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Comparing Outcomes Between Two Engineering Majors in a Deterministic Operations Research Course

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Comparing Outcomes Between Two Engineering Majors in a Deterministic Operations Research Course

Abstract

In an introductory undergraduate-level deterministic modeling course that covers linear and integer programming, students apply modeling and optimization approaches to address challenges related to network flows, project management, transportation, and assignment problems. They also acquire proficiency in various solution strategies, including the simplex method and the branch-and-bound approach. Duality and sensitivity analysis are comprehensively covered, as well as their economic interpretations. Both Industrial Engineering and Mechanical Engineering students share access to identical learning modules, completing the same assignments and exams. The objective of this study is to compare the performance of these two student cohorts and assess their abilities in three crucial areas: proficiency in matrix algebra, the capacity to identify and formulate engineering problems, and the ability to solve and interpret these problems. The study's findings reveal that Mechanical Engineering students outperformed their counterparts overall. This group demonstrated stronger skills in comprehensively understanding the problem scope and formulating problems into mathematical models. Additionally, the study underscores the significance of applied examples, serving as a crucial bridge connecting theoretical understanding with practical application. This pedagogical approach fosters a deeper comprehension of the subject matter, proving beneficial for students across various engineering disciplines.

Introduction

To train engineers comprehensively, the undergraduate engineering curriculum should not only be solidly grounded in the fundamentals of engineering but also aim to instill a commitment to lifelong learning in students [1]. It is essential for students to receive exposure to multiple technical disciplines so they can broaden their vision of engineering overall [2]. Typically, schools require students to take engineering elective courses outside their primary engineering major, thereby fostering connections with other engineering domains. Electives present an excellent opportunity for students to showcase their talents, cultivate new interests, and develop additional abilities [3], [4]. Moreover, these elective courses create an environment for students from various engineering majors to collaborate, thus enhancing their communication and teamwork skills with other future engineers [5], [6], [7].

Engineering elective courses are usually required courses for a specific major, so these courses bring together both major and non-major students, resulting in a diverse group of students. Instructors deliver identical content and assess all students using the same instruments. However, limited research has explored student outcomes across different major cohorts. Therefore, additional analyses were conducted to uncover the strengths and weaknesses of each cohort within each learning module. This exploration aims to enhance our understanding of the varied impacts of engineering electives on students from different majors and helps to contribute valuable insights into the ongoing improvement of engineering education.

At the authors' institute, all undergraduate junior students in the Industrial Engineering program are required to enroll in the course IE 405 - Deterministic Models in Operations Research. This course serves as an introductory exploration of deterministic modeling, guiding students in formulating linear programs, network models, and integer programs. The curriculum encompasses solution strategies such as the simplex method and branch and bound approach. It also incorporates duality and sensitivity analysis, along with their economic interpretations. Optimization software is employed for solving formulations. Practical examples, along with a comprehensive case study, are presented to facilitate a deeper understanding for students. Given the practical applications of linear and integer programs, a class in matrices is a prerequisite for IE 405. Thus, students are expected to be acquainted with systems of linear equations, matrix algebra, and linear systems of differential equations before enrolling in Deterministic Models in Operations Research. The IE 405 course revolves around four main themes: (1) matrix operations and linear algebra; (2) linear programming (LP); (3) sensitivity analysis; and (4) integer programming (IP). To provide a structured overview, **Table *1*** outlines the detailed learning topics within each of these themes, delineating the three main learning modules for the course.

Table 1. Four Main Learning Modules for the Course

Matrix Operations and Linear Algebra	Linear Programming	Basic Solutions and Simplex	Integer Programming
• Matrix basics • Inverse matrices • Gauss-Jordan elimination	• Model formulation • Graphical solution techniques • Basic solution concepts	• Simplex • Duality • Sensitivity analysis	• Network models • Scheduling • Assignment problems
• Homework 1 • Homework 2 • Exam 1 (part 1)	• Homework 3 • Homework 4 • Homework 5 • Exam 1 (part 2)	• Homework 6 • Homework 7 • Homework 8 • Exam 2	• Homework 9 • Homework 10 • Exam 3

Furthermore, the previously mentioned IE 405 - Deterministic Models in Operations Research course is designated as one of the engineering elective options available to Mechanical Engineering (ME) students. ME students have the flexibility to enroll in this class during either their junior or senior years.

Course Modality and Performance Evaluations

Students took notes based on the instructor's chalkboard work, similar to a typical math lecture class. Occasionally, handouts containing in-class problems were distributed to deter direct copying from notes. Students had the option to take notes on the handout or in their personal notebooks.

Each of the four learning modules included 2–3 weekly homework assignments aimed at assessing students' performance and aiding them in staying on track. Out of the 10 total homework assignments, three assignments focusing on linear and integer programming modeling required the use of computer-based optimization software for problem-solving. Microsoft Excel Solver was introduced to all students in this context. Throughout the course, the homework assignments were complemented by three exams designed to evaluate students' effectiveness. Solutions to the weekly homework sets were made available on the university's course management system prior to the exams. Additionally, the instructor held a one-hour office period three days a week, providing students with the opportunity to seek additional assistance with class material and homework assignments. For topic coverage on the exams, the first exam covered modules one and two: Matrix Operations and Linear Algebra Module, and Linear Programming Module, the second exam addressed Basic Solutions and Simplex Module, and the last exam focused on the Integer Programming Module. Each exam was independent, and there was no cumulative final exam. Homework and exams collectively contributed to 40% and 60%, respectively, of the semester grade.

Results

A total of 180 students enrolled in the eight IE 405 classes offered from 2018 to 2023. Generally, IE 405 was offered in the Fall semester, but in 2021 and 2022, it was offered in both Spring and Fall. **Table *2*** provides a summary of student enrollment status in the study, revealing that 22.2% were female, and the remaining were male. Of the enrolled students, 54.4% were IE students, and 45.6% were ME students.

This study found no significant differences in student performance based on gender or the semester in which the class was taught. However, a significant difference (p=0.047) was identified, indicating that ME students achieved higher overall grades in IE 405 than IE students. Nevertheless, the results indicated no significant differences between the two majors in performance for any of the three individual learning modules. A statistically significant difference was also observed in the "Linear Algebra and Linear Programming" module based on the school year. The 2019 and 2020 cohorts exhibited a relatively lower average in the module compared to other years.

Table 2. Student Demographics and Performance Evaluations

			Linear Algebra & Linear Programming	Basic Solutions, Simplex & Duality	Integer Programming
		N		***p-value*** *Mean (SD)*	
Variables					
			0.554	***0.653***	***0.942***
Gender	Male	*140*	85.30 (12.32)	81.73 (18.87)	79.58 (20.27)
	Female	*40*	86.62 (12.88)	83.36 (24.13)	79.29 (29.36)
			0.190	***0.101***	***0.057***
Major	IE	*98*	84.48 (11.82)	79.85 (22.09)	76.60 (25.72)
	ME	*82*	86.92 (13.12)	84.78 (17.16)	83.00 (17.47)
			0.718	***0.230***	***0.315***
Semester	Fall	*131*	85.80 (12.84)	83.20 (19.56)	80.55 (21.34)
	Spring	*49*	85.04 (11.33)	79.15 (21.38)	76.75 (25.43)
			0.025*	***0.092***	***0.199***
Year	2018	*34*	89.61 (6.98)	86.39 (17.07)	86.69 (16.96)
	2019	*16*	80.84 (15.23)	84.91 (10.98)	80.90 (11.98)
	2020	*22*	81.44 (21.05)	72.77 (32.00)	73.23 (34.34)
	2021	*44*	84.55 (13.17)	80.25 (24.13)	76.14 (28.86)
	2022	*41*	84.64 (8.72)	80.87 (15.41)	77.66 (17.70)
	2023	*23*	90.59 (5.93)	88.41 (6.78)	83.70 (10.16)

*$P<0.050$

Figure *1* illustrates the performance disparities between IE students and ME students. While ME students generally outperformed IE students in all three learning modules, no statistically significant difference was found for any individual module.

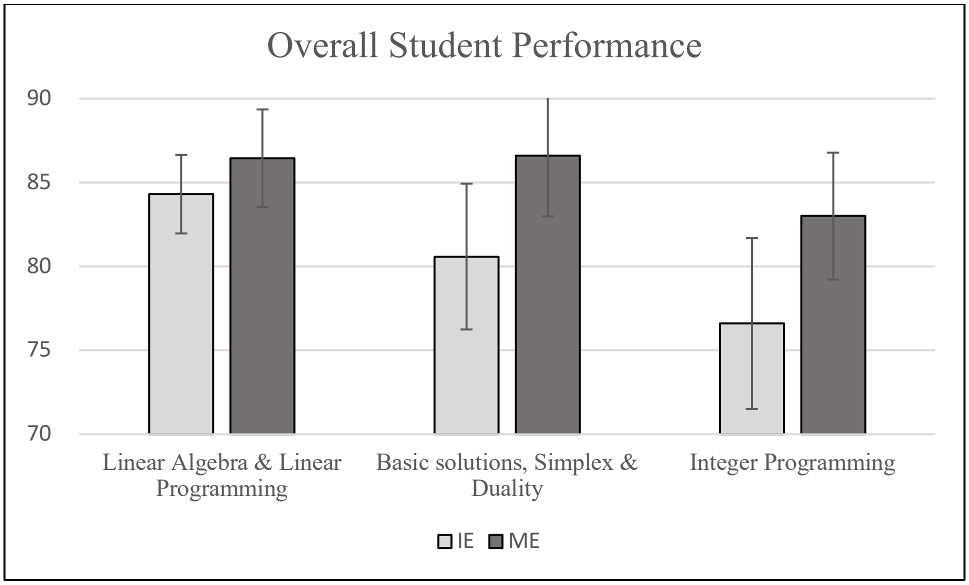

Figure 1. Student Overall Performance Evaluation IE vs. ME *(95% C.I.)*

To delve deeper into the evaluation instruments and assess performance consistency between the two engineering major cohorts, students displayed significant differences in exam performance, while no significance was found in their homework assignments, as indicated in Table *3*.

Table 3. Student Evaluation Instruments

			Homework	**Exams**
			p-value	
		n	*Mean (SD)*	
			0.205	***0.027****
Major	IE	*98*	81.24 (24.27)	80.23 (16.95)
	ME	*82*	85.24 (16.28)	85.49 (14.16)

**P<0.050*

Upon conducting a more in-depth to each examination, it became apparent that there were no notable distinctions in the performance of the two cohorts during the initial and intermediate exams. However, a significant contrast *(p=0.003)* did appear on the final exam, as illustrated in Figure *2*.

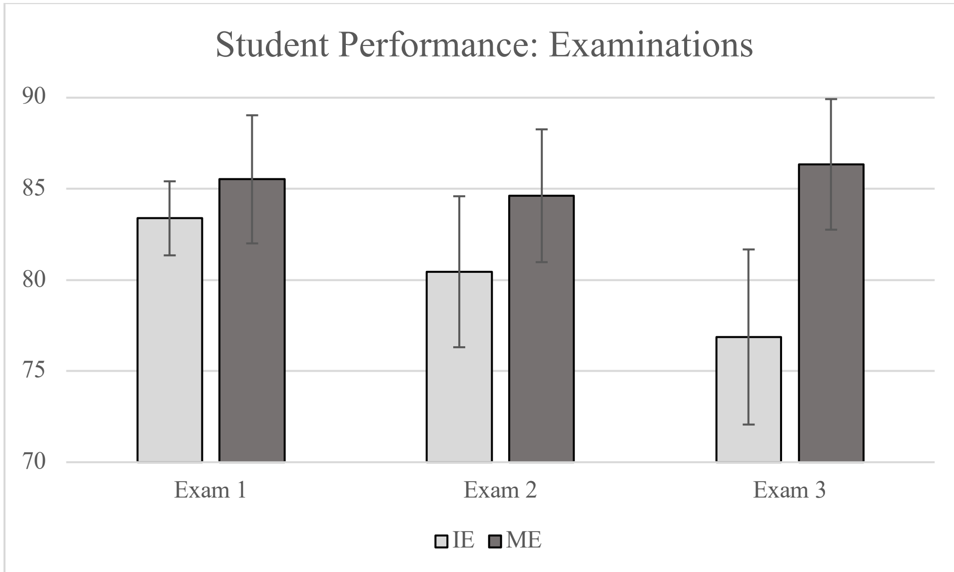

Figure 2. Student Evaluation: Examination IE vs. ME *(95% C.I.)*

The observed trend indicates that the IE students experienced a decline in performance from the first to the last exams. In contrast, the ME students exhibited their most impressive performance during the last examination. It is worth noting that the last exam exclusively focused on the Integer Programming learning module and was not designed as a cumulative final exam.

Although no significant differences were initially identified between the two groups, a closer investigation of the 10 homework assignments unveiled notable distinctions, particularly in Homework 4 *(p=0.013)* and Homework 8 *(p=0.002)* among the two cohorts (**Figure *3***). ME students demonstrated significantly better performance on these two assignments.

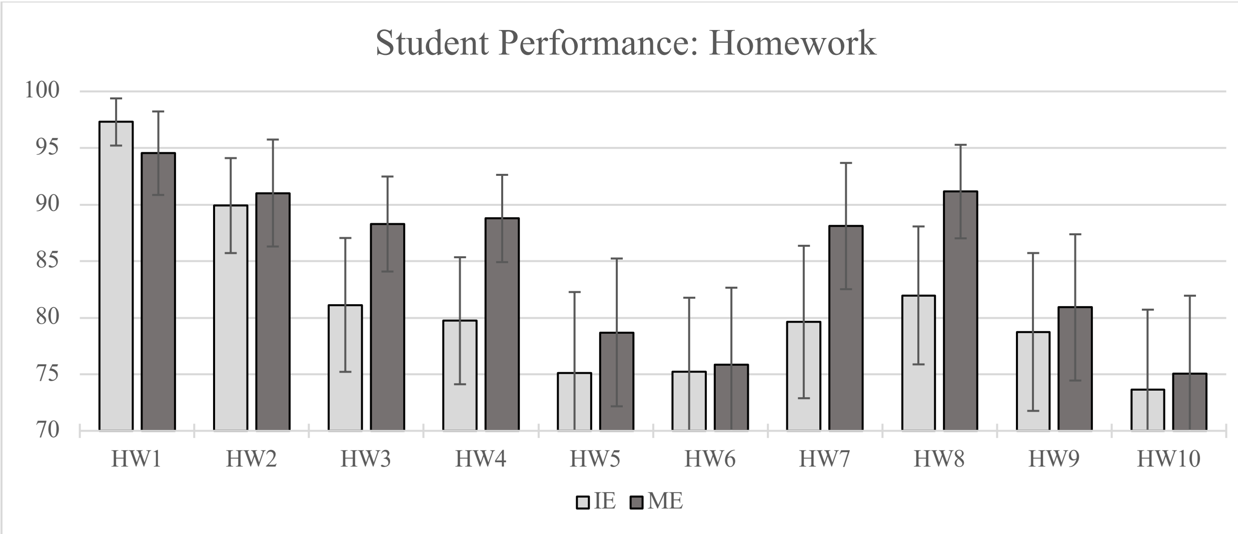

Figure 3. Student evaluation: Homework IE vs. ME (95% C.I.)

Homework 4 was the introduction to linear programming (LP) formulation, serving as the initial step in solving optimization problems. This assignment required students to interpret scenarios, establish decision variables, formulate an objective function, and define mathematical constraints. The four formulation questions on Homework 4 included optimizing production profit, addressing scheduling issues related to job shift assignments, solving supply and demand problems, and tackling material-mix problems. Students were expected to develop LP formulations; however, problem-solving was not a mandatory requirement. On the other hand, Homework 8 centered around the theme of Duality. Duality represents a mathematical relationship between two LP problems - primary and dual, creating a cohesive pair of interconnected problems. This concept provides a unifying theory that explains the connections between a given linear program and another LP problem stated in terms of variables with a shadow-price interpretation. On Homework 8, students were required to transform primary LP models into dual formats and vice versa. Additionally, they needed to understand how to interpolate the shadow-price from the duality concept.

Discussion

In the study, no significant differences were observed concerning gender, major, or semester across the three learning themes/modules. However, a distinct variation in student performance emerged when considering different academic years. Particularly noteworthy was the lower average performance of students in the years 2019 and 2020, specifically in the domains of Linear Algebra and Linear Programming. It is crucial to underscore that these two particular years witnessed a reduced student count due to the challenges posed by the COVID period, with many students opting for online or hybrid learning modalities. While the analysis did not reveal significant differences in student performance for the other two modules, it is pertinent to acknowledge that the Linear Algebra module may demand more in-person instruction compared to the other modules. The divergence in instructional methods might contribute to the observed performance trends, with the nature of the subject matter potentially benefiting from a more traditional, face-to-face approach rather than remote learning structures. As education adapted to the challenges of the pandemic, these findings shed light on the importance of instructional modalities in influencing student outcomes, particularly in subjects with varying demands for in-person engagement [8], [9], [10].

Overall, ME students demonstrated better performance than IE students in the class. Results also indicated that the two engineering cohorts showed no performance inconsistencies between each learning module, but ME students outperformed IE students on exams. In addition, there was no distinction in the 10 homework assessments and the first two exams, but a substantial gap between the two cohorts emerged in the third exam. IE and ME students had an average score of 76.87 and 86.34, respectively, on the last exam. Although each exam contributed equally (20%) to the overall semester grade, the performance gap was only evident in the final exam. To gain a deeper understanding of this divergence, further investigation is required. Engaging with students through surveys or interviews would be beneficial to explore the strategies they employed in preparing for the last exam. Understanding their approaches and time management strategies for the final course evaluations could provide valuable insights into the factors influencing performance disparities.

Significant differences were identified within homework assignments, particularly on the themes of LP modeling/formulation and the concepts of Duality, where ME students exhibited better performance compared to their counterparts majoring in IE. The disparity in performance highlights the proficiency of ME students in grasping and applying the details of LP modeling and Duality concepts. The learning objectives for LP modeling/formulation include the ability to translate verbal descriptions of optimization problems into mathematical models. Students are tasked with formulating real-world problems as LP models, involving the identification and definition of decision variables, the objective function, and constraints within a given problem [11]. In simpler terms, this requires the capacity to read and comprehend the scope of a problem and subsequently translate story-based scenarios into precise mathematical formulations. Therefore, the ability to read and comprehend is crucial in the domain of optimization modeling. Emphasizing the reading abilities and comprehensive understanding in this learning objective is important due to the absence of any required mathematical solving process [12], [13], [14], [15]. The success in meeting the demand is solely reliant on individuals' proficiency in translating the problem scope into LP formulations.

The learning objectives for Duality in Operations Research include the ability to explain the relationship between primal and dual problems, grasp the significance of the dual problem in providing insights into the primal problem, and understand how changes in resource availability impact the optimal solution in both primal and dual problems. To navigate these objectives successfully, students need to acquire the skill of switching between LP primary and duality formulations. Thus, instructors typically introduce the method of transformation between primal and dual problems before covering applications of the concept in problem-solving.

As the curriculum progresses, specific concepts within the primal Simplex method are explored, including the interactions of resources, shadow prices, and binding constraints, all of which are thoroughly discussed within applied LP problems in subsequent assignments. It becomes apparent that IE students may gravitate towards learning materials closely related to practical applications, favoring content with concrete examples rather than abstract concepts or procedures devoid of specific applications. Offering specific applications can assist students in immediately grasping how to apply theoretical concepts to real-world scenarios. On the other hand, ME students may initially grasp mathematical concepts or procedures, intending to apply these skills to real engineering problems at a later stage. Numerous studies have reported that providing relevant examples can enhance the effectiveness of mathematical learning. [16], [17]. The instruction of duality concepts with real-world examples has the potential to significantly improve student performance, not only for IE students but also extending its impact to ME students. The incorporation of examples can bridge the gap between theoretical understanding and practical application, thereby fostering a deeper comprehension of the subject matter for students across engineering disciplines.

Conclusion

Two cohorts of engineering majors, sharing the same class, exhibited differing overall performance. A notable difference emerged in the performance of ME students, particularly in the final exam. This divergence prompts the need for further investigation to uncover the factors influencing IE students' performance in the concluding examination. A thorough exploration of these factors will not only shed light on the disparities observed but also contribute to the identification of effective learning strategies, thereby fostering improvements in academic outcomes for both cohorts.

Furthermore, the significance of reading abilities and comprehensive understanding as essential skills cannot be overstated. These skills are paramount in translating the problem scope into LP mathematical models, emphasizing the ability to articulate problems mathematically rather than focusing solely on procedural aspects of mathematical problem-solving. By recognizing the importance of these cognitive skills, educators can better equip students with the tools necessary to navigate the complexities of LP modeling successfully. In conclusion, integrating mathematical concepts with applied examples can serve as a crucial bridge, linking theoretical understanding to practical application. This approach fosters a deeper comprehension of the subject matter, benefiting students across engineering disciplines. Through delving into the intricacies of engineering education, it becomes evident that a holistic approach, encompassing factors such as effective learning strategies, cognitive skills development, and practical application, is essential for nurturing well-rounded and successful engineering students.

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