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A Performance Analysis of Two Engineering Majors in Probability Theory

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Performance Comparison Between Two Engineering Majors in a Probability Theory Course

Abstract

In a junior-level probability theory course that covers probabilistic models, discrete and continuous probability distributions, sampling distributions, and point and interval estimation, students are tasked with applying modeling techniques to address real-world engineering problems involving uncertainty. The course assumes proficiency in elementary algebra, as well as differential and integral calculus. Both Industrial Engineering (IE) and Polymer Engineering and Science (PES) students engage with the same learning modules and are evaluated through identical quizzes and exams. The aim of this study is to compare the performance of these two groups and assess their competencies in three key areas: understanding sample space and events, including Bayes' Theorem; identifying random variables and various discrete and continuous probability distributions; and solving and interpreting problems related to cumulative distribution functions and probability density functions. The results show no significant performance differences was found. The 2023 cohort demonstrated stronger performance in quizzes assessing a comprehensive understanding of problems related to sample spaces and counting techniques, including permutations and combinations. Additionally, the research highlights the importance of using real-world examples to bridge theoretical concepts with practical applications. This teaching approach significantly enhances students' comprehension, particularly for those from diverse engineering disciplines.

Introduction

Engineering students typically take foundational courses from various departments to prepare for entry into their desired majors, which generally occurs in their sophomore year. For instance, students intending to pursue majors such as Civil, Mechanical, or Industrial Engineering often take Statics during their second year, a course offered by the Mechanical Engineering Department. Similarly, developing programming skills is essential for engineering students, and courses covering languages like C++, MATLAB, or Mathematica are typically provided by the Computer

Science Department. These interdisciplinary courses play a critical role in equipping students with the necessary knowledge and skills for success in their chosen engineering fields [1][2][3]. Departments offering service courses for engineering students face significant challenges in accommodating the large and diverse student population[4]. These departments often manage not only large class sizes but also multiple sections to ensure all students can enroll. Large class sizes can affect the effectiveness of teaching compared to smaller classes[5], while coordinating multiple sections introduces additional complexities [6][7][8]. Faculty members teaching these sections must invest considerable time and effort to align their teaching progress, assignment deadlines, and grading policies, ensuring consistent course quality across sections[9][10]. Additionally, universities must provide sufficient resources, such as common spaces for exams, to support these high-enrollment courses[5][11].

Despite these efforts, concerns have been raised regarding how well these service courses meet the needs of engineering students. Because service courses are designed to accommodate all general engineering students, the content often focuses on broad, foundational concepts rather than being tailored to specific engineering disciplines [12][13]. As a result, faculty members in specialized programs may feel these courses fail to adequately prepare students for their majors [14]. Similarly, students sometimes perceive these courses as unrelated to their future fields due to the generalized nature of the content or the inclusion of examples they find irrelevant to their chosen majors[15][16].

This study aims to examine the performance of engineering students from various majors in a shared engineering service course, with a focus on identifying factors that influence their learning outcomes and proposing interventions to enhance the quality of these courses. Specifically, we investigate differences in student performance across different learning models and explore strategies to address these disparities. Our analysis focuses on a probability theory course offered by the Industrial Engineering (IE) Department, which serves as a foundational requirement for many engineering disciplines. For example, sophomore Polymer Engineering and Science (PES) students often enroll in this course to fulfill their curriculum requirements and gain essential probability knowledge applicable to their field. By analyzing the performance of PES students and others, we aim to uncover trends and insights that can inform improvements to the structure and delivery of such service courses.

At the author's institution, sophomore Polymer Engineering and Science (PES) students typically take IE 322: Probabilistic Models in Industrial Engineering, a junior-level course offered by the Industrial Engineering Department, to fulfill their curriculum requirement related to probability theory. The PES program does not offer a standalone probability course and instead lists IE 322 as a required course in its curriculum. This course introduces students to key concepts in probability theory and modeling, as well as discrete and continuous probability distributions, which are essential for solving real-world engineering problems involving uncertainty. Additionally, the course covers topics such as sampling distributions, and point and interval estimation for means, variances, and proportions, providing students with critical analytical tools. **Table 1** shows the three main learning modules (1) Probability Theory, (2) Discrete Probability Distributions, and (3) Continuous Probability Distributions along with the detailed topics covered in the course.

Table 1. Main Topics for IE 322: Probabilistic Models in Industrial Engineering

Probability Theory	Discrete Probability Distributions	Continuous Probability Distributions
• Sample Space & Events • Permutations and Combinations • Conditional Probability • Multiplication & Total Probability Rules • Independence • Bayes' Theorem	• Discrete Random Variables; Mean & Variance • Probability Mass Functions (PMF) & Cumulative Distribution Functions (CDF) • Discrete Uniform, Binomial, Geometric, Negative Binomial, Hypergeometric & Poisson Distributions	• Discrete Random Variables; Mean & Variance • Probability Density Functions (PDF) • Continuous Uniform, Normal, Exponential, Gamma, Weibull & Beta Distributions • Normal Approximation
• Quiz 1- 4 • Exam 1	• Quiz 5 - 9 • Exam 2	• Quiz 10 - 12 • Exam 3

To succeed in this course, students are expected to have a solid foundation in elementary algebra and both differential and integral calculus, which support the advanced mathematical concepts presented in the curriculum.

Course Structure and Evaluations

IE 322 follows a traditional in-person lecture format, with 50-minute sessions held three times a week. The instructor provides class slides on the university's course management system in advance, while students primarily take notes during lectures based on the instructor's chalkboard work. The course is divided into three learning modules, each supported by three to four weekly quizzes designed to assess student performance and help them stay engaged with the material. For instance, out of the 12 total quizzes, the first four focus on foundational principles of probability, covering topics such as sample spaces and events, counting techniques: permutations and combinations, addition and multiplication rules, conditional probability, the law of total probability, independence, and Bayes' theorem. These quizzes are supplemented by three exams distributed throughout the semester, each aimed at evaluating the students' understanding of the material.

The instructor ensures accessibility and support by holding office hours three times a week, offering students additional help with class material and quizzes. Quiz solutions are also made available on the course management system prior to the exams, allowing students to review and prepare effectively. The three exams align with the course's modular structure. The first exam focuses on foundational principles of probability and basic operations. The second exam emphasizes discrete random variables and distributions, introducing common discrete distributions such as Discrete Uniform, Binomial, Geometric, Negative Binomial, Hypergeometric, and Poisson distributions. The final exam addresses continuous random variables and distributions, including Uniform, Normal, Exponential, Gamma, Weibull, and Beta distributions. Each exam is independent, with no cumulative final exam. Weekly quizzes contribute 40% of the semester grade, while the three exams account for the remaining 60%. This balanced assessment strategy ensures that students are consistently evaluated on their understanding of both foundational and advanced topics.

Data Analysis and Results

This study examines the enrollment patterns of five IE 322 course offerings between 2021 to 2023, comprising two sections conducted during the Spring semesters and three during the Fall semesters. **Table 2** provides a detailed summary of the enrollment demographics, indicating that 36.96% of the participants were female, with the remainder being male. Additionally, 73.91% of the enrolled students were affiliated with the IE program, while approximately one-quarter were from the PES program.

Table 2. Demographic and Evaluations in Three Main Topics

			Probability Theory	**Discrete Probability Distributions**	**Continuous Probability Distributions**
				p-value	
		n		*Mean (SD)*	
Variables					
Gender			***0.904***	***0.407***	***0.467***
	Male	29	82.19 (6.34)	84.41 (7.28)	82.77 (11.43)
	Female	*17*	82.46 (8.72)	82.38 (8.99)	85.16 (9.09)
Major			***0.694***	***0.071***	***0.267***
	IE	*34*	82.03 (7.28)	84.91 (8.15)	84.69 (10.04)
	PES	*12*	83.00 (7.29)	80.13 (6.22)	80.71 (11.97)
Semester			***0.875***	***0.292***	***0.337***
	Fall	*24*	82.45 (6.11)	84.85 (7.81)	85.10 (10.00)
	Spring	*22*	82.11 (8.40)	82.36 (8.01)	82.07 (11.20)
Year			***0.009****	***0.269***	***0.946***
	2021	*9*	80.29 (6.51)	83.06 (6.40)	84.11 (11.92)
	2022	*21*	79.85 (7.92)	85.64 (8.87)	84.01 (10.06)
	2023	*16*	86.61 (4.38)	81.41 (7.08)	82.93 (11.16)

**P<0.050*

This study found no significant differences in student performance based on gender, major, or the semester in which the course was offered. **Figure 1** shows the performance disparities between two majors; however, no statistically significant differences were identified among the three learning modules.

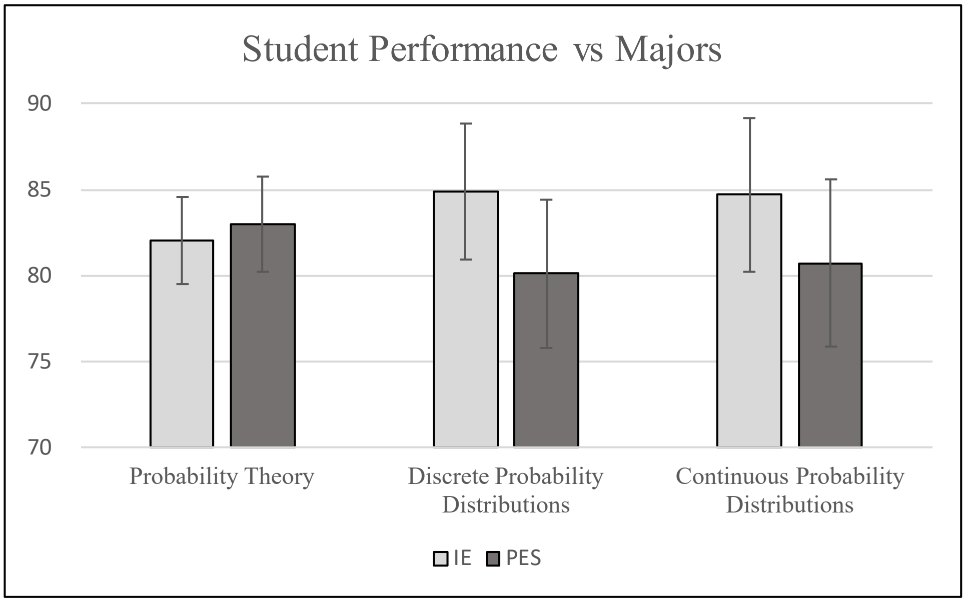

Figure 1. Overall Performance Evaluation IE vs. PES (95% C.I.)

A statistically significant difference (*p = 0.009*) was observed, indicating that the 2023 cohort demonstrated superior performance in the probability theory module. Further investigation revealed that, in 2023, students performed significantly better in both probability theory quizzes (*p = 0.045*) and the exam (*p = 0.021*). Overall, the 2023 cohort outperformed other years in both probability theory-related quizzes and the exam (**Figure 2**).

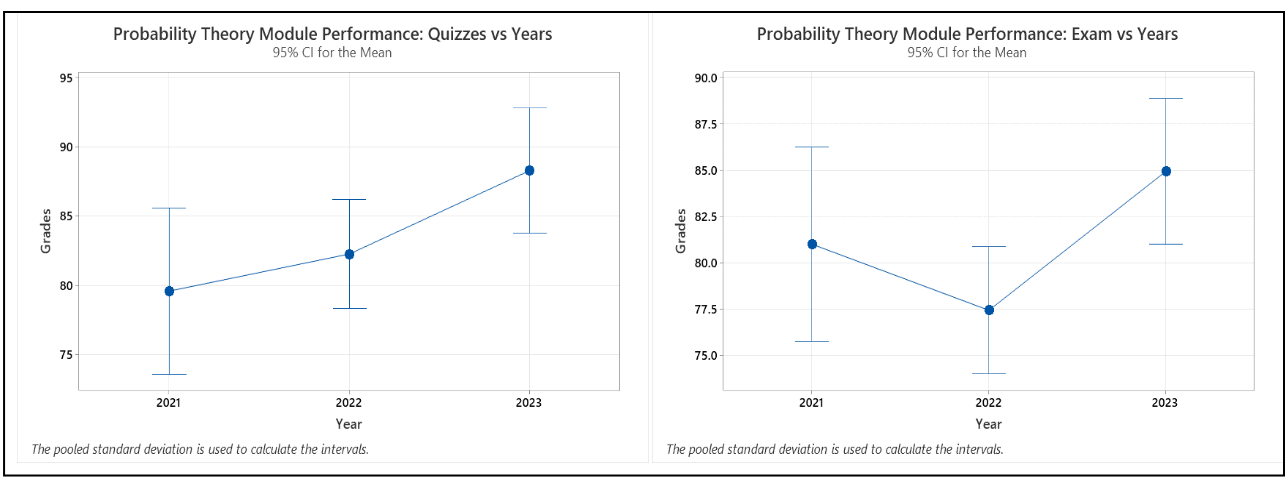

Figure 2. Probability Theory Module Performance vs Years

Within the probability theory module, significant differences were observed in two out of four quizzes: Quiz 2 and Quiz 3. These quizzes covered the topics of sample spaces and event ($p = 0.001$) and the counting techniques: permutations and combinations ($p < 0.001$), respectively. The 2023 cohort consistently demonstrated superior performance in these two topics. Although no significant differences were found between majors in overall quiz performance, a detailed analysis of individual subtopics revealed significant differences in Quiz 5, which focused on probability Mass Functions (PMF) and cumulative distribution functions (CDF) ($p < 0.001$), and Quiz 11, which addressed continuous distributions with an emphasis on exponential distributions ($p = 0.018$), between the two majors (Figure 3).

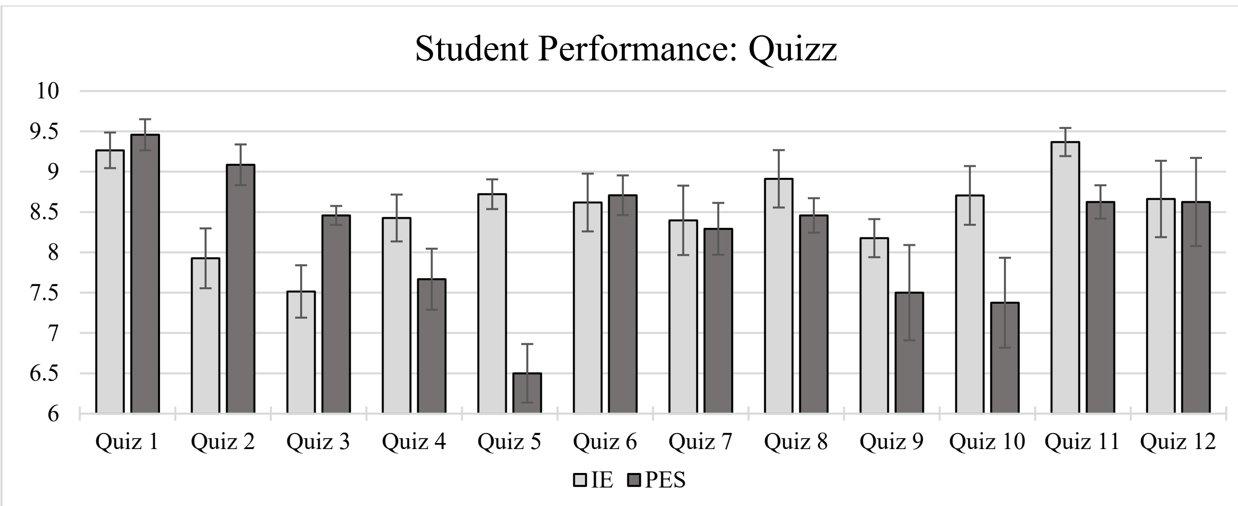

Figure 3. Homework performance among two majors (95% C.I)

Quiz 5 assessed students' understanding of describing a random variable's probability distribution using cumulative probabilities, such as $P\ (X \leq x)$. Cumulative probabilities can be utilized to determine the probability mass function of a discrete random variable. Students were expected to recognize that, for any discrete random variable with possible values $x_1, x_2, \ldots$, the events $\{X = x_1\}$, $\{X = x_2\}, \ldots$ are mutually exclusive. Therefore, $P\ (X \leq x)$ represents the summation of probabilities for x_i. In contrast, Quiz 11 focused on the continuous exponential distribution. Students were required to understand that a random variable X, representing the distance between successive events in a Poisson process with a mean number of events greater than zero per unit interval, follows an exponential distribution. Since the exponential distribution is a continuous probability distribution, determining the range of probabilities involves applying integral techniques to compute cumulative probabilities, which result in the probability density function (PDF).

Discussion

In general, no significant differences in overall student performance were observed based on gender or major. This outcome suggests that the instructor maintained consistent teaching methods and applied uniform assessment tools, such as quizzes and exams, throughout the course. However, a notable exception was identified in the 2023 cohort, which exhibited significantly better performance in the probability theory module compared to other years. Especially in the topic of sample space (Quiz 2) and counting techniques (Quiz 3). After consulting with the course instructor regarding these findings, it was noted that additional examples were incorporated into the 2023 class to reinforce key concepts in probability theory. For instance, the topic of sample spaces—defined as the set of all possible outcomes of a random experiment—was emphasized. This concept serves as the foundation for understanding possible events in random experiments. To aid comprehension, the instructor utilized Venn diagrams to illustrate two primary counting techniques: permutations and combinations. Given that many students were encountering these counting techniques for the first time, insufficient examples could have hindered their understanding. To address this, the instructor used vivid, practical examples to clarify the concepts. For example, the instructor presented a bag containing 2 red balls and 5 blue balls, then asked students to determine the possible outcomes when selecting 4 balls from the 7. This hands-on approach helped to elaborate the principles of counting techniques and improve student comprehension.

Performance differences between the two majors were observed only in the topics of discrete probability: cumulative distribution functions (Quiz 5) and continuous exponential distribution (Quiz 11). Both topics require students to understand the concept of accumulating event probabilities over a certain range. However, one pertains to discrete probability distributions, while the other focuses on continuous distributions. IE students demonstrated superior performance in understanding cumulative probability ranges, particularly in the discrete probability category. Upon reviewing their work, it was evident that IE students had a stronger grasp of the concept of probability ranges. In comparison, while the concept of probability ranges in the exponential distribution is analogous to that in discrete distributions, applying it to continuous probabilities necessitates the use of integral techniques from calculus. The analysis of student submissions revealed that many students struggled with the integration process required to determine probabilities within continuous distributions. This challenge likely contributed to the observed differences in performance between the two majors.

It appears that no significant differences were observed for PES students taking a statistical probability theory course offered by another engineering program. This curriculum structure, which allows students from diverse engineering majors to enroll in the same course, can foster collaboration within the classroom. Such an environment may also prepare students to work with multidisciplinary professionals both on-campus and in future career settings. A review of the institution's curriculum revealed that a probability theory course is also offered by the Department of Mathematics. This alternative option could provide students with the opportunity to collaborate with peers from mathematical disciplines, further enriching their learning experience. Additionally, it offers greater scheduling flexibility, allowing students to better align the course with their overall academic plan.

Although the institution mandates students to complete teaching evaluations to assess course structure and instructor effectiveness, the evaluation results are presented anonymously. Consequently, the research team was unable to distinguish feedback based on the different cohorts or majors. This lack of differentiation limits the ability to analyze how students from varied academic backgrounds perceive and engage with the course content. To address this limitation, future efforts should focus on collecting detailed feedback from students, categorized by their respective majors. Such data would provide valuable insights into the specific needs, challenges, and preferences of diverse student groups. Comparing the opinions and suggestions across various majors would enable instructors to identify patterns and trends, thereby tailoring their teaching strategies more effectively. This information could also aid in the development of a more inclusive and comprehensive course plan. For instance, it would allow instructors to incorporate examples and applications that are directly relevant to students' fields of study, enhancing their engagement and understanding. Additionally, it could help optimize the design of service courses to ensure they meet the interdisciplinary demands of engineering and related programs, ultimately improving the overall learning experience.

Conclusion

The study compared the performance of two engineering majors in a service probability theory course. Overall, the students from both majors exhibited similar performance across quizzes and exams throughout the study. However, slight differences were observed in the 2023 cohort, where students performed better on specific quizzes compared to previous cohorts. This improvement was attributed to the instructor's additional effort in providing more examples and focusing on reinforcing foundational topics such as sample spaces and counting techniques. A more detailed analysis of quiz performance revealed that IE students outperformed the PES cohort on topics related to cumulative probability ranges in discrete and exponential distributions. This suggests that IE students may have developed a stronger understanding of cumulative probability concepts, likely due to the explicit examples provided by the instructor to clarify these topics. Mastery of these concepts often requires a solid understanding of probability ranges, which was more evident among the IE students. Additionally, challenges were noted in topics involving continuous distributions, particularly in the application of integration techniques required to calculate probability ranges. These difficulties highlight the need for students to have a firm grasp of prerequisite calculus skills to succeed in such topics. To address this, instructors might consider incorporating preliminary calculus review sessions or practice exercises into the course curriculum. These preparatory activities could help students strengthen their mathematical foundation, enabling them to engage more effectively with advanced probability concepts and perform better across related assessments.

Exposure to peers from diverse engineering disciplines fosters collaborative learning, promotes interdisciplinary problem-solving skills, and enhances students' ability to apply theoretical concepts in varied contexts. Such an environment prepares students to work effectively in multidisciplinary teams, a critical skill in both academic and professional settings. However, maintaining the quality of the classroom atmosphere while accommodating a diverse group of students presents unique challenges. Institutions may need to establish better trade-off policies to ensure optimal class sizes that balance inclusivity and effective learning. In addition, Instructors also play a pivotal role in addressing these challenges by adopting innovative teaching strategies tailored to the needs of a diverse student body. Providing a wider range of examples that encompass applications relevant to various engineering fields can help bridge gaps in understanding.

implementing distinctive teaching approaches—such as active learning, case studies, or hands-on demonstrations—can accommodate students with different academic backgrounds and learning preferences. By fostering an inclusive and engaging learning environment, instructors can ensure that all students, regardless of their prior knowledge or field of study, benefit equally from the course.

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