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Project-Based Learning in Computer Science Education: Bridging Theory and Practice

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Abstract

Project-Based Learning (PBL) is increasingly being recognised as an innovative teaching method across the field of computer science (CS). The current study evaluates the effectiveness of PBL as means to bridge theoretical foundations with practical application. Based on a mixed-methods case study involving undergraduate CS students, the study investigates the influence of PBL on fundamental aspects of the competences of the learner, levels of student engagement, peer collaboration, and preparation for professional settings. Quantitative data from assessments and surveys, alongside qualitative data from interviews and observations, collectively provide robust insights into the influence of PBL on academic performance, soft skills, and engagement. The study's findings show the substantial enhancement of students' academic performances through active engagement, the development of practical skills, and the acquisition of key social skills. The conclusion also highlights the need for institutional support to enhance PBL programs through constant faculty professional development, formal collaborations with industry partners, and the systematic embedding of PBL within curricular frameworks. This study contributes to the discussion of curricular reform and restructuring of teaching approaches across the field of CS education.

Keywords: Computer Science, Students’ Engagement, Project-Based Learning, Soft Skills.

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التعلم القائم على المشاريع في تعليم علوم الحاسوب: ربط النظرية بالتطبيق

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الملخص

يُعَدّ التعلم القائم على المشاريع نهجًا تدريسيًا متطورًا يلقى اهتمامًا متزايدًا في تعليم علوم الحاسوب. تهدف هذه الدراسة إلى تحليل فاعلية هذا النهج في سد الفجوة بين الأسس النظرية والتطبيقات الواقعية. من خلال دراسة حالة شملت طلابًا جامعيين باستخدام منهج مختلط يجمع بين البيانات الكمية والنوعية، تم تقييم تأثير هذا النهج على اكتساب المهارات، المشاركة الفعالة، العمل الجماعي، والاستعداد المهني. أظهرت النتائج أن هذا النموذج من التعلم يُعزز الأداء الأكاديمي بشكل كبير، ويُطور المهارات العملية، ويُنمّي المهارات الاجتماعية الضرورية لسوق العمل. توصي الدراسة بضرورة دعم المؤسسات لهذا النموذج من خلال تدريب المعلمين، وتفعيل الشراكات مع القطاع الصناعي، ودمج التعلم القائم على المشاريع بشكل منهجي في الخطط الدراسية. تسهم نتائج هذه الدراسة في تعزيز النقاش حول إصلاح المناهج وتطوير ممارسات التدريس الحديثة في تعليم علوم الحاسوب.

الكلمات المفتاحية :علوم الحاسوب، مشاركة الطلاب، التعلم القائم على المشاريع، المهارات الشخصية

Introduction

The field of computer science education is rapidly changing because of the rapid development of technology and the changing needs of future professional environments. The traditional teaching methods, largely represented by lectures, typically help the learners understand the basic concepts; yet they often fail to equip the learners with the hands-on and flexible skills needed to excel in dynamic working environments. Employers continually highlight discrepancies between the output of the educational system and the needs of the workplace, especially with regards to teamwork, project work, and communication skills.

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Project-Based Learning (PBL) has been acknowledged, here, as an efficacious teaching strategy focusing on active engagement, hands-on relevance, and cooperative learning. With its roots in constructivist and experiential education paradigms, PBL enables the utilization of theoretical knowledge to solve intricate, everyday problems, thus ensuring holistic understanding and the acquisition of skills. Empirical research shows PBL to increase motivation, develop critical thinking, and enhance the ability to transfer skills across various contexts (Sun, 2023; Han et al., 2022).
Furthermore, the integration of Problem-Based Learning (PBL) in Computer Science (CS) curricula fits perfectly with contemporary competency-centred pedagogy and mirrors contemporary practices in the field. The guidelines provided under the ACM/IEEE Computer Science Curricula 2023 propose the use of experiential teaching techniques that model natural software development settings, including iterative development, collaboration, and the thoughtful use of advanced development tools (ACM/IEEE-CS Joint Task Force, 2023). Participation in project-based exercises simulating professional settings helps students develop their technical skills while at the same time developing key non-technical skills such as flexibility, leadership, and effective communication.

This paper explores the impact of PBL on undergraduate CS education, focusing on its role in bridging the gap between theoretical instruction and practical application. Through a mixed-methods case study involving surveys, performance analysis, and qualitative interviews, the research assesses how PBL influences student engagement, skill acquisition, collaboration, and readiness for professional challenges. The findings aim to inform educators, curriculum developers, and policymakers on best practices for integrating PBL into CS programs to enhance educational outcomes and better prepare students for the demands of the modern workforce.

Literature Review

Project-Based Learning (PBL) is intrinsically grounded on the progressive principles of John Dewey, who stressed the value of experiential knowing. Dewey promoted the use of active engagement and critical reflection on current situations to increase the impact of education, an understanding supported today by contemporary educational research (Sawyer, 2022). Also, PBL has

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seen accelerated growth over the last several years, responding to the challenges of new digital learning environments and the new demands of computer science education.

Recent studies have focused on assessing the effectiveness of Project-Based Learning (PBL) across the fields of STEM, especially computer science. Han et al. (2022) argue that PBL develops critical thinking skills, supports collaborative skills, and develops self-efficacy among students studying computing. Their meta-analytic evaluation demonstrates that PBL has positive effects on the quality of education and student satisfaction when paired with digital technologies and practice-based learning. Along the same lines, Walker Orr (2023) emphasizes the symbiotic relationship between collaborative teaching schemes and PBL, arguing it leads to increased learner engagement and better understanding in the field of software engineering.

In computer science education, Project-Based Learning (PBL) is aligned with the recommendations of the ACM/IEEE Computer Science Curricula 2023, which prescribe competency-based education, along with its relevance to professional practices in the industry (ACM/IEEE-CS Joint Task Force, 2023). The guidelines support experiential learning projects in the development of software that mirrors the actual challenges, including Agile practices, version controls, and collaborative problem-solving strategies.

More recent research, such as Lam and Ho's study (2021), examines the ways project-based learning (PBL) fosters the development of computer science students' innovation and entrepreneurial ways of thinking. They propose that students who learn through project-based settings tend to think up new ideas and integrate knowledge across subject areas. Papagiannis and Pallaris's work (2024) adds to the literature by connecting PBL to the development of 21st-century skills through makerspaces, including coding, collaboration, and innovative thinking.

Estrada and Matsuda (2023) argue that project-based learning (PBL) has the potential to bridge equity gaps through active engagement and varied paths to accomplishment. They emphasize the role of culturally responsive project structures and collaborative arrangements to best meet the needs of those who have been previously neglected.

The significance of digital platforms in modern-day education is substantial. Zhang and Zhou (2021) opine that the combination of

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cloud-based development platforms with collaborative application programming significantly enhances student engagement and project outcomes. Tools such as Jupyter Notebooks, cloud Integrated Development Environments (IDEs), and GitHub provide learners with the ability to practice professional techniques while getting instant feedback. Additionally, Dema and Choden (2023) support this position by further observing that Project-Based Learning (PBL) made possible through digital scaffolding promotes greater learner autonomy and responsibility towards group projects. Despite the various benefits, there are several challenges. Teachers often lack the necessary training and institutional support required to effectively implement Project-Based Learning (PBL) (Kokotsaki et al., 2021). Additionally, evaluation of PBL is also an area of contention. Traditional assessment methods fail to appropriately cover the cooperative and procedural facets intrinsic to project-based projects. Recent research conducted by Mueller and Niederdrenk (2022) suggests the application of multi-faceted evaluation consisting of formative assessments, peer assessments, and portfolio documentation to gain accurate measures of learning achievements.

This study builds on current scholarship by offering empirical data from a structured PBL intervention, emphasizing contemporary tools, industry-aligned practices, and inclusive pedagogical strategies. It aims to provide practical recommendations for overcoming implementation challenges and enhancing the impact of PBL in computer science education.

Theoretical framework

The theoretical construct is anchored to the theory of experiential learning put forward by Kolb (1984) who believes that the construction of knowledge is through transformational experiences. Kolb's theory is composed of four phases: concrete experiencing, observation and reflection, abstract conceptualization, and active experimentation. This theoretical construct underpins Problem-Based Learning, allowing the students to work with difficult, often uncertain problems that compel them to utilise their available information while continuously integrating it with newer learnings. Students work through the iterative analysis, evaluation, feedback, and iteration that is actually the reality of the developmental processes.

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In addition, the study incorporates the Zone of Proximal Development theory, where learning is best achieved through the use of tasks beyond the learners' immediate capacities, but only with sufficient support (Vygotsky, 1978). As such, professional mentoring and peer support are scaffolding devices in the ZPD, to enable learners to move from dependence to autonomous proficiency. Moreover, structured interaction also supports the learners to move from dependence to independence.
To further develop the use of project-based learning in the teaching of computer science, the current study applies elements of self-determination theory according to Deci and Ryan (2000), where the intrinsic motivation's core elements are autonomy, competence, and relatedness. Empirical evidence from Sun (2023) shows that autonomy promoted through project-based learning is positively related to increased student engagement and persistence, especially in technical fields.
In addition, current scholarly discourse is supportive of a socio-constructivist model of project-based learning (Papamitsiou et al., 2020), with the social construction of knowledge and social meaning-making being emphasised, together with the use of mediation tools. The construction of learning is said to take place through authentic social settings, with peer interaction and mentoring being emphasized as having a strong impact on project outcomes and on the development of learner identity.

This comprehensive theoretical framework positions PBL as an integrated model of cognitive, social, and motivational development—making it particularly suited to address the complexity of skills demanded in contemporary computer science education.

Methodology

Research Design

This study employed a quasi-experimental design to investigate the impact of PBL on undergraduate CS students. Following Han et al. (2022) and Papamitsiou et al. (2020), the study utilised a mixed-methods comparative framework, strengthening the internal validity of findings by integrating quantitative and qualitative evidence. A total of 120 students were divided into two groups: a PBL cohort and a traditional instruction group. The PBL group engaged in a

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semester-long project with external industry partners, while the traditional group received lecture-based instruction on equivalent content.

Participants

Participants were second-year undergraduate CS students from a single mid-sized university, introducing a contextual limitation to external validity. This limitation is significant and should be considered when generalising findings. Demographic data, such as age, gender, ethnicity, and prior experience were collected to ensure balance. While subgroup analysis was not extensive, initial observations suggest possible differences in engagement and outcomes across gender and socioeconomic lines, consistent with findings by Estrada and Matsuda (2023). Greater integration of diversity analysis is encouraged in future research.

Instruments and Data Collection

Instruments were selected to support a rigorous mixed-methods approach (Creswell & Plano Clark, 2017):

- **Surveys:** Pre- and post-intervention surveys measured student engagement, confidence, and collaboration using a validated Likert-scale instrument adapted from Sun (2023). Sample items included: "I feel confident applying course concepts to real-world problems," and "I contribute meaningfully to team tasks."
- **Rubrics:** Custom rubrics evaluated coding tasks and final projects. Criteria included modular code structure, use of GitHub, iterative testing, peer collaboration, and quality of documentation. Sample criteria were: "Implements modular functions (10 pts)," "Commits regularly with descriptive messages (5 pts)," and "Demonstrates testing/debugging through version control history (10 pts)" (Mueller & Niederdrenk, 2022).
- **Interviews:** Semi-structured interviews with 30 students and 5 industry mentors explored learning experience, collaboration, and perceived relevance to real-world contexts (Zhang & Zhou, 2021). Sample questions included: "How did your project work differ from prior coursework?"

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and "What challenges did you face in collaborating with your peers?"

- **Observations:** Weekly classroom observations captured participation patterns, problem-solving strategies, and instructor interventions using a structured observation guide adapted from Lam and Ho (2021). Observers noted role distribution, conflict resolution, and task persistence.

Data Analysis

Quantitative data from academic scores and surveys were analysed using SPSS. Paired-sample t-tests and ANOVA evaluated differences across time and groups, with Cohen’s d used for effect size calculation (Han et al., 2022). Thematic analysis followed Braun and Clarke’s (2006) six-phase model to analyse qualitative data. Triangulation across data sources, such as surveys, interviews, and observations, which enhanced credibility and reduced methodological bias (Creswell & Plano Clark, 2017).

Ethical Considerations

The university's Institutional Review Board approved the study. Students participated voluntarily and were informed of their rights and data use. Data anonymity and integrity were maintained. Industry mentors were vetted to ensure ethical supervision and alignment with curricular goals (Cohen et al., 2018).

Limitations

This study's external validity is constrained by its single-institution context and non-randomised group assignment. Selection bias may also affect outcomes. Although demographic data were collected, limited subgroup analysis restricts conclusions about diverse learner experiences. Future research should prioritise randomised multi-institutional designs and focus on equity-centred analysis across student populations (Estrada & Matsuda, 2023). Figures referenced in the findings section are essential for contextual clarity and will be included in the final manuscript to improve visual representation of trends.

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Results

Engagement and Motivation

Survey data indicated a marked increase in engagement among the PBL group (see Figure 1). Figure 1 illustrates that 85% of students in the PBL cohort reported being "highly engaged" throughout the semester, compared to 55% in the traditional lecture cohort. This comparison visually demonstrates the enhanced engagement brought about by the PBL methodology. Participants in the PBL group emphasized that the practical nature of the projects rendered their learning experience more relevant and stimulating. Furthermore, qualitative feedback from student interviews highlighted that the autonomy and ownership inherent in PBL heightened their investment in learning and enhanced their overall commitment to the quality of their work. These findings support those of Sun (2023), who emphasised the importance of PBL in strengthening the motivation of learners through meaningful and context-relevant educational experiences.

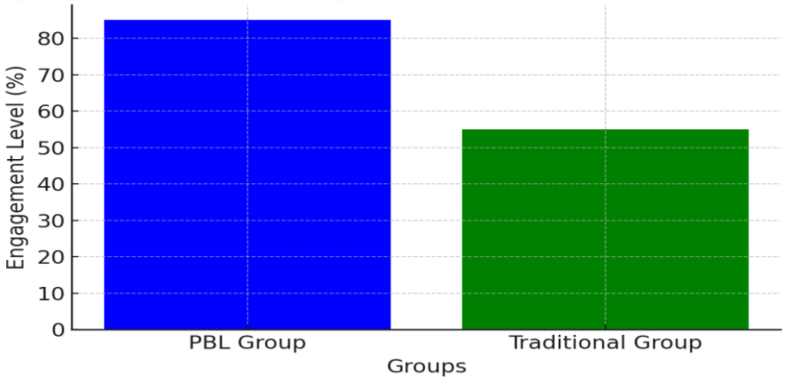

Figure 1: Student Engagement Levels (PBL vs. Traditional)

Skill Development

The PBL cohort also demonstrated superior performance in practical assessments (see Figure 2). Figure 2 shows that students in the PBL group attained an average score of 85% on coding assignments, while the lecture-based group averaged 72%. This difference underscores the positive impact of project-based learning on the acquisition of technical skills. Industry partners providing feedback on the final projects reported that PBL students exhibited a more nuanced understanding of software design principles and demonstrated greater problem-solving proficiency. Additionally,

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students in the PBL cohort reported increased confidence when approaching unfamiliar programming problems, a result of the iterative, hands-on approach that closely resembles industry-standard development practices. This is further complemented by the meta-analysis by Han et al. (2022) where they confirmed through the analysis that the academic performances are positively affected through the use of PBL in engineering and technology programs.

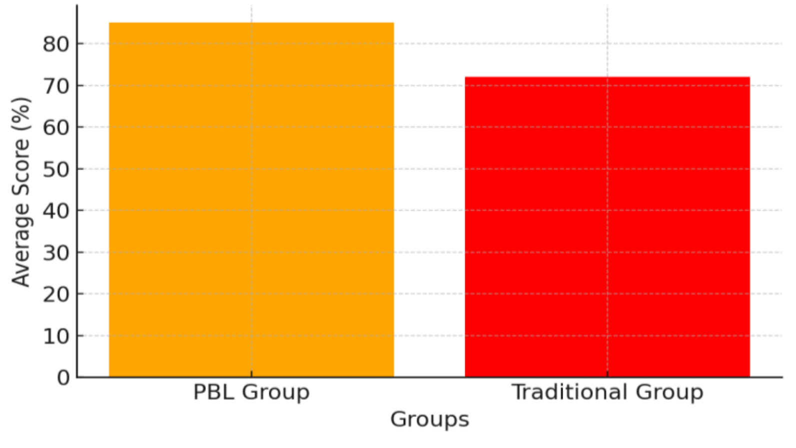

Figure 2: Average Coding Assignment Scores (PBL vs. Traditional)

Collaborative & Soft Skills

Students in the PBL group were also surveyed about their experiences related to teamwork and communication. Results showed that 78% of PBL students felt that their ability to collaborate effectively improved through these project activities, compared to 42% in the traditional group. Interviews with students revealed that working on projects modelled after real-world challenges necessitated clear communication and a strategic division of responsibilities, effectively mimicking the collaborative demands of professional software development environments (Johnson et al., 2021).

Industry mentors corroborated these findings, noting that students in the PBL group demonstrated a more comprehensive understanding of project management principles, including task prioritization and deadline management. The ability to handle unexpected challenges and maintain clear communication with peers and supervisors emerged as key outcomes of the PBL

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approach. Such competencies are highly valued in the tech industry, where teamwork and adaptability are crucial for success in dynamic project settings. This is consistent with Zhang and Zhou's (2021) conclusion that there is the need for the development of technical skills through the simulation of reality through the use of project-oriented settings.

Challenges and Opportunities for Improvement

Despite the positive results, several challenges were realized while conducting project-based learning (PBL). Students expressed concerns related to time management and working with peers. Additionally, teachers reported an increased need for resources and accurate evaluation measures to objectively measure individual contribution. Mueller and Niederdrenk (2022) confirmed the challenges and suggested careful planning, proper instructor preparation, and systematically structured evaluation schemes to increase the effectiveness of PBL.

However, the adoption of Project-Based Learning (PBL) for computer science has seen improved academic accomplishment, enhanced social and technological skills, and higher student engagement levels. As challenging as this form of teaching is, overall, the effect of PBL shows to be positive, highlighting its effectiveness as an educational strategy to prepare students to meet the needs of the modern workplace (Lam & Ho, 2021; ACM/IEEE-CS Joint Task Force, 2023).

Discussion

The findings from this study offer compelling evidence for the value of PBL in computer science education. Students in the project-based group exhibited statistically significant improvements in academic performance and reported greater engagement and self-efficacy. These outcomes align with Han et al. (2022), who emphasize PBL's contribution to deeper conceptual understanding and practical application.

Beyond cognitive outcomes, this approach supports the development of transferable skills such as communication, leadership, and conflict resolution (Johnson et al., 2021). The structured yet flexible nature of collaborative tasks fosters a learning culture in which students actively construct knowledge and assume ownership of their work. This was evident in qualitative feedback from interviews, where students described the sense of

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accomplishment and relevance derived from completing real-world projects.

Crucially, the mixed-methods approach enabled richer interpretation. Quantitative data highlighted significant learning gains, while qualitative insights revealed nuances in teamwork dynamics, motivation, and perceived relevance. Such triangulated findings underscore the importance of evaluating educational innovations from multiple angles (Creswell & Plano Clark, 2017).

Challenges remain. Student comments highlighted time management as a recurring issue, particularly around balancing coding tasks with peer coordination. Similarly, instructors noted a need for professional development in scaffolding team-based projects. Mueller and Niederdrenk (2022) suggest integrating digital tools like project management dashboards to support time tracking and accountability.

Initial demographic observations pointed to differential experiences. Female students and those from underrepresented backgrounds reported feeling more empowered in roles involving communication and planning but less confident in advanced technical tasks. These patterns call for inclusive practices, such as peer mentoring, rotating leadership, and differentiated task structures, to ensure equitable participation (Estrada & Matsuda, 2023).

Overall, this study confirms that when implemented thoughtfully, PBL can align curricular outcomes with industry demands, foster personal development, and create meaningful engagement in CS education. Institutional investment in faculty support, tool adoption, and equity design will be critical to sustainable implementation.

Limitations and Ethical Issues

The study was limited to only one course at one college, and this may limit the scope to which the results may generalize. Future research should study the long-term effects across institutions and disparate areas of study, including community schools, graduate schools, and Web settings. The study also did not factor the varied backgrounds and individual differences of the learners, whose impact may have been significant.

Ethical clearance was obtained. Participation was voluntary, and anonymity was maintained. Industry partners were vetted to ensure

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student welfare and meaningful engagement. Confidentiality and academic integrity were upheld throughout the study.

Implications for Policy Making and Implementation

Policymakers should recognize PBL as a core strategy for CS education. Funding should support:

- Faculty development initiatives for promoting active learning.
- Continued partnerships with technology companies to drive practical projects.
- An integrated system intended to enable collaborative works, including versioning mechanisms, cloud platforms, and flexible laboratory settings.

Universities should revise accreditation standards to include experiential learning metrics. Curriculum committees can collaborate with industry boards to align academic outcomes with professional expectations. Career services can align with PBL by offering resume-building workshops, project showcases, and internship pipelines.

Future Research Directions

Potential directions for future research may include:

- Longitudinal tracking of PBL graduates' employment, retention, and advancement
- The impact of project-based learning on innovation development, startup formation, and entrepreneurial behaviour.
- A study undertaken across diverse cultures, disciplines, and teaching methods (face-to-face versus virtual).
- The incorporation of modern technologies like machine learning and artificial intelligence into project-based learning environments.
- Evaluating PBL's role in promoting diversity and inclusion in tech education

Conclusion

This research reinforces the growing consensus that project-based learning is a powerful tool for enhancing learning in computer science. It bridges theoretical instruction with applied practice, preparing students for real-world problem solving. By adopting a

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mixed-methods design, the study offers robust insights into the pedagogical and developmental impacts of the approach.
While PBL enhances technical and interpersonal skills, effective implementation requires structural adjustments, such as faculty training, revised assessment frameworks, and access to collaborative tools. The research also highlights the need for inclusive design to support students from diverse backgrounds. These elements are not peripheral but central to optimizing outcomes.
The study's limitations, including particularly its single-institution scope and modest demographic depth, which suggest caution in generalisation. However, the consistent trends observed suggest broader relevance and provide a foundation for future inquiry.

Moving forward, universities and policymakers should prioritise experiential learning models and embed project work into core computing curricula. With thoughtful execution, PBL can become a cornerstone of 21st-century computer science education, equipping students not only with coding proficiency but also with the mindset and skills required to lead in dynamic, collaborative environments.

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