Subject Correlation Analysis in the Fundamentals of Engineering Exams

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***Abstract*— This Research-to-Practice Full Paper presents the correlation analysis of subjects in the Fundamentals of Engineering (FE) exam, which is a nationally standardized test developed by NCEES (National Council of Examiners for Engineering and Surveying). It is generally the first step in the process of becoming a professional licensed engineer (P.E.) and hence serves as a valuable assessment tool for evaluating students' learning objectives and outcomes. Based on CPP (Cal Poly Pomona) and National FE exam data from 2005-2011, this study intended to explore the relationship between different subjects from morning and afternoon sessions. Additionally, the comparison was also performed between the observations from CPP and National results to highlight the discrepancies which can shed more insight to teachers for their design of curriculum and pedagogy strategies aiming to enhance students' outcomes. The results illustrated the presence of statistically significant correlation among many subject pairs across morning and afternoon sessions. Moreover, some of the pairs demonstrated comparable relationship between CPP and National exam results, but the correlation analyses successfully highlighted the discrepancies which would allow the faculty to develop focused strategies for improvement of weaker subjects.**

Keywords—Fundamentals of Engineering Exam, Student Outcome, Correlation

I. INTRODUCTION

In an effort to continuously improve the engineering curriculum, it is necessary to evaluate the student outcomes from diverse perspectives. The literature is replete with multiple methods employed for assessment of student outcomes including, but not limited to, analysis for relationship between exams and other outcomes [1, 2], in-classroom assessment [3], analysis of specially designed industrial survey [4], and statistical analysis for identification of differing influential factors [5], impact of active learning [6], and so on. Since California State Polytechnic University, Pomona (or, CPP) hosts one of the largest Civil Engineering programs in the US with 1300+ enrolled undergraduates and 200+ graduate students, CPP has implemented different strategies for assessment of students' learning outcomes based on the national-level Engineering in Training Licensing Exams, Senior Exit Survey, Graduation Writing Test, Senior Project Symposium, etc. One such outcome is the Fundamentals of Engineering (FE) exam, which is a nationally standardized test developed by NCEES (National Council of Examiners for Engineering and Surveying). It is generally the first step in the process of becoming a professional licensed engineer (P.E.). It is also designed for recent graduates and students who are close to finishing an undergraduate engineering degree. Therefore, the FE exam is a valuable assessment tool for evaluating students' learning objectives and outcomes.

Even though many studies have been centered on the evaluation of FE exam results, very few of them have been dedicated to examining the correlation of the results of various subjects. To fill this gap, This Research-to-Practice Full Paper presents a correlation analysis of subjects in morning and afternoon sessions in the FE exam. Additionally, the observations from CPP results are also compared with the National results to highlight the areas of concern so as to dedicate more resources for their investigation and improvement. The average percent of correct answers for both CPP and National Civil Engineering examinees spanning from October of 2005 to April of 2011 were collected for each of the subjects in the morning and afternoon sessions. The results from correlation analyses are presented in the figures which illustrate the quantified relationship and the statistical significance between subjects for CPP and National examinees separately. The common results identified among these two groups are anticipated to yield more reliable correlation analysis results. It is expected that the research results can provide more insights to both students and faculty, when preparing the FE exams and designing the curriculum, respectively. The detailed information about the methods, data collected, and pertinent results are shown in the sections that follow.

II. DATA DESCRIPTION

Before the implementation of the computer-based exam administered year-round, the paper-based FE exam was administered twice per year (or, April and October). We collected the data from the period of October 2005 to April 2011, where each year generated two datasets, with the exception of 2005 and 2011 where only one dataset was incorporated from each of those two years. The FE exam is split into two sessions, morning and afternoon, which covered a wide range of engineering subjects. In the morning session, the subjects include Mathematics, Engineering Probability and

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Statistics, Chemistry, Computers, Ethics and Business Practices, Engineering Economics, Engineering Mechanics (Statics), Strength of Materials, Material Properties, Fluid Mechanics, Electricity and Magnetism and Thermodynamics. In the afternoon session, the students can choose either the general FE subjects (similar to morning subjects) or the program-specific subjects such as Civil Engineering, Mechanical Engineering, and Electrical Engineering, and so on. The Civil Engineering subjects usually contain Surveying, Hydraulics and Hydrologic Systems, Soil Mechanics and Foundations, Environmental Engineering, Transportation, Structural Analysis, Structural Design, Construction Management and Materials. This study obtained the data from CPP FE exam results as well as the National results for the concerned time period, where the latter acted as the reference for comparison of CPP results. The subject names for each session are documented in Table 1 with the abbreviations, which are adopted only for the sake of simplicity and are limited to this study only.

TABLE I. DESCRIPTION OF SUBJECTS

Symbology/abbreviation	Full Name	Number of questions
A.M. (morning session) Subject		
Math	Mathematics	19
EPS	Engineering Probability and Statistics	8
Chem	Chemistry	11
Comp	Computers	8
EBP	Ethics and Business Practices	8
EEcon	Engineering Economics	10
EMS	Engineering Mechanics (Statics)	8
SOM	Strength of Materials	5
MP	Material Properties	8
FM	Fluid Mechanics	8
EM	Electricity and Magnetism	8
Thermo	Thermodynamics	11
P.M. (afternoon session) Subject		
Survey	Surveying	7
HHS	Hydraulics and Hydrologic Systems	7
SMF	Soil Mechanics and Foundations	9
EEngg	Environmental Engineering	7
Trans	Transportation	7
SA	Structural Analysis	6
SD	Structural Design	6
CM	Construction Management	6
Mat	Materials	5

III. METHODOLOGY AND RESULTS

As mentioned previously, the primary objective of this study is to explore the relationship among different subjects of FE exam and compare the results with the trends observed in National FE exam so as to highlight the areas of concern for designing more informed curriculum. The relationship between subjects is established by conducting a correlation analysis, where the Pearson's correlation coefficient quantifies the strength of dependency among the concerned subjects and the p-values indicate the statistical significance. The correlation coefficient is obtained by dividing the covariance of the two variables by the product of their standard deviations [7]. Mathematically, the population correlation coefficient $\rho_{X,Y}$ between two random variables X and Y with expected values μ_X and μ_Y and standard deviations σ_X and σ_Y is defined in Equation 1:

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \quad (1)$$

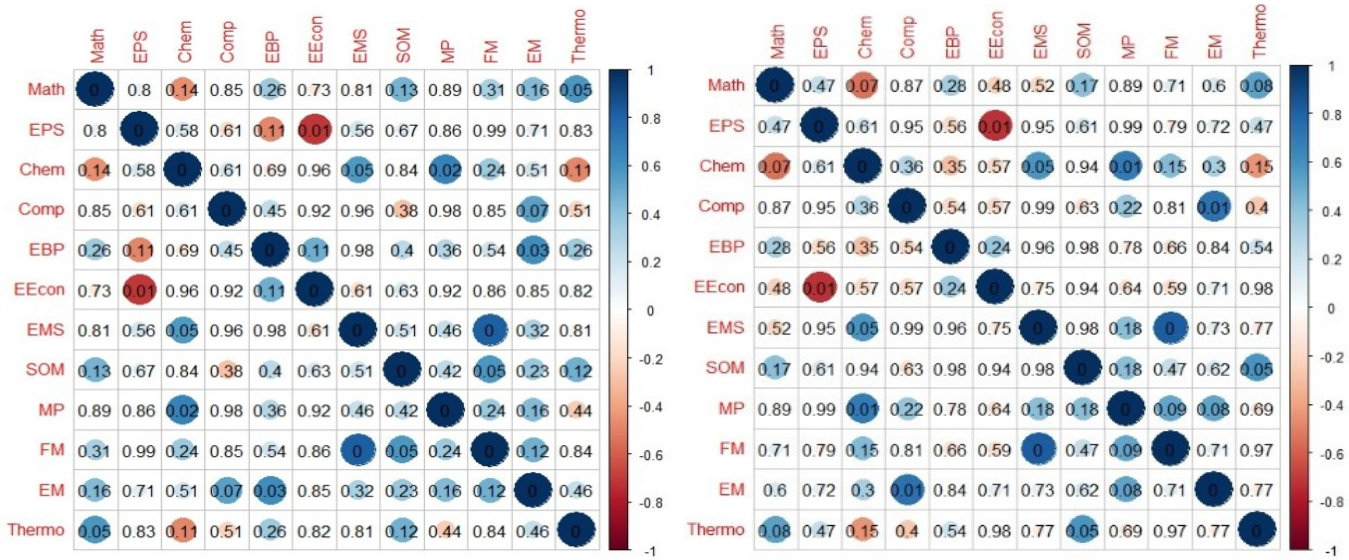
where E is the expected value operator, cov means covariance.

The correlation coefficient of +1 indicates the case of a perfect direct (increasing) linear relationship (correlation), −1 in the case of a perfect decreasing (inverse) linear relationship, and some value in the open interval (−1, 1) in all other cases, indicates the degree of linear dependence between the variables. As it approaches zero there is less of a relationship (closer to uncorrelated). The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables. It is also important to discuss the role of p-value in determination of dependency among subjects (variables). The p-value with different significance level indicates the confidence interval up to which the results would hold true. Since different objectives may require different significance levels, this study presents the results with all concerned p-values so that the statistically significant correlation may be established as per requirements. The 'corrplot' package within the software R was employed to conduct the correlation analyses and develop plots, which are shown in Fig. 1 and Fig. 2.

As shown in Fig. 1, many subjects from the a.m. session demonstrate the presence of dependency, reflected by the darker shaded circles for both CPP and National FE exams. In case of CPP, the largest positive correlation is observed for (EMS & FM), followed by the pairs of (Chem & MP), (EBP & EM), (EMS and Chem), (Comp & EM), and (Math & Thermo). All these correlations are statistically significant at the p-value of 0.1. These results suggest that for the given data pertaining to FE exam results of CPP students, the proficiency at Engineering Mechanics (EMS) is highly associated with equivalent performance in the subject of Fluid Mechanics (FM). A similar observation is also evident from the National results where the concerned subject pair demonstrates highest correlation value suggesting that a conceptual understanding of mechanics may prove advantageous for competency in two subjects. Furthermore, the proficiency in Chemistry (Chem) is also strongly linked with EMS and Material Properties (MP) for both the CPP and National exam results. Conversely, there

are a few discrepancies between the positively correlated subject pairs for CPP and National exam. The Strength of Materials (SOM) and FM are noted to be strongly related in case of CPP while also satisfying the condition of statistical significance, but the concerned pair neither demonstrates strong correlation nor significance in case of National results. Similar trend is also observed for the pair of Ethics and Business Practices (EBP) & EM. Such discrepancies justify the objective of this research as it uncovers that CPP students may develop skills for specific subjects due to curriculum design or faculty attention.

It is also worth discussing the interesting trends observed for the presence of negative correlations between subject pairs such as Chem & Math, Chem & Thermo, and EPS (Engineering Probability and Statistics) & EBP (Ethics and Business Practices), and EPS & EEcon. (Engineering Economics). The negative relationship between chemistry and mathematics may be explained by the different work approach required for mastering the concerned subjects. Mathematics may appear relatively abstract and gaining a good grade at examination may require repetitive practice of questions, along with concept building, whereas in the case of chemistry, the students who lack patience for repetition and rely on the understanding of conceptual knowledge alone may secure good grades. Such students should be made accustomed to the different approach for excelling in mathematics. The relationship between chemistry and thermodynamics may again reflect the fundamental difference between mindset of students as chemistry deals at a very micro scale of atoms while thermodynamics is generally associated with the macro scale physical world. The most noteworthy and counterintuitive relationship is observed for the very strong and statistically significant correlation between EPS & EEcon. Generally, it is expected that students who excel at EPS will perform well at EEcon too since EPS forms the foundation of understanding the economics in engineering through development of econometric models. The possible explanation for this counterintuitive observation could be the difference between EPS and EEcon, where the former mainly deals with mathematical concepts with little real-world application problems while the latter deals with applied statistics from the perspective of engineering and may also involve study of policy framework governed by economics. The fundamental difference in the nature of subjects may lead to discrepancy in students' performance. However, the faculty may introduce more curriculum related to applied statistics in EPS so that students are able to better handle the transition to EEcon.



(a) CPP

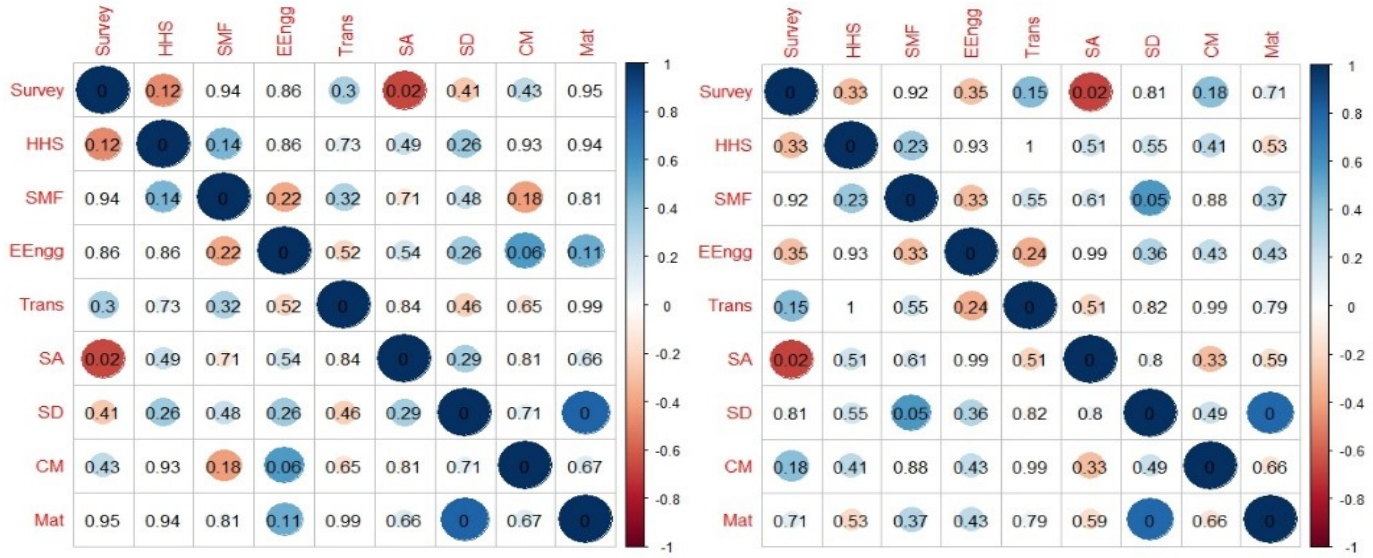
(b) National

Fig. 1. Correlation plots for a.m. (morning session) subjects

Notes: 1. The negative or positive correlation is indicated by color scheme where white refers to zero value of correlation coefficient; shades of blue refer to positive (0 to 1); shades of orange refer to negative (0 to -1).

2. The size of each colored circle indicates the numerical value of correlation coefficient where a larger value has larger circle and vice versa.

3. The numerical value shown within each circle reflects the p-value.



(a) CPP (b) National

Fig. 2. Correlation plots for p.m. (afternoon session) subjects

Notes: 1. The negative or positive correlation is indicated by color scheme where white refers to zero value of correlation coefficient; shades of blue refer to positive (0 to 1); shades of orange refer to negative (0 to -1).

2. The size of each colored circle indicates the numerical value of correlation coefficient where a larger value has larger circle and vice versa.

3. The numerical value shown within each circle reflects the p-value.

Unlike the multiple instances of strong correlation occurrence for the subjects of morning session, relatively less number of subjects are observed to be correlated for afternoon session, as clearly shown in Fig. 2. The statistically significant correlations at 0.1 significance level are observed for SA (structural analysis) & Survey, CM (Construction Management) & EEngg (Environmental Engineering), SD (Structural Design) & SMF (Soil Mechanics and Foundations), and SD & Mat (Materials). The only discrepancy between CPP and National trend is that CM & EEngg is strongly correlated for CPP while SD & SMF is correlated for National results. The negative correlation between surveying and structural analysis (SA) indicates the difference between the skills required to excel at the respective subjects. Surveying involves a more practical knowledge of directions and geometry while SA involves a more comprehensive mathematical understanding of applied physics in different geometric objects made up of diverse materials. The fact that this negative correlation is observed for both CPP and National results illustrates that such trend is common among students and potentially related to general perception of minds of students towards the physical world. The faculty may address this wide discrepancy between the knowledge of these subjects by introducing projects which involve realistic scenarios where the students are encouraged to build a foundation of directions and geometry and then proceed to conduct the analyses of structures. In contrast to the negatives correlation, a very strong and statistically significant correlation is observed at both CPP and National level between SD & Materials, which indicates that the students who obtain better understanding of material properties are able to transfer their knowledge for generating better structural designs.

IV. Summary

Based on CPP and National FE exam data from 2005-2011, this study intended to explore the relationship between different subjects from morning and afternoon sessions. Additionally, the comparison was also performed between the observations from CPP and National results to highlight the discrepancies which can shed more insight to teachers for their design of curriculum and pedagogy strategies aiming to enhance students' outcomes. The results illustrated the presence of statistically significant correlation among many subject pairs across morning and afternoon sessions. Moreover, some of the pairs demonstrated comparable relationship between CPP and National exam results but the correlation analyses successfully highlighted the discrepancies which would allow the faculty to develop focused strategies for improvement of weaker subjects.

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