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A Statistical Analysis Between Fundamentals of Engineering Examination Results, Grade Point Average, and Specific Course Performance

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Abstract

The Fundamentals of Engineering Examination (FEE), administered by the National Council of Examiners for Engineering and Surveying (NCEES), is a nationally normed assessment of examinees' understanding of knowledge gained during undergraduate studies in engineering.

Using a database of by-name pass/fail performance inclusive of four-years of information (2019, 2020, 2021, and 2022) this study investigated if a positive correlation exists between pass/fail performance and performance within specific electives. Statistical analysis was performed to determine the significance of any relationships that were found. Discussion is presented to address the potential for differences in causation and correlation between variables.

This study was conducted to help the civil engineering program at a specific academic institution to evaluate if particular elective courses result in better preparation for students to pass the FEE. This study will help inform curricular changes that are under consideration and improve student advising. The results of this study will be of interest to the faculty and administrators at other civil engineering programs as they evaluate changes to their own curricula.

Background

At the United States Military Academy (West Point), all students pursuing a degree in engineering are required to take the Fundamentals of Engineering Examination (FEE). Students enrolled in civil engineering at West Point are not required to pass the FEE unless they are pursuing a "with honors" designation on their transcript and diploma. Like all engineering programs with students taking the FEE, the civil engineering program receives an aggregated summary of student performance in each specification area which includes a national-level comparison. Students in the civil engineering program at West Point are required to self-report their pass/fail results. This allows the civil engineering program to compile a by-name listing of student performance (overall pass/fail but not by specification area).

A degree in civil engineering at West Point requires completion of 16 courses in the civil engineering program in addition to a robust common curriculum (146 total credits). Of those courses, two are selected from a list of engineering technical electives. Students pursuing a degree with honors are required to take one additional elective. The choice to select specific electives and academic performance in those electives was presumed to influence student preparation and performance on the FEE and is part of the focus of this study.

There are 25 electives available for students to take in the civil engineering program. While each of those electives may address some topics covered on the FEE, two courses focus on FEE topic areas that are not covered elsewhere in the curriculum: CE495, Transportation Engineering, and EV380, Surveying. There are two other electives that reinforce several important topic areas from the FEE: CE472, Advanced Soil Mechanics and Foundation Engineering, and CE491, Advanced Structural Analysis. Finally, one elective course is very popular among students but does not directly relate to FEE topic areas: CE490, Special Topics in Civil Engineering (currently focused on Energy Efficient Buildings). The course catalog description and a brief additional explanation of each of these five courses follows.

CE495 – Transportation Engineering. This course provides a solid introduction to the principles of transportation engineering with a focus on highway engineering and traffic analysis. The material learned provides the basic skill set that allows students to solve transportation problems that are likely to appear in professional practice, on the FEE, and on the Principles and Practice of Engineering exam (PE).[1] The topic of transportation engineering is covered to a very limited extent in one required course in the civil engineering curriculum. Accordingly, students who do not take CE495 would have little formal preparation for the transportation engineering topic questions on the FEE. This course has two pre-requisites – one course focused on soil mechanics and a second course focused on hydraulics and hydrology – and reinforces concepts from these topics. Importantly, this course includes two 25-question multiple choice mid-term exams, providing students with experience answering questions in a similar format as they will see on the FEE.

EV380 – Surveying. A framework for understanding and applying practical surveying methods is developed. Consideration of error theory and the concepts of precision and accuracy yields understanding of the probabilistic nature of measurements. The principles of differential leveling, electronic distance measurement, angular measurement, global navigation satellite system (GNSS) positioning, and terrestrial laser scanning (a.k.a. Lidar) are studied and applied using state-of-the-art surveying equipment and software tools. Plane surveys are principally explored, although the fundamentals of geodetic surveys are also presented. Traverse, triangulation, trilateration, level networks and the proper adjustment of related measurements are examined. Control survey, land survey, topographic survey, horizontal and vertical curve design, and Geographic Information System (GIS) software applications are included. Extensive use of laboratory periods permits the application of surveying fundamentals, methods and planning skills to actual field situations.[1] The topic of surveying is not covered in any required courses within the civil engineering curriculum. EV380 requires no pre-requisites and is offered and taught by faculty outside of the civil engineering program.

CE472 – Advanced Soil Mechanics and Foundation Engineering. Students extends knowledge learned in Soil Mechanics and Foundation. Topics covered are: slope stability, field testing, field instrumentation, designing braced excavations, designing piles and drilled shafts, designing flexible walls, designing earth retaining structures, and designing earth structures using geosynthetics. [1] The civil engineering curriculum includes a required 3.5 credit hour course in soil mechanics and foundation design which is a pre-requisite for CE472. Unlike the topics of transportation engineering and surveying, students in the civil engineering program of study receive coverage of all geotechnical engineering FEE topic areas as part of the curriculum; CE472 reinforces these geotechnical topics along with statics and mechanics of materials topics.

CE491 – Advanced Structural Analysis. This course builds upon the material covered in CE403 to develop a better understanding of structural behavior. Two-dimensional analysis of trusses and frames is reviewed and extended into 3D. Matrix analysis methods, including an introduction to continuum finite elements are developed as the basis for modern computer-based structural analysis. An introduction to nonlinear analysis is presented. Coursework involves extensive use of the computer as an analytical tool. Students use state-of-the-art structural engineering analysis and design software.[1] The civil engineering curriculum includes a required 3 credit hour course in structural analysis, and two 3.5 credit hour courses in structural design (one on structural steel and the other in reinforced concrete). The structural analysis course is a pre-requisite for CE491. Unlike the topics of transportation engineering and surveying, students in the civil engineering program of study receive coverage of all structural engineering FEE topic areas as part of the curriculum; CE491 reinforces these topics along with statics and mechanics of materials topics.

CE490 – Special Topics in Civil Engineering (current offering: Energy Efficient Buildings). This course provides in-depth study of a special topic in engineering mechanics or in structural, geotechnical, environmental, water resources, construction, or transportation engineering not offered elsewhere in the curriculum. The course is intended to broaden the exposure to the civil engineering discipline. Course content is based on the special expertise of the visiting professor or a senior civil engineering faculty member. [1] The current offering of this course was developed in 2013 and focuses on energy efficient building design. This course has no pre-requisites and does not directly relate to any FEE topic areas.

The investigators initiated this study with the following research questions:

- *Does the completion of one or a combination of specific electives improve the chance of passing the Fundamentals of Engineering Examination?*
- *Does academic performance in one or a combination of specific electives improve the chance of passing the Fundamentals of Engineering Examination?*

Literature Review

Much has been written about using the FEE as an assessment tool for programs, outcomes, etc. [2-9] Rockstraw, et al [10] cite data from eight universities who use the FEE as an assessment tool for their engineering and engineering technology programs. Crawford et al [11] describe how reports of performance by subject area may provide information that can help programs evaluate success in achieving student outcomes. They suggest that such reports can also help programs document the effects of "curriculum revisions, teaching innovations, and other actions taken to improve student mastery of engineering topics."

However little has been written regarding the ability to predict student performance on the FEE based on other possible predictive variables. With a 2022 national pass rate of 55% on the Civil Engineering FEE [12] it would be beneficial to identify what specific variables lead to a passing score. Taking and passing practice exams and being familiar with the FEE Reference Handbook are certainly positive contributors [13-15]. Crepeau et al [16] developed short online videos on topics so that students could focus on areas where their knowledge needs improvement. They found thru post-course surveys that "students found using the videos and online example problems to be both motivating and instructionally effective." But what variables in a program might contribute to increased pass rates and may possibly be used as a predictor of passing?

Studies that do predict student success on national exams include Hashemi et al [17] who investigated the use of machine learning techniques to predict student performance on a national medical exam with good results. Gnanapragasam et al [18] conducted a four-year study to evaluate the relationship between grades earned in specific mechanics-related courses and performance in a simulated FEE. The study focused on five courses: statics, dynamics, mechanics of materials, soil mechanics and fluid mechanics. The authors concluded that there is a direct correlation between higher student overall GPA and student performance in the simulated FEE. They found very low correlation between scores in the simulated FEE sections and student GPA in the specific courses. However, statics and strength of materials exhibited somewhat higher correlation in simulated FEE performance "possibly because many of the advanced mechanics courses reinforce the concepts learned in these two basic courses."

FEE specifications effective beginning with the July 2020 examination are listed below showing the topics that the examination covers and the range of the number of questions in each topic area (Table 1). Examinees have 6 hours to complete the exam, which contains 110 multiple-choice questions. The 6-hour time also includes a tutorial, a break, and a brief survey at the conclusion [11].

Table 1. Civil Engineering Topics on the Fundamentals of Engineering Examination and Related Number of Questions [11]

Civil Topic	No. of Questions
Mathematics and Statistics	8-12
Surveying	6-9
Ethics and Professional Practice	4-6
Water Resources and Environmental Engineering	10-15
Engineering Economics	5-8
Environmental Engineering	10-15
Statics	8-12
Structural Engineering	10-15
Dynamics	4-6
Geotechnical Engineering	10-15
Mechanics of Materials	7-11
Transportation Engineering	9-14
Materials	5-8
Construction Engineering	8-12
Fluid Mechanics	6-9

Methods

Data for this study was compiled from historical enrollment and academic performance records maintained by the civil engineering program for all students who graduated with a civil engineering degree in 2019, 2020, 2021, and 2022 – a total of 154 students. Data included student elective choices, elective grades, and FEE pass/fail result. As described above, five specific electives were considered in this study. These courses are specified in Table 2. Note four of these courses are listed with Civil Engineering (CE) and one is listed with Environmental Engineering (EV).

Table 2. Courses Considered in this Study.

Course ID	Course Title
CE472	Advanced Soil Mechanics
CE490	Topics in Civil Engineering
CE491	Advanced Structural Analysis
CE495	Transportation Engineering
EV380	Surveying

In total, twelve variables (features) were considered: (1) the total number of these electives taken by a student, (2) the student's average GPA for these electives, (3-7) indicator variables describing which electives the student took, and (8-12) the student's GPA for each elective they took. There were sixteen students in the database that did not take any of these five specific electives and were omitted from the analyses. This means the resulting analyses cannot explicitly evaluate the effect of not taking any of these electives; however, they can quantify potential gains in FEE pass rate due to participation in these electives.

The available data, based on 138 students who took at least one of the five specific electives considered in this study, were organized to setup a classification problem in which the objective is to use the identified variables to predict the FEE "class": pass or fail. A number of supervised learning methods are applicable to this problem such as logistic regression, decision trees, support vector machines, neural networks, etc. To maintain model interpretability, the analyses started with simple logistic regression models where only one variable was considered for each model. The next sections describe the resulting model fits, model adequacy, and predictive capabilities. After implementing logistic regression, other machine learning (ML) including Decision Trees, Support Vector Machines, Naive Bayes, and K-Nearest Neighbors were explored and overall, produced comparable results.

Results

Twelve logistic regression models were evaluated: one for each variable. Table 3 presents a summary of the model fits. It is important to note the variations in sample size for each model. The models that considered grades (GPA) only include the total number of students who enrolled in the course whereas the indicator variables, e.g., "did this student take CE472?", can include the total population (N=138). The p-value column shows the result of the significance test for the variable; low p-values indicate that the fitted coefficient is statistically significantly different from zero, i.e., a statistically significant relationship with FEE scores. Models with p-values below 0.05 were selected for further consideration.

Details of the five models selected are shown in Table 4. The *odds ratio* and the *receiver operating characteristics area under the curve (ROC AUC)* are two metrics that are useful for interpretation and comparison of classification models. The *odds ratio* is computed from the coefficient of the model and can be interpreted as the estimated increase in the probability of "success" associated with a one-unit increase in the variable [19]. The variables in B, D, J, and L all use the same GPA scale, thus the odds ratio can be used to quickly compare how much more likely a student is to pass the FEE based on a letter grade increase in each course.

Table 3. Summary of All Logistic Regression Models Considered

Model	Variable	Sample Size	Coeff. pValue	Select?
A	No. of Electives	138	0.017	Y
B	Electives GPA	138	<0.001	Y
C	Taken CE472?	138	0.324	N
D	CE472 GPA	51	0.026	Y
E	Taken CE490?	138	0.076	N
F	CE490 GPA	45	0.513	N
G	Taken CE491?	138	0.307	N
H	CE491 GPA	14	1.000	N
I	Taken CE495?	138	0.285	N
J	CE495 GPA	109	<0.001	Y
K	Taken EV380?	138	0.697	N
L	EV380 GPA	39	0.014	Y

The ROC AUC metric is a number between 0 and 1; a value of 0.5 indicates a random guess while a value of 1.0 indicates 100% true positive detection with 0% false positives. Overall, values above 0.70 indicate satisfactory predictive capabilities. The ROC curves for the five selected models in Table 4 are shown in Figure 1.

Table 4. Summary of Best Performing Logistic Regression Models

Model	Variable	Sample Size	Coeff Est.	Coeff S.E.	Odds Ratio	ROC AUC
A	No. of Electives	138	0.65	0.27	1.91	0.654
B	Electives GPA	138	2.44	0.54	11.48	0.808
D	CE472 GPA	110	2.27	0.55	9.69	0.834
J	CE495 GPA	109	2.23	0.55	9.30	0.830
L	EV380 GPA	39	3.77	1.54	43.55	0.889

A 70-30 ratio for the split between training and testing data was chosen to allow adequate testing samples for model L, which had the smallest sample size. The training and testing data were randomly selected from the populations. For example, in model A, the training data had 97 samples and the testing data had 41 samples – both groups selected at random. Similarly, in model L, the training data had 28 samples, and the testing data had 11 samples. The logistic regression models were fit only to the training data. Then, the testing data were input into the fitted models to make FEE predictions. Figure 2 shows the ROC curves for the five Logistic Regression models in both training and testing phases.

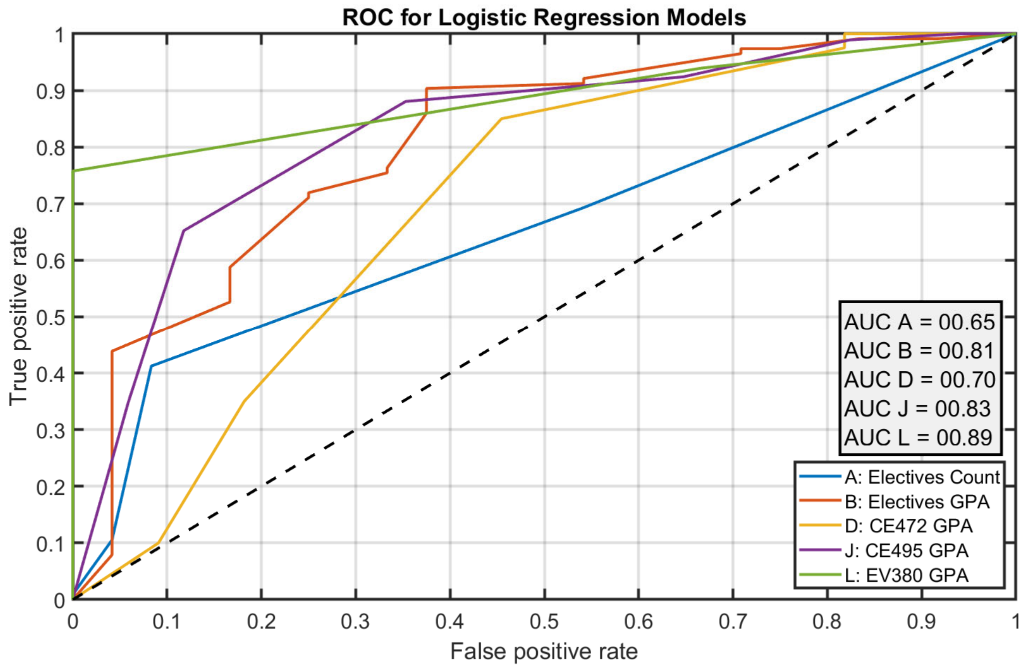

Figure 1. Receiver Operating Characteristic (ROC) curves for the five selected Logistic Regression models fit to full datasets.

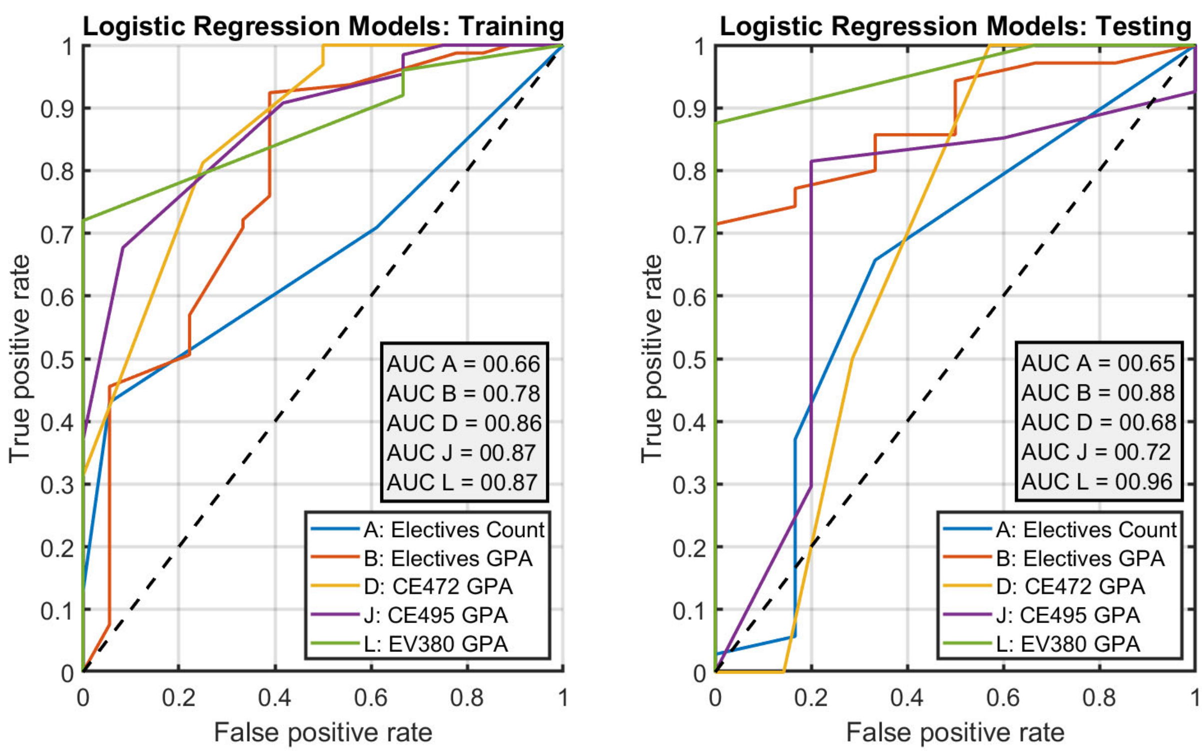

Figure 2. Receiver Operating Characteristic (ROC) curves for the three Logistic Regression Models for training and testing.

Discussion

Given the significance testing for the variables (Table 3), five models had p-values below 0.05 (> 95% significance) which indicate potentially successful predictors and were selected for further analyses: models A, B, D, J, and L. These correspond to the variables number of electives, electives GPA, CE472 GPA, CE495 GPA, and EV380 GPA. When comparing the odds ratio (Table 4) of the variables, EV380 (model L) stands out with an odds ratio of 43. This suggests that every letter grade improvement in EV380 corresponds to a 43-fold increase in the odds a student passes the FEE (similarly, a half-letter grade improvement corresponds to a 6-fold increase in passing odds). Of course, these interpretations have limitations and extrapolate outside the observed domain (especially since GPAs cannot exceed 4.33), but nevertheless provide a point of comparison for the efficacy of the EV380 GPA compared to the other predictors.

The ROC AUC values (Figure 1) for the models B, D, J, and L exceed 0.80 which suggests these variables have strong predictive power. Model L stands out by achieving a 75% true positive rate with a 0% false positive rate. Note that for model J or model B to achieve a 75% true positive rate, it would correspond to about a 25-30% false positive rate. These initial results suggest that model L provides the best FEE predictions. However, it is important to mimic actual model performance by splitting the data into two parts: training and testing. In general, the ROC AUC values for the overall model tend to be higher than those in testing, but the testing ROC AUC is considered more reliable as it mimics the prediction process.

Overall, the training ROC AUC values are consistent with those shown in Figure 1 and Table 4. In the testing phase, the ROC AUC values for models D and J drop by about 0.15. Meanwhile, the ROC AUC values for models B and L increase. Overall, the ROC curves for model L are the most consistent and have the highest AUC in both testing and training phases. This suggests that model L would have the best predictive performance in future use. Nonetheless, models B, D, J, and L produce good predictive capabilities, especially for their simplicity (only one variable). In summary, while doing well in all these electives a good predictor as indicated by electives GPA (model B), doing well in CE495 (model J) or EV380 (model L) are comparable predictors. These results suggest a student who does well in CE495 or EV380 is likely to pass the FEE.

While the student GPA for EV380 presents itself as the best predictor for performance on the FEE, it is important to note that this sample population size was the smallest of the predictors with the largest coefficient of standard error (Table 4). Typically, the students choose this elective course to gain exposure to material on the FEE that is not otherwise taught among the standard courses for the Civil Engineering program. While the causation for this result is unknown, there is potential that the performance in this elective course is a signal for the individual student’s motivation to perform well on the FEE. Even though the similar arguments concerning student motivation could be made for the other predictors, the EV380 GPA currently serves as the best single predictor for FEE performance.

This study has several limitations. First, it only considers models with single variables for predictors. Even though cursory investigation did not improve predictive power with the inclusion of multivariable models, further study with such models is certainly desirable. Next, variability among students was not considered, as standardized test-taking abilities, exposure to course material under specific instructors, and core course performances could also affect and predict performance on the FEE. While the purpose of this study was to focus on identifying the relationship between elective performance and FEE performance, such additional indicators were not considered. Even despite these limitations, continued data collection and future analysis of these predictors is warranted.

Conclusions

Based on the analysis of the elective courses and FEE data compiled from 2019-2022, this study intended to highlight the consistency between students' pass/fail performance on FEE and their academic performance within specific electives: Surveying (EV380), Advanced Soil Mechanics and Foundation Engineering (CE472), Special Topics in Civil Engineering (CE490), Advanced Structural Analysis (CE491) and Transportation Engineering (CE495). Logistic regression models were used to evaluate predictive capabilities of FEE pass rate based on the selection of and performance in these electives and the receiver operator characteristic area under the curve (ROC AUC) metric was used to compare the models.

Overall, results showed that the selected electives GPA was a very good predictor for whether a student would pass the FEE, which is an intuitive result. Simultaneously, the students who elected to take EV380 or CE495, and did well in the course, were very likely to pass the FEE. Importantly, a student's GPA in CE485 or EV380 provided the most reliable predictions of FEE pass rate (better than the overall electives GPA model). Specifically, ROC AUC values near 0.90 indicate that the model based on EV380 GPA would have the best predictive power (over 75% true positive rate with about zero false positives) and could be used in the foreseeable future.

The strength of the conclusions in this statistics-based study are limited by the size of the population. Replicating this study over a longer period of time would assist with strengthening conclusions related to trends but the year-to-year population will make it challenging to make definitive claims about specific year-groups.

The conclusions reached during this study are associated with a unique population of students who have selected to pursue their studies at a military academy. The ability to generalize to a broader population of civil engineering students or even more broadly to all engineering students may be limited.

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