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ABSTRACT

The relatively large number of students who perform poorly in freshman chemistry courses signals the need for the identification of criteria that will result in correct placement decisions for incoming college students. Research findings have generally reported placement criteria that correlate significantly with performance in college chemistry coursework however, predictions of course grades have tended to be very inaccurate because most of this research focused on the development of regression models in which a single predictor was utilized. The study reported in this paper used the meth of discriminant analysis to predict membership of the target sample of freshman students into one of two groups: those that received a grade of "A," "B," or "C" in their first semester of Chemistry; an those that received a grade of "D," "F," or "W.• An acceptable statistical model, in terms of assumptions on normality and homogeneity of variance, was developed from discriminant functional analyses and multiple regression analyses of data from previous freshman classes. The factors that were identified as best predictors of performance in college Chemistry--in order of standardized relative weightings--were the mathematics score on the student's college entrance examination, high school grade point average (GPA), course grade in high school chemistry, high school mathematics GPA, and course grade in high school English. The model correctly predicted the discriminant group for almost three out of four students (73.7%). (18 references)(JJK)

PREDICTING PERFORMANCE

IN

FRESHMAN CHEMISTRY

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of the American Chemical Society
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Introduction[1]

The relatively large number of students who perform poorly in freshman chemistry is a persistent problem for college chemistry teachers. Previous authors (1-16) have reported placement criteria which correlate significantly with performance in chemistry. These researchers have developed statistical models designed to predict grades in college chemistry using as predictors high school records, standardized test scores, and results of placement examinations.

The mostly commonly reported predictors of performance are Scholastic Aptitude Test (SAT) scores, American College Testing Program (ACT) scores, high school grades in chemistry and mathematics, high school rank or grade point average, and placement examinations developed at the authors' institutions. Of these variables, the SAT mathematics test score has been found to have one of the highest correlations with grades in college chemistry (1-3). It has been observed that grades of "C" or less in high school chemistry tend to predict low grades in college chemistry, but that higher grade alone may or may not predict success (4).

Most of the studies have reported the development of simple regression models in which a single predictor (e.g., SAT mathematics score, high school chemistry grade, score on placement test) was correlated with grades in college chemistry. Although moderate correlation coefficients (0.40) have been

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[1]Based on the author's doctoral dissertation of the same title, Northern Arizona university, 1989 (Ann Arbor: UMI, 1989).

obtained, predictions of grades themselves have tended net to be very accurate. For example, an SAT mathematics score of 700 or higher may predict an "A" or "B" in chemistry, and a score below 500 a "D" or "F" but scores between 500 and 700 may predict nothing. A student with an SAT score in the 500-700 range may earn any grade from "A" to "F" (5).

Multiple regression equations include more than one predictor variable. Multiple correlation coefficients tend to be higher than simple correlation coefficients. Still, predicting an "A" or an "F" (i.e., grades at the extreme ends of the range) appears to be more successful than predicting a "C." In this study a different--and possibly more powerful--approach was taken. Rather than predicting performance along a continuum of "A" to "F," discriminant function analysis was employed to assign membership in one of two discrete groups--students who would be predicted to earn a "C" or better in chemistry ("successful" students), and those predicted to earn less than a "C" ("unsuccessful" students).

The Problem

Before fall, 1985, all engineering students at the author's institution had to complete a 2-semester sequence in general chemistry.Since fall, 1985, engineering students have been required to complete a 5-credit course, PS 110, Chemistry for Engineers, generally in their first semester. This course assumes as prerequisite knowledge mu h of the material found in the first one-third of general chemistry textbooks like those authored by Brown and LeMay, Masterton, and Slowinskl, and Brady and Humiston. PS 110 is an accelerated course covering states of matter, sol ions, kinetics, thermodynamics, equilibrium, electrochemistry, and introductory organic chemistry. To take PS 110 students must have taken high school chemistry and pass a placement test, or first complete a preparatory chemistry course, or transfer in chemistry credit from another college or university.

Virtually all incoming engineering students have taken high school chemistry, but high school courses vary widely in level of presentation and topics covered. Therefore, neither the fact of having taken high school chemistry nor the grade earned suffices for a placement decision. The problem in this study was that too many students perform poorly in PS 110 if they lack sufficient background for an accelerated chemistry course. Therefore, criteria are needed that will result in correct placement decisions.

The Purpose

The purpose of this study was to contribute to solving the problem of students being unsuccessful in freshman chemistry by identifying factors which may be used to predict performance. The plan was to collect existing data on gr des earned in high school, scores earned on aptitude and performance tests, and demographic data obtained on students prior to matriculation. A discriminant function was developed that was intended to assign membership in one of two groups: (l) those who received an "A," "B," or "C" in their first semester of chemistry; (2) those who received a "D," "F," or "W." Only the grade earned in a student's first attempt was used; grades received in subsequent attempts were excluded. It is believed that this is the first time the methods of discriminant analysis have been applied to the problem of predicting performance in freshman chemistry.

Sample Groups

Data were collected on 980 engineering students who had taken freshman chemistry between fall, 1980, and spring, 1989. Most of the students were white males, 18-20 years old, whose home towns were outside Arizona. Females, older students, and ethnic minorities (including foreign students) comprised about 15 to 20% of the population.

Variables

Independent variables measuring aptitude or achievement included the following: high school grades in chemistry, mathematics, physics, and English; high school grade point average (GPA); high school class rank; ACT and SAT scores; and scores on the Nelson-Denny Reading Test. Demographic variables included the following: age, gender, ethnicity, state or country in which student's high school was located, size of city in which high school was located, type of high school (public or private), years since high school graduation, number of extracurricular activities in which student participated in high school, and number of transfer credits from other post-secondary institutions.

Other variables were used as well. The GPA was calculated for high school mathematics courses, and individual grades in high school courses were coded as binary variables. As an example of the latter, the variable, “‘A’ in Chemistry,” was coded with a "1" if an •A• had been earned, and with a “0” if less than "A" had been earned or if chemistry was not taken in high school.

Methodology

All computations were performed on the Honeywell mainframe computer at Northern Arizona University, Flagstaff, Arizona, using the Statistical Package for the Social Sciences (SPSS^{x}: 17). Initially, descriptive statistics were obtained on all variables to check for univariate normality and for outliers. Chi-square tests were run to test the possibility that differences in students• performances might have been due to demographic characteristics rather than to differences in scholastic aptitude or ability. Pearson correlation coefficients (r) were computed for all pairwise combinations of the independent variables among themselves and with the criterion, performance in freshman chemistry. Only those variables whose correlation coefficients with performance were greater than 0.30 were found later to be important in the analyses. One-way analysis of variance (ANOVA) tests were performed for English, mathematics, and composite SAT/ACT test score means for groups of students differentiated by their letter grades in chemistry. Multiple-regression analyses were run on various combinations of predictor variables in an attempt to identify statistically-significant variables and to validate the assumption of multivariate normality.

Discriminant function analysis of data from past classes was used to develop the statistical model which could then to be used as a placement tool for future students. Discriminant analysis is a multivariate statistical procedure in which linear combinations of variables are used to distinguish between two or more mutually elusive categories of cases. The variables "discriminate" between groups of cases and predict into which category or group a case falls based upon the values of these variables (18). In this study, there were two groups--students who had earned a "C" or better and students who had earned less than a "C." To be a valid analysis, there were three underlying assumptions: (1) variables had to represent samples drawn from a multivariate normal population; (2) sample variance/covariance matrices had to be equal; (3) there could not be any cases of multi-collinearity or singularity in the data. SPSS[x] includes tests which showed that the first two assumptions were satisfied. By carefully choosing combinations of variables that themselves were not too highly correlated or linear combinations of each other, the third assumption was satisfied.

It was felt that the best discriminant model would be one which predicted correctly the greatest number of cases and which ended itself most easily to interpretation. Various subsets of variables and of subjects (students) were tried in order to find the optimum combination. The main precaution was to avoid combinations of variables which gave redundant information either by being too highly correlated or by bring linear combinations of one another.

Findings

All variables were found to have univariate normal distributions and, collectively, to be multi-variately normally distributed.

The chi-square tests showed that, with respect to gender, ethnicity, type of high school, state or country, or number of extracurricular activities, the null hypothesis of no relationship was retained, i.e., no relationship existed at the 5% level of significance ($p = 0.05$) which might have threatened the internal validity of the study. With respect to size of city, the null hypothesis ·as rejected at the 5% level. Students from rural high schools appeared to outperform students from suburban or urban schools, although the difference was still too small for size of city to be significant in the discriminant function finally obtained.

The Pearson r correlations between grade in college chemistry and several of the predictor variables were in the range 0.30 or higher. These correlations are shown in Table 1. All other predictor variables that were tried had values of r less than 0.30.

Approximately 260 students had taken both the SAT and the ACT. Most of the remaining students <with the exception of those from foreign countries) had taken one of the two. For students who had taken both tests, correlations between corresponding scores were found to be quite high: $r = 0.623$ on verbal tests, $r = 0.721$ on mathematics tests, and $r = 0.774$ on composite scores. Regression equations were developed that would convert one set of scores to the other, so that a single, •generalized" test score could be used in the statistical analyses. For example, if a student took the SAT, his or her SAT mathematics score was used. If, however, he or she took the ACT, but not the SAT, then the ACT mathematics score was converted to an equivalent SAT score using the following regression formula:

$$\text{SAT Math} = 14.385 * \text{ACT Math} + 200.$$

The ANOVA tests demonstrated that the assumptions of normality and homogeneity of variance were satisfied. For the numbers of degrees of freedom, each F-ratio was found to be significant at the 0.01 level of significance, i.e., the higher the letter grade earned in freshman chemistry, the higher a mean standardized test score would be for the group which earned that grade. As an example, the summary table for means of mathematics scores is given in Table 2. Although the analysis suggests a significant difference in group means, it should be noted that the range of test scores is so large for each letter grade that an SAT mathematics score alone would not be a very reliable predictor of performance.

The multiple regression analyses were run using the stepwise method of entering variables into the equation. The overall high school GPA and the SAT/ACT mathematics test score were found to be the most important predictors of grade in college chemistry. The grade earned in high school chemistry was of lesser importance. No other variables contributed to the regression model. The multiple R was found to equal 0.428. The regression equation that was developed was the following, where all variables are expressed in raw-score form:

$$\text{Grade} = 0.5176 * \text{HS GPA} + 0.004516 * \text{Math Test} + 0.2299 \bullet \text{HS Chem Grade} - 3.165.$$

Using this model the percentage of correct predictions of grade in college chemistry was calculated. The model tends to under predict performance, to the extent that a grade of "A" was never predicted. The number of correct predictions was only about 30 - 35%.

The results of the preceding statistical analyses were used to select appropriate combinations of predictor variables and subgroups of students for the discriminant analysis. A summary of the discriminant function model felt to best represent the data is given in Table 3. The factors that were identified as best predicting performance in chemistry--in order of relative beta weights (standardized coefficients>--were found to be the SAT/ACT mathematics test score, high school GPA, grade in high school chemistry, high school mathematics GPA, and grade in high school English. There were 395 students for whom data were complete on all these variables. The canonical correlation coefficient was 0.471, and 73.7% of the cases were correctly classified.

Classification is accomplished by comparing a student's calculated value of the function "D" to the average of the group centroids <-0.227). If D < -0.227, the student is predicted to earn a D, F or W in chemistry and is placed into the preparatory course. If D > -0.227, the student is predicted to earn an A, B or C and is placed into PS 110.

The records were examined of students ho were not classified correctly. Among students whose performance was lower than had been predicted, it was found that almost all of them had received "D's," with only a few "W's" and almost no "F's." This pattern suggests that they really did have the ability to be successful if they had only worked a little harder. Among students whose performance was higher than had been predicted, almost all the grades were "C's," suggesting that these students managed to put forth the additional effort needed to be successful. Few of these students earned higher than a "C." Those students who did receive a higher grade tended to have been older than traditional freshmen and to have transferred credit from other institutions.

Conclusion

The discriminant function model that has been developed fairly successfully explains the performances of past students in freshman chemistry. The usefulness of the model, however, lies in its ability to assist in placement decisions for future students. As it turned out, this study was very timely. As the study was being concluded, it was decided at the author's institution not to conduct placement testing anymore for incoming engineering students, but to base placement decisions on high school records. Therefore, as of this writing (spring, 1990), the author is in the process of testing the discriminant model by having used it to place approximately 300 incoming students into either engineering or preparatory chemistry. After one to two years of using the discriminant model as a placement tool, it is expected that a follow-up study will be conducted to evaluate the model's effectiveness.

Table 1

Pearson correlation Coefficients
Between Grade in Chemistry
and Predictor Variables

Variable	Coefficient	Number of Students
SAT Math	0.425	436
SAT Composite	0.346	436
ACT English	0.298	271
ACT Math	0.387	272
ACT Soc Sci	0.301	263
ACT Nat Sci	0.414	263
ACT Composite	0.416	264
HS Math GPA	0.406	514
HS Overall GPA	0.428	434
HS Class Rank	0.339	422
HS Chemistry	0.371	481
HS English	0.309	551
HS Advanced Math	0.383	249
HS Calculus	0.427	116
"A" in HS Chem	0.317	726
"C" in HS Chem	-0.303	726
"A" in HS English	0.320	726

Table 2

Summary Table of ANOVA Test of Means of Mathematics Test Scores for Each Letter Grade in Chemistry

Grade	Count	Group Mean	Std. Dev.	Min.	Max.
A	41	641.40	64.77	?10	780
B	154	588.19	70.49	410	760
C	174	581.90	68.70	410	730
D	137	543.33	73.15	280	720
F,W	162	524.42	79.24	320	730
Total	668	565.15	79.24	280	780

Source	D.P.	Sum of Squares	Mean Squares	F Ratio	Prob.
Between Groups	4	702,844	175,711	33.42	<0.01%
Within Groups	663	3,485,615	5,257		
Total	667	4,188,459			

Table 3

Discriminant Function Model to Predict
Performance in Chemistry

Grade	Number of Cases by Group
D,F, or W	120
A,B, or C	275
Total	395

Group Means (on an "A" = 4.0 scale)

Grade	High School GPA	Chemistry Grade	English Grade
D,F, or W	2.90	2.53	2.62
A,B, or C	3.35	3.18	3.16
Total	3.22	2.98	2.99

Grade	Standardized Mathematics Test	High School Mathematics GPA
D,F, or W	540	2.65
A,B, or C	596	3..20
Total	579	3.03

Discriminant Function Coefficients

Variable	Standardized	Unstandardize d
Mathematics Test	0.47506	[illegible]
High School GPA	0.28855	[illegible]
High School Chemistry	0.24663	0.2974724
Mathematics GPA	0.23521	0.3676798
High School English	0.19851	0.2536787
(Constant)		-8.422316

The Discriminant Function in Unstandardized Form:

ѳ = 0.00650 * Math Test + 0.58936 * HS GPA + 0.29747 * HS Chem
+ 0.36768 * Math GPA + 0.25368 * HS English - 8.422316

Multiple R = 0.471

(continued on next page)

Table 3 (continued)

Discriminant Function Evaluated at Group Means (Group Centroids)

Grade	Value
D,F or W	-0.80542
A,B or C	0.35146

Classification Results

Actual Group	No. of Cases	Predicted Group Membership	
		D,F,W	A,B,C
D,F,W	120	69 17.5%	51 12.9%
A,B,C	275	53 13.4%	222 56.2%

Percent of Cases Classified correctly: 73.7%

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