The Reform Practice of Project-Based Teaching in Probability Theory and Mathematical Statistics Courses

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Abstract: Traditional instruction in Probability Theory and Mathematical Statistics (PTMS) often suffers from a disconnect between abstract theory and real-world application, resulting in fragmented knowledge and underdeveloped practical competencies among students. To bridge this gap, this study implements a comprehensive project-based learning (PBL) model. The course was restructured around authentic, industry-relevant projects, with a central case on "Bank Wealth Management Team Performance Evaluation" guiding students through the full cycle of statistical inquiry—from problem definition to data analysis and evidence-based reporting. A quasi-experimental design compared an experimental class (n=42) taught with the PBL model against a control class (n=43) using traditional lecture methods. Results demonstrate that the PBL cohort significantly outperformed their peers in post-test scores (72.6vs.63.4, $p<0.001$) and showed markedly higher proficiency in justifying methodological choices and applying statistical software. Qualitative feedback further revealed a paradigm shift among students, from viewing statistics as a set of computational procedures to seeing it as a tool for rational decision-making under uncertainty. This paper provides a replicable, system-oriented model for integrating foundational mathematics courses into the engineering education ecosystem.

Keywords**:** project-based learning; Probability Theory and Mathematical Statistics; curriculum reform; statistical thinking; authentic assessment

1. Introduction

The persistent gap between theoretical instruction and practical application in Probability Theory and Mathematical Statistics (PTMS) leaves many engineering graduates ill-equipped to handle data-driven challenges in their professional lives. Conventional pedagogy, centered on formula derivation and isolated problem sets, often neglects the cultivation of systematic thinking and the ability to translate real-world ambiguity into solvable statistical models. This "threefold disconnection"—between theory and practice, algorithms and tools, and knowledge and innovation—represents a critical bottleneck in new engineering education.

To address this, we propose project-based learning (PBL) as a powerful catalyst for PTMS reform. PBL's core strength lies in its systematic, lifecycle-oriented approach to learning, where students engage with complex, open-ended problems that mirror professional practice. In the context of PTMS, the "product" is not a physical artifact, but a defensible statistical solution to a real-world challenge. This paper details our practical implementation of this vision, its empirical validation through a controlled experiment, and its implications for foundational STEM education. We argue that by framing learning as the construction of a complete statistical argument, PBL can move students beyond rote calculation toward systematic, evidence-based reasoning.

2. Designing the Reform: A PBL-Centric Framework

Our reform began with a fundamental redefinition of course objectives, shifting from mere knowledge acquisition to the integrated development of three key dimensions: a deep conceptual understanding of randomness and inference, practical competency in designing and executing statistical analyses, and the professional attitude of data-driven, critical decision-making.

This new objective directly informed a complete reconstruction of course content. We abandoned the traditional linear progression of topics in favor of a project-centered architecture. The entire syllabus was organized around a central, authentic engineering challenge: evaluating the performance of bank wealth management teams. Within this single, rich context, all core concepts found their purpose:

Problem Framing: Students grappled with defining "performance" amidst market noise, leading naturally to random variables and expectation.

Method Selection & Design: The need to compare teams introduced sampling distributions, hypothesis testing logic, and the critical importance of verifying assumptions (e.g., homogeneity of variance).

Implementation: Students executed their analyses using Python (SciPy/statsmodels) in a Jupyter Notebook environment, moving from theory to tangible code.

Communication & Reflection: The final deliverable was a decision report for bank management, requiring clear communication of results, effect sizes, and model limitations.

To support this active learning model, we developed essential resources: a repository of cross-disciplinary cases and a pre-configured online analytics platform. Our teaching methodology shifted to a guided project cycle, where the instructor's role evolved from lecturer to cognitive coach, posing probing questions rather than providing direct answers.

3. Practice and Effectiveness Evaluation

3.1 The Bank Performance Evaluation Project in Action

The project tasked students with determining if significant performance differences existed among two bank teams, given monthly return data confounded by overall market trends.

During the Problem Framing phase, students moved beyond simple mean comparisons to propose evaluating "market-adjusted excess returns," demonstrating an early grasp of confounding variables. In the Design phase, most groups initially selected a t-test but were required to validate its assumptions. Upon discovering heteroscedasticity (Levene's test, $p=0.032$), several groups autonomously pivoted to the non-parametric Mann-Whitney U test, documenting their rationale in a formal analysis plan. The Implementation phase saw students write and debug Python code, with a focus on the logic behind each command. Finally, in the Communication phase, student reports went beyond stating "Team B is better ($p=0.018$)" to discuss practical significance (via effect size) and the model's limitations, such as small sample size.

3.2 Empirical Assessment of Learning Outcomes

We employed a quasi-experimental design with a 2023 cohort ($n=42$, experimental) and a 2022 cohort ($n=43$, control). Both classes were taught by the same instructor, used identical textbooks and assessments, and had statistically equivalent prior math achievement ($p>0.05$).

The results were compelling. On the final exam, the experimental class scored significantly higher (72.6/100 vs. 63.4/100; $t=5.12$, $p<0.001$). Crucially, 76% of the PBL group could correctly justify their choice of a non-parametric test for non-normal data, compared to only 31% in the control group. A post-course survey confirmed these gains, with the experimental class reporting much higher confidence in explaining statistical conclusions to non-experts ($M=4.1$ vs. $M=2.7$ on a 5-point Likert scale).

Qualitative interviews captured a deeper transformation. One student noted, "I now see a p-value not as an endpoint, but as a starting point for asking better questions." This shift from a "problem-solver" to a "challenge-addressor" mindset is the true hallmark of the reform's success. Challenges remain, particularly in managing the time-intensive nature of projects within a standard semester, suggesting a need for more granular scaffolding in future iterations.

4. Conclusion

This study demonstrates that a well-structured project-based learning model can be successfully implemented in a foundational mathematics course like PTMS, yielding a powerful paradigm shift. By framing learning as the construction of a complete "statistical solution," we moved students beyond rote calculation toward systematic, evidence-based reasoning. The empirical evidence is clear: students exposed to the PBL model develop superior analytical competencies and a more mature understanding of the discipline's real-world value.

While our pilot focused on a single course, the framework is inherently scalable. Future work will explore embedding more diverse real-world enterprise projects into the curriculum to further strengthen the industry-academia link and expand the model to other foundational STEM courses. This research offers a concrete, system-oriented blueprint for aligning core STEM curricula with the holistic demands of modern engineering education, ultimately fostering a generation of graduates who are not just proficient in statistics, but fluent in the language of data.

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