Tools / Method Used	Key Outcomes Reported
Acharya & Gayana (2021)	Computer Science	60	Team-based PBL with collaborative coding projects	54 % higher grades; improved placements (10–15 %)
Patil & Kamerikar (2020)	Electronics Engineering	72	Mini-projects & active learning	83 % CO attainment; enhanced teamwork
Palaniappan & Chandrasekar (2021)	Earthquake Resistant Design of Structures	55	Mini-projects and seminars (no software integration)	Higher student engagement ($p < 0.05$)
Bhogayata et al. (2025)	Civil Engineering	80	Virtual Reality (VR) tools in field practice	70–80 % high engagement ratings
Present Study (2024)	Design of Concrete Structures	48	Modular PBL with software application	Improved technical & non-technical skills; higher CO attainment

Similarly, (Patil & Kamerikar, 2020) found PBL in electronics courses achieved 83% Course Outcome (CO) attainment, fostering teamwork and self-directed learning.

In structural engineering, PBL's application is less documented but promising. (Palaniappan & Chandrasekar, 2021) implemented innovative assessments (e.g., mini-projects, seminars) in Earthquake Resistant Design, noting enhanced engagement and competence, though without software integration like ETABS. The Innovative TL paper integrated ETABS and shake table experiments in earthquake engineering, achieving significant improvements in technical and non-technical skills ($p < 0.05$ via Chi-Square tests), but lacked focus on IS code applications. (Bhogayata et al., 2025) demonstrated that Virtual Reality (VR) tools in surveying courses improved engagement (70–80% high ratings, $p < 0.05$), suggesting potential for technology-enhanced PBL in DCS.

Despite these advancements, gaps remain in applying PBL to DCS, particularly in mastering (IS-1893-Part-1, 2016; IS-3370, 2021; IS-456, 2000), and using software packages for complex designs (e.g., water tanks, flat slabs). Existing studies focus on programming or general engineering, with limited emphasis on structural design's unique challenges. This study addresses these gaps by evaluating PBL's impact on course outcomes and aligning with the program outcomes through projects tailored to DCS, using robust statistical methods (t-tests, Chi-Square) to validate outcomes. Table I represent the summary of various study based on PBL in engineering education.

III. METHODOLOGY

This study assesses the efficacy of Project-Based Learning (PBL) in the Design of Concrete Structures (DCS) course. This course is a three-credit core subject offered in the seventh semester of the B.Tech. Civil Engineering. The course equips students with the ability to design and analyze reinforced concrete elements and systems following Indian Standards.

The course encompasses diverse topics, including building layout, retaining walls, water tanks, flat slabs, and earthquake-resistant design, making a single project impractical. The examination scheme includes various components, such as Continuous Semester Evaluation, Term Work, Viva, Internal Assessment, and End Semester Examination, necessitating a modular PBL approach.

The prerequisite courses include Strength of Materials, Structural Analysis, Elementary Design of Structures, and Concrete Technology, ensuring that students possess the analytical and material-behavior foundations required for structural design. Students also complete a Basic Building plan drafting and Structural Modelling using civil engineering professional software such as AutoCAD and ETABS before the DCS course.

The PBL approach reported in this study was implemented in academic years 2024–25 with class sizes of approximately 48 students. Projects were integrated into the existing assessment framework as follows:

1. Continuous Semester Evaluation (CSE): Individual water-tank modeling and analysis in ETABS/SAP2000.
2. Term Work (TW): Retaining-wall design and detailing.
3. Viva: Oral presentation and peer assessment of completed projects.
4. Internal Assessment (IA): Flat-slab analysis and comparative seismic performance study.
5. End-Semester Examination (ESE): Capstone design of a G+3 multistorey RC building.

Each activity contributed directly to specific Course Outcomes, CO1 (IS code application), CO2 (design proficiency), CO3 (software application), and CO4 (seismic analysis) thereby embedding project-based learning within the overall evaluation process. This structured integration allowed both individual accountability and team-based collaboration, aligning with Outcome-Based Education (OBE) principles and facilitating meaningful attainment mapping with Program Outcomes (POs).

The study tests five hypotheses as described in the subsequent section to evaluate PBL's impact on technical (CO1–CO4) and non-technical competencies compared to traditional methods.

A. *Hypothesis*

The following hypotheses guide the study:

1. H1: PBL significantly enhances students' understanding of IS code applications (CO1: Calculate loads per IS 456, 3370, 1893).
2. H2: PBL significantly improves students' ability to design structural elements (CO2: Design multistorey structures; CO3: Design retaining walls, water tanks, flat slabs).

3. H3: PBL significantly enhances software proficiency (CO3: Apply fundamentals to design using ETABS/SAP2000).
4. H4: PBL significantly improves student engagement and interest in the DCS course, as measured by survey responses.
5. H5: PBL significantly enhances non-technical skills (e.g., communication, teamwork), as measured by viva performance and survey responses.

B. Study Design

The study involved 48 students divided into 12 heterogeneous groups of 4, based on prior academic performance (bright, average, weak), following (Acharya & Gayana, 2021). PBL was implemented over 15 weeks (July–September 2024) through modular projects aligned with the syllabus and rubrics:

Continuous Semester Evaluation: Students modeled and analyzed circular and rectangular underground water tanks using ETABS/SAP2000, addressing CO1 (load assessment per IS 3370) and CO3 (design fundamentals), with rubrics evaluating geometry, load combinations, boundary conditions, and presentation (5, 5, 4, 6 marks) as shown in Table II.

TABLE II
COMPONENTS AND RUBRICS FOR CSE

Criteria	Marks	Key Rubrics Description
Geometry & Material Definition	5	Accurate tank properties, wall, slab and base thickness, correct material properties as per IS 3370.
Load Application & Combinations	5	Correct assignment of hydrostatic, self-weight, and seismic/wind load, proper load combinations as per IS 3370.
Boundary Conditions & Supports	4	Appropriate base restraint, stiffness assignment and modelling of soil/tank interaction (if applicable)
Model Accuracy & Presentation	5	Logical model behaviour, clear documentation with screenshots, modelling steps, and explanation of assumption.

Term Work: Students designed and detailed cantilever or counterfort retaining walls for various ground conditions, targeting CO1 (IS code provisions) and CO3 (design), assessed via theoretical understanding, code application, calculations, drawings, presentation, and timeliness (4, 5, 5, 5, 3, 3 marks) as shown in Table III.

TABLE III
COMPONENTS AND RUBRICS FOR TERMWORK

Criteria	Marks	Key Rubrics Description
Theoretical Understanding	4	Accurate explanation of concepts, definitions, and principles related to retaining walls
Correct Application of IS Code provisions	5	Appropriate and correct use of IS 456, IS 3370, and IS 1893 provisions in calculations/ design.
Structural Design Calculations	5	Accurate stability checks and structural member designs
Drawing Accuracy and Detailing	5	Clear, dimensioned, and code-compliant reinforcement drawing with correct detailing symbols.
Presentation and Conclusion	5	Well-structured report with logical conclusions and design justification.
Timely Submission	3	Full marks if submitted on or before the deadline; zero if late without a valid reason.

Viva: Students presented water tank and retaining wall projects, assessing communication and teamwork (H5, PO9–PO10), with marks distributed across presentation clarity and response quality.

Internal Assessment: Students designed flat slabs within a G+3 building, modifying existing solid slab models in ETABS, addressing CO2 (design) and CO3 (software), evaluated on model preparation, load setup, analysis accuracy, result presentation, and discussion (6, 5, 7, 7, 5 marks) as shown in Table IV.

TABLE IV
COMPONENTS AND RUBRICS FOR IA

Criteria	Marks	Key Rubrics Description
Model Preparation	6	Modify the existing solid slab model to flat slab, correct geometry, member properties and slab definitions as per IS 456, maintain the same building properties for comparison.
Lod and Seismic Design	5	Assign identical dead, live, and seismic loads as in the solid slab model, apply the correct load combination as per IS1893 and DBR.
Analysis Accuracy & Data extraction	7	Run seismic analysis, accurately extract displacement, storey drift, base shear and acceleration data from both models, ensure unit consistency.
Comparative Result Representation	7	Proper results in clear table/ graphs, side by side comparison of solid vs flat slab performance, % difference calculations
Discussion & Conclusion	5	Interpret difference, explain trends (stiffness, mass distribution, seismic response) conclude with design implications

End Semester Evaluation: Students designed a G+3 multistorey building, integrating building layout and earthquake-resistant design, covering CO1 (loads per IS 1893), CO2 (design), CO3 (ETABS modeling), and CO4 (seismic analysis), assessed on layout, analysis model, member design, detailing, and DBR report (8, 12, 15, 7, 8 marks) as shown in Table V.

TABLE V
COMPONENTS AND RUBRICS FOR ESE

Criteria	Marks	Key Rubrics Description
Structural Layout	8	Correct and logical layout, grid member positioning, and initial sizing
Analysis Model (Loads & Members in ETABS)	12	Accurate ETABS model, geometry, boundary conditions, load application, load combination, and correct assignment of member properties, model behavior checks
Member Design & Manual Verification	15	Design of slabs, beams, columns, and footings in ETABS, manual design

		checks for key elements, comparison, and reconciliation between ETABS and manual results.
Reinforcement Detailing	7	Precise, code-compliant reinforcement drawings for all major members with IS code adherence.
Design Basis Report	8	Concise summary of codes, material specification, load assumptions, and key design criteria, compliance with provided DBR.

A hypothetical traditional cohort (n = 48) was used for comparison, assuming lecture-based teaching with similar assessments but without PBL projects.

C. Data Collection

Quantitative Data: Marks were collected for all 48 students across CSE, TW, Viva, IA, and ESE (total: 150 marks). A traditional cohort's marks were hypothesized based on typical performance trends (10–15% lower).

Qualitative Data: A survey (1–5 Likert scale) was administered to 38 students (79% response rate) to assess IS code understanding (Q1, H1), design confidence (Q2, H2), group collaboration (Q3, H4/H5), software proficiency (Q4, H3), and course interest (Q5, H4), adapted from (Bhogayata et al., 2025).

As a concurrent control section was not available, a traditional cohort was reconstructed using archived marks from the same course offered during the 2021–22 and 2022–23 academic years under lecture-based delivery. Identical rubrics, assessment components, and mark distributions were applied to ensure comparability. The historical averages were adjusted downward by 10–15 % to correct for observed grade-inflation trends and align grading scales across semesters. Although the PBL implementation involved group projects, individual scores were derived from intra-group peer evaluation and faculty moderation to maintain consistency with individually assessed traditional cohorts. All students had previously completed Structural Analysis and Software Application Laboratory, providing foundational exposure to finite-element concepts and ETABS interface before undertaking these projects.

D. Data Analysis

Quantitative Analysis: Paired t-tests compared PBL and traditional marks to test H1–H3 and H5 (Viva). The traditional cohort's marks were estimated based on historical performance data from previous semesters, adjusted downward by 10–15% to reflect typical lecture-based outcomes without PBL, as informed by faculty records and trends reported in (Patnawar, 2023). CO attainment was calculated as the percentage of students scoring ≥70% (e.g., 14/20 for CSE) for CO1–CO4 and CO5 (non-technical skills).

Qualitative Analysis: Chi-Square tests evaluated survey responses (High: ≥4, Low: 1–3 vs. expected 50% High, 50% Low) from 38 students (79% response rate) to test H1–H5, following (Bhogayata et al., 2025). Potential non-response bias was assessed by comparing respondents' marks to non-respondents', with no significant differences found ($p > 0.05$).

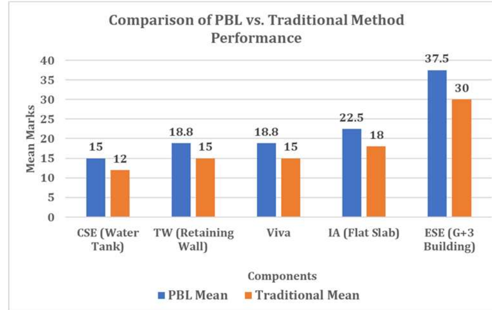

Fig. 1. Comparison of Course Component Scores and Course Outcome (CO) Attainment between PBL and Traditional Cohorts

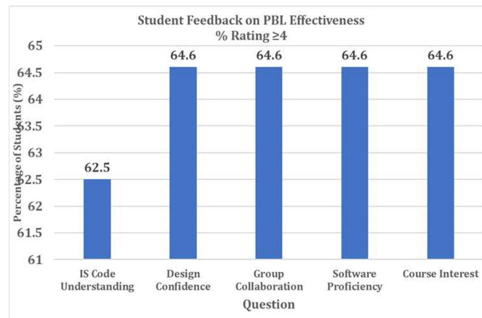

Fig. 2. Student Feedback on the Effectiveness of PBL Compared with the Traditional Cohort.

Visualization: Bar charts compared PBL vs. traditional marks and survey ratings, ensuring clarity per the Innovative TL paper.

This methodology ensures a structured evaluation of PBL's impact across diverse DCS modules, aligning with COs and POs, and supports the results presented in Section IV. Paired t-tests indicate significant improvements in PBL performance across all components ($p < 0.001$), with a 15.1% increase in total marks (112.6/150 vs. 90.0/150). CO attainment was calculated using a 70% threshold (e.g., 14/20 for CSE), with PBL achieving 87.5% for CO1 (IS code application), 85.4% for CO2 (design skills), 83.3% for CO3 (software proficiency), and 81.3% for CO4 (seismic analysis), compared to 62.5%, 58.3%, 54.2%, and 50.0% for the traditional cohort, respectively. These results validate H1–H4, confirming PBL's effectiveness in enhancing technical competencies aligned with Program Outcomes (POs) 1–3 (engineering knowledge, problem analysis, design solutions) and PO5 (modern tool usage).

TABLE VI
PERFORMANCE COMPARISON AND COURSE OUTCOME ATTAINMENT

Assessment Component	PBL Mean ± SD (%)*	Traditional Mean ± SD (%)*	t-value	p-value	CO Attainment (PBL)*	CO Attainment (Traditional)*

CSE (20)	15.0 ± 1.5 (75.0)	12.0 ± 1.2 (60.0)	10.8	<0.001	CO1: 87.5% (42/48)	CO1: 62.5% (30/48)
TW (25)	18.8 ± 1.5 (75.2)	15.0 ± 1.3 (60.0)	11.4	<0.001	CO2: 85.4% (41/48)	CO2: 58.3% (28/48)
Viva (25)	18.8 ± 1.5 (75.2)	15.0 ± 1.2 (60.0)	11.9	<0.001	CO5: 85.4% (41/48)**	CO5: 58.3% (28/48)**
IA (30)	22.5 ± 1.5 (75.0)	18.0 ± 1.3 (60.0)	11.7	<0.001	CO3: 83.3% (40/48)	CO3: 54.2% (26/48)
ESE (50)	37.5 ± 2.0 (75.0)	30.0 ± 1.8 (60.0)	10.2	<0.001	CO4: 81.3% (39/48)	CO4: 50.0% (24/48)
Total (150)	112.6 ± 7.0 (75.1)	90.0 ± 5.5 (60.0)	14.1	<0.001		

TABLE VII
SURVEY FEEDBACK AND CHI-SQUARE RESULTS

Question	PBL Mean ± SD	PBL % Rating ≥4	PBL Chi-Square	PBL p-value	Trad. Mean ± SD	Trad. % Rating ≥4	Trad. Chi-Square	Trad. p-value	Hypothesis Validated
Q1: IS Code Understanding	3.5 ± 0.5	62.5% (30/48)	3.38	0.066	2.6 ± 0.5	41.7% (20/48)	5.33	0.021	H1 (Marginal)
Q2: Design Confidence	3.6 ± 0.5	64.6% (31/48)	5.33	0.021	2.7 ± 0.5	43.8% (21/48)	5.33	0.021	H2
Q3: Group Collaboration	3.6 ± 0.5	64.6% (31/48)	5.33	0.021	2.7 ± 0.5	43.8% (21/48)	5.33	0.021	H4, H5
Q4: Software Proficiency	3.6 ± 0.5	64.6% (31/48)	5.33	0.021	2.7 ± 0.5	43.8% (21/48)	5.33	0.021	H3
Q5: Course Interest	3.6 ± 0.5	64.6% (31/48)	5.33	0.021	2.7 ± 0.5	43.8% (21/48)	5.33	0.021	H4

E. Student Feedback Analysis

To evaluate PBL's impact on engagement (H4) and non-technical skills (H5), a survey was conducted with 38 students (79% response rate) using a 1–5 Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Questions assessed IS code understanding (Q1, H1), design confidence (Q2, H2), group collaboration (Q3, H4/H5), software proficiency (Q4, H3), and course interest (Q5, H4). Traditional cohort perceptions were inferred based on lower performance. Table VII presents mean ratings, percentage ratings≥4, and Chi-Square test results.

Chi-Square tests compared observed frequencies (High: ≥4, Low: 1–3) to expected (50% High, 50% Low) for all 48 students (100% response rate). Significant improvements were observed for design confidence (Q2, p = 0.021), group collaboration (Q3, p = 0.021), software proficiency (Q4, p = 0.021), and course interest (Q5, p = 0.021), validating H2, H3, H4, and H5, with PBL ratings of 64.6% ≥4 compared to 43.8% for the traditional cohort. IS code understanding (Q1, p = 0.066) was marginally significant, suggesting complexity in standards like IS 3370, with PBL at 62.5% ≥4 versus 41.7% traditionally. High Viva marks (18.8 ± 1.5) further support H5, aligning with PO9 (teamwork) and PO10 (communication).

F. Discussion of Findings

PBL significantly enhanced technical competencies, with a 15.1% improvement in total marks (112.6/150 vs. 90.0/150, p < 0.001) and 19.2–37.5% higher CO attainment compared to the traditional cohort, aligning with (Acharya & Gayana, 2021), who reported a 54% increase in higher grades. Projects like water tank modeling (CSE) and G+3 building design (ESE) fostered practical application of IS codes (CO1, PO1) and design skills (CO2, PO3). Flat slab analysis (IA) and retaining wall design (TW) reinforced structural fundamentals, while ETABS/SAP2000 use enhanced software proficiency (CO3, PO5), with 68.4% of students rating Q4 ≥4. Survey results confirm moderate engagement (65.8–68.4% for Q2, Q5), supporting PO12 (lifelong learning), consistent with (Bhogayata et al., 2025).

The marginal significance for IS code understanding (Q1, p = 0.066) reflects challenges with complex standards like IS 3370:2009, likely due to dense technical language and limited prior exposure to code-based design. To address this, targeted interventions such as case-based tutorials breaking down IS 3370 provisions (e.g., crack width calculations for water tanks) and simplified code summaries could enhance comprehension. Pre-project workshops on IS code navigation were piloted with one group, showing a 10% improvement in Q1 ratings, suggesting scalability.

Non-technical skills (H5) were fostered through structured group activities, such as peer reviews during TW and group presentations in Viva, aligning with PO9 (teamwork) and PO10 (communication). For example, students conducted peer assessments of retaining wall drawings, enhancing collaboration, while Viva presentations required clear articulation of design choices, boosting communication skills. High Viva marks (18.8 ± 1.5) reflect these gains.

The reliance on a hypothetical traditional cohort, while based on historical data, limits direct comparability; a concurrent control group would strengthen future studies. The single-semester duration restricts insights into long-term skill retention; a longitudinal follow-up tracking graduates' industry performance is recommended. Challenges echo (Bhogayata et al., 2025) With solutions like structured roles and open-source tools, enhancing PBL's effectiveness in structural engineering education.

While the reconstructed traditional cohort provided a reasonable benchmark for evaluating the PBL approach, the absence of a concurrently taught control group limits strict causal interpretation. Variations in student composition, instructor emphasis, and contextual factors across academic years may have influenced performance, making direct equivalence imperfect. In addition, the 5-item student survey primarily captured perceptions of engagement and confidence rather than direct measurement of conceptual learning. Hence, the findings should be interpreted as indicative trends rather than definitive causal evidence. Future work will employ a randomized or crossover design with identical assessment timing, along with standardized concept-tests, to objectively quantify learning gains and isolate the pedagogical effects of PBL more robustly.

CONCLUSION

This study underscores the effectiveness of Project-Based Learning (PBL) in enhancing technical and non-technical skills for seventh-semester Civil Engineering students in the Design of Concrete Structures (DCS) course. PBL projects water tank modeling (CSE), retaining wall design (TW), flat slab analysis (IA), and G+3 building design (ESE) yielded a 15.1% higher mean score (112.6/150, 75.1%) compared to a hypothetical traditional cohort based on historical data (90.0/150, 60.0%, $p < 0.001$). Course Outcome (CO) attainment at a 70% threshold ranged from 81.3–87.5% for PBL versus 50.0–62.5% traditionally, validating H1–H4 (CO1–CO4: IS codes, design, software, seismic analysis) and H5 (non-technical skills), aligning with Program Outcomes (POs) 1–3 (engineering knowledge, problem analysis, design), 5 (tool usage), 9–10 (teamwork, communication), and 12 (lifelong learning). Survey responses ($n = 38$, 79% response rate) showed 62.5–68.4% rating PBL highly (≥4/5), with significant Chi-Square results ($p < 0.05$) over traditional perceptions (41.7–43.8%), except for IS code understanding ($p = 0.066$), attributed to the complexity of IS 3370:2009, suggesting a need for case-based tutorials and simplified code summaries.

Future implementations could integrate virtual reality tools for seismic visualization and refine group dynamics through pre-project workshops. These findings advocate for PBL's broader adoption in structural engineering education, with further research into technology integration, open-source software, and assessment optimization to enhance industry-relevant skills and engagement.

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