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From Projects to Performance: A Data-Driven Analysis of Problem-Based Learning in Physics Education

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Abstract

Traditional lecture-based teaching in University Physics often limits student engagement and the development of applied problem-solving skills required in technical disciplines. This study evaluates the effectiveness of Project-Oriented Problem-Based Learning (POPBL) in an introductory Physics course for Informatics students to assess learning outcomes. A retrospective cohort analysis was conducted using institutional academic records from 3,576 undergraduate students enrolled in the Physics 1 course between 2014 and 2024. Two instructional models were compared: traditional lecture-based teaching (nTL = 1,614) and POPBL (nPOPBL = 1,962), both following the same curriculum and contact hours. The analytical framework combined descriptive statistical analysis, non-parametric hypothesis testing, and machine-learning modelling. To further explore predictors of student performance, two gradient-boosting machine-learning models with 5-fold cross-validation were applied to predict final grades and analyse performance determinants. Model interpretability was analysed using SHAP values to identify the relative influence of behavioural, assessment, and prior academic variables on final grades. The results show that POPBL students achieved significantly higher final grades (mean = 7.91) than TL students (mean = 7.24; $p < 0.001$, Cohen's d ? 0.74) and demonstrated reduced grade variability. Correlation analysis ($r = 0.72–0.89$) indicated strong relationships between project task performance and final course outcomes. Machine-learning interpretation revealed that engagement-related behaviours were the strongest predictors of success in the POPBL environment. These findings illustrate how combining statistical and machine-learning approaches can enhance the evaluation of pedagogical innovations in STEM education, enabling deeper insights into learning outcomes.

Keywords: Project-Based Problem Learning; Learning Analytics; Machine Learning; Statistical

Analysis; STEM Education