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NAVAL POSTGRADUATE SCHOOL
Monterey, California

FACTORS INFLUENCING MANAGEMENT STUDENT PERFORMANCE IN MATHEMATICS COURSES

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Students admitted to the eighteen month Administrative Sciences Curriculum at the Naval Postgraduate School are automatically enrolled in a series of three mathematics courses: differential calculus, integral calculus, and matrix algebra. Students entering the program have diverse academic backgrounds, some having had extensive training in mathematics and related subjects and others having had very little previous work in mathematics. A student who

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already has the necessary background may attempt to validate the courses through examination, but there is presently no effective transcript review process to facilitate validation. Nor is there any formal process for placing students in mathematics courses on the basis of their ability and previous training.

This study analyzes the factors influencing student performance in these three mathematics courses. Validation guidelines are presented for two of the courses, and a procedure for establishing validation guidelines which could easily be applied to other courses and to other curricula is described. Recommendations for changes in the mathematics program for management students conclude the paper.

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I. INTRODUCTION

Students admitted to the eighteen month Administrative Sciences Curriculum (hereafter shortened to 'management program') at the Naval Postgraduate School are automatically enrolled in a series of three mathematics courses during their first two quarters of study: (1) MA 2305, Differential Calculus, (2) MA 2306, Integral Calculus, and (3) MA 2040, Matrix Algebra. These courses are business-oriented and are designed to give students the fundamental mathematics background necessary for study in economics, statistics, and operations research.

Students entering the management program have diverse academic backgrounds. Many students have studied mathematics and related subjects extensively. Others have little or no background in college-level mathematics.

The student who already has the necessary background may attempt to validate the courses through examination, or he may decide to remain enrolled and complete the course. He must take the initiative. There is presently no effective transcript review process to facilitate validation. Instructors offer students the opportunity to validate during the first week of classes, but there is no formal review of transcripts to determine which students are qualified for validation. As a result, only a small percentage of those students who are capable of validating ever do so.

There are several reasons why a student might desire not to validate:

1. Though officers who have been selected for the management program are sent a list of recommended algebra and calculus books suitable for self-study, due to the demands of their present jobs, delays in obtaining study materials, and lack of a study plan or something to force them to study on a regular basis, most students arrive at the School unprepared for a validation examination. As selectees are not made aware of validation procedures and prerequisites, few are motivated to find the time necessary for careful study.

2. There are few alternative courses available to students that early in the curriculum.

3. Most students are reentering an academic environment after several years of military duty. The School's academic environment inculcates a feeling among students that they must attain as high a grade average as possible during their first two quarters. The student usually feels, therefore, that the mathematics courses will provide a needed review, a high grade, and an opportunity to readjust to an academic routine.

This situation has a detrimental effect upon both the students with and the students without adequate backgrounds in mathematics. The student with an adequate background is losing the opportunity to take other courses. Once in the mathematics courses he becomes the driving force in the classroom, setting the pace of study, and determining the depth at which the material is covered. The student for whom mathematics is new is faced with unfair competition; he is reluctant to slow the class when he does not understand the material; he performs poorly when tested.

II. OBJECTIVES OF THE STUDY

This research was conducted in an attempt to determine which variables influence success in the required mathematics courses. Analyses were performed to relate pertinent explanatory variables to grades in each of the three mathematics courses. It was felt that benefits would follow if significant relationships could be found. Courses could be tailored to students' backgrounds. Criteria for placement could be established. School procedures could be revised to better prepare incoming students and to advise these students concerning possible validation well in advance of their coming on board.

III. DESCRIPTION OF THE VARIABLES

The records of students presently enrolled in the management program were reviewed to obtain the necessary data. The data consisted of information contained in each student's college transcript, each student's Graduate Record Examination mathematics score, and the grades he received in each of the three mathematics courses. Though a larger set of observations would have been preferable from a statistical standpoint, a complete set of data could be compiled for just thirty-seven of the more than one hundred students who have studied in the management program since quarter I, AY 73-74, when the MA 2040-2305-2306 sequence was introduced into the curriculum.

Thirteen pertinent variables were selected initially. Grades from the three courses were the dependent variables. The ten possible explanatory variables were:

1. The number of years (to the nearest quarter) between the student's graduation from college and his matriculation at NPS.

2. The number of course-years[1] (to the nearest quarter) of mathematics courses the student had taken prior to his arrival at NPS.

3. The number of course-years (to the nearest quarter) of mathematics-related courses the student had taken previously. These courses included advanced economics, physics, engineering and other applied science courses.

4. The number of course-years (to the nearest quarter) of mathematics courses involving calculus and higher mathematics the student had taken previously.

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[1] A course-year is equivalent to a two-semester or yearlong course.

5. A dummy variable taking on the value one if the student had taken calculus previously and the value zero if he had not.

6. The student's college grade point average in mathematics and mathematics-related courses (converted to the NPS 4-point scale).

7. The student's Graduate Record Examination (GRE) mathematics score (the ending zero was dropped for the computer analyses, e.g., 650 became 65).

8. The type of collegiate institution from which the student had graduated: (1) Naval Academy, (2) Coast Guard Academy, (3) public university, (4) private university or (5) Naval Postgraduate School (Baccalaureate Curriculum).

9. The student's overall college grade point average.

10. The number of years (to the nearest quarter) prior to entering NPS since the student had last taken a calculus course.

The SNAP/IEDA statistical computing package was used in performing the analyses. One limitation of this package is that it allows for only ten variables. Since the information required to rate the quality of undergraduate education each student had received was not available, variable 8 was dropped. Variable 9 was excluded since variable 6 would provide a more relevant measure of the student's undergraduate performance. Since none of the students in the sample had taken a calculus course between their graduation from college and their arrival at the School, with variable 1 in the model variable 10 became redundant. So variable 10 was dropped, leaving the first seven independent variables listed above as variables 1 through 7 in the three performance models. Variables 8,9, and 10 in the analyses were then the MA 2305, MA 2306, and MA 2040 grades, respectively. Hereafter the variables will be referred to as X_n, where the subscript identifies the variable according to the ordering described above.

IV. THE MODELS

Three performance models were formulated, one for each of the three mathematics courses.

Model 1: MA 2305

$$X_8 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7$$

Model 2: MA 2306

$$X_9 = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_6 X_6 + \alpha_7 X_7$$

Model 3: MA 2040

$$X_{10} = \gamma_0 + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 + \gamma_5 X_5 + \gamma_6 X_6 + \gamma_7 X_7$$

It was expected that each of the variables X_2 through X_7 would be positively correlated with the dependent variable in each model. A larger number of mathematics and mathematics-related courses taken, greater success in these courses as indicated by the student's grade average, and a higher aptitude for mathematics as indicated by the student's GRE score in mathematics, would each be expected to produce a better performance (i.e., a higher grade) in each of the three courses. The coefficient of variable X_1, measuring time elapsed between the student's graduation from college and his matriculation at NPS, was expected to be negative. The greater the elapsed time the more difficult it is to recall concepts previously learned and the more difficult it is to readjust to an academic environment.

It was recognized that some of the explanatory variables would be correlated with one another. Those variables indicating the number of course-years of mathematics courses taken, X_2, the number of course-years of mathematics-related courses taken, X_3 , and the number of course-years of courses taken involving calculus and higher mathematics, X_4 , were expected to be positively correlated. In addition, the dummy variable X_5 would become redundant if either X_2 or X_4 were included in the model. It was decided to let the stepwise regression package sort out the relevant explanatory variables, and it was anticipated that this would result in at least three of the explanatory variables being dropped from each model.

It should be noted that the three models omit a very important factor influencing student performance: the attitude of the student towards the management program in general and towards the mathematics courses in particular. This omission was unavoidable since data were not available. It is, however, an important factor which undoubtedly affected the final results. In some cases a student who had a rather weak background in mathematics and who had achieved average grades in college was able to earn an 'A' in each of the three courses. This was due in large part to nonquantifiable factors such as the student's determination to do well because his performance at NPS would affect his career. Leaving these factors out of the models would tend to diminish their explanatory power.

It should also be noted that only one student in the sample had ever had a course in matrix algebra. Thus a student's previous work in mathematics would be expected to have a smaller effect on his MA 2040 grade than on the grades he received in the other two courses. Time elapsed since graduation and mathematics aptitude would be expected to be relatively more important in model 3 than in either model 1 or model 2.

V. DATA COLLECTION: PROCEDURES USED AND DIFFICULTIES ENCOUNTERED

Data collection involved numerous difficulties. Transcripts differed widely as to (1) course title and designation, (2) course description,

(3) length of academic term, and (4) grading scale. Course content also varied. Some interpretation was required to translate the information to a common base for analysis.

Establishing values for variables X_2, X_3, X_4 and X_5 required some assumptions concerning course content. Since time constraints precluded a careful evaluation of each college's mathematics courses, a rough comparison was made on the basis of course titles. It was assumed that two semesters were equivalent to three quarters, which were in turn equivalent to one academic year. It was felt that the above assumptions would have only a very small effect on the study's findings.

A second major difficulty encountered was the lack of complete information on all students. For some students there was no GRE score. Some had not received grades for MA 2306 as of the time of the study. Transcripts were unavailable for other students. Students for whom complete information was not available were excluded from the analyses. This meant that all Coast Guard students were excluded from the analyses since they lacked GRE scores. While seventy-eight sets of records were reviewed initially, complete data were available for just thirty-seven students. As long as the thirty-seven students in the sample were representative of the entire group, these data limitations would not seriously affect the overall results. However, the exclusion of a large group of students, for example the Coast Guard students, could have biased the results. It was felt that the amount of bias, if any, was small.

VI. DATA ANALYSIS

The statistical properties of the ten variables used in the models are listed in the table on page 10. These properties provide an informative abstract of the background and characteristics of the thirty-seven management students in the sample. When he entered the program the average management student had been out of college 8¼ years, though some students had been out as little as 2½ years. Some had been out of college as much as 15 years prior to entering NPS.

The students' mathematics backgrounds also varied. The average student had taken $2\frac{1}{3}$ course-years of mathematics courses as an undergraduate. As many as five course-years of mathematics and as little as one-half course-year of mathematics were found. The average student had taken 4½ course-years of mathematics-related courses, but the range extended from zero to 14½ course-years.

Over eighty per cent of the students had taken calculus previously, but undergraduate mathematics grades were about average (clustered in the C+, B- range). Graduate record mathematics examination scores averaged between 620 and 630 and ranged from 450 to 770.

Grades in the NPS mathematics courses were high and clustered. The average grade was in the B+ to A- range for all three courses and the three standard deviations were small. This lack of variation made it difficult to separate out the effects of the different factors influencing student performance in the three mathematics courses.

VII. REGRESSION RESULTS

The associations between the variables were examined through correlation analysis. As anticipated X_2, X_3 and X_4 were found to be highly correlated with one another. Moreover, they were found to be highly correlated with X_5 . As X_5 had a higher partial correlation coefficient with each of the dependent variables than did X_2, X_3 or X_4 , it was decided to adjust for multicollinearity by excluding X_2, X_3 and X_4 from the regression. After this adjustment no significant multicollinearity remained in any of the models.

TABLE
STATISTICAL PROPERTIES
OF THE TEN VARIABLES
37 OBSERVATIONS

VARIABLE 1
(Years Since Graduation):

MEAN	8.216
STANDARD DEVIATION	3.605
MEDIAN	7.500
MINIMUM VALUE	2.500
MAXIMUM VALUE	15.000
RANGE	12.500

VARIABLE 2
(Course-Years of Mathematics Courses):

MEAN	2.343
STANDARD DEVIATION	0.997
MEDIAN	2.300
MINIMUM VALUE	0.500
MAXIMUM VALUE	5.000
RANGE	4.500

VARIABLE 3
(Course-Years of Math-Related Courses):

MEAN	4.457
STANDARD DEVIATION	3.782
MEDIAN	4.000
MINIMUM VALUE	0.000
MAXIMUM VALUE	14.500
RANGE	14.500

VARIABLE 4
(Course-Years of Calculus
And Higher Math Courses):

MEAN	1.584
STANDARD DEVIATION	1.096
MEDIAN	1.500
MINIMUM VALUE	0.000
MAXIMUM VALUE	5.000
RANGE	5.000

VARIABLE 5
(Calculus - Yes(1), No(0)):

MEAN	0.838
STANDARD DEVIATION	0.374
MEDIAN	1.000
MINIMUM VALUE	0.000
MAXIMUM VALUE	1.000
RANGE	1.000

VARIABLE 6
(College Math and Math-Related GPA):

MEAN	2.533
STANDARD DEVIATION	0.733
MEDIAN	2.410
MINIMUM VALUE	1.210
MAXIMUM VALUE	4.000
RANGE	2.790

VARIABLE 7
(GRE Math Score):

MEAN	62.514
STANDARD DEVIATION	7.629
MEDIAN	63.000
MINIMUM VALUE	45.000
MAXIMUM VALUE	77.000
RANGE	32.000

VARIABLE 8
(MA 2305 Grades):

MEAN	3.451
STANDARD DEVIATION	0.664
MEDIAN	3.700
MINIMUM VALUE	1.700
MAXIMUM VALUE	4.000
RANGE	2.300

VARIABLE 9
(MA 2306 Grades):

MEAN	3.549
STANDARD DEVIATION	0.532
MEDIAN	3.700
MINIMUM VALUE	2.300
MAXIMUM VALUE	4.000
RANGE	1.700

VARIABLE 10
(MA 2040 Grades):

MEAN	3.492
STANDARD DEVIATION	0.638
MEDIAN	3.700
MINIMUM VALUE	1.700
MAXIMUM VALUE	4.000
RANGE	2.300

Also as expected, all the variables except X_1 were positively correlated with each of the dependent variables. Of the four explanatory variables employed, X_5 was the most highly correlated with X_8, while X_7 was the most highly correlated with X_9, and X_1 was the most highly correlated with X_{10}. Of the three dependent variables X_{10} showed the least correlation with the explanatory variables.

Stepwise regression was performed employing variables X_1, X_5, X_6 and X_7 as explanatory variables in each of the models. Several different forms for each model, including logarithmic and semilogarithmic forms, were tested. It was found that the linear model yielded the best results in each case.

A decision rule was chosen that set the significance level at .05. For each of the three models one-sided tests of significance were carried out on the regression coefficients. An observed t statistic was computed and compared against the .05 critical value. To test the significance of each model an observed F value was computed for each model and compared against $F_{.05}$.

First, variable X_8 was regressed on variables X_1, X_5, X_6 and X_7. Stepwise regression indicated that only X_1 and X_5 should be included in the model, resulting in the following form for model 1:

<u>Model 1</u>

<u>Student Performance in MA 2305</u>

$\bar{R}^2 = .401$

$F_{obs} = 13.05$

$$X_8 = 3.332 - \underset{[3.166]}{.076X_1} + \underset{[3.745]}{.884X_5}$$

The observed t value (with 34 degrees of freedom) for each regression coefficient appears in brackets beneath the coefficient. Each regression coefficient is highly significant at the .05 level and remains significant even at the .005 level. The observed F value is highly significant at the .01 level. The adjusted coefficient of multiple correlation $\overline{R}^2$ for this regression equation indicates that variation in variables X_1 and X_5 explains 40.1 per cent of the variation in variable X_8 . According to the model a student's MA 2305 grade will be on average .076 grade points lower for each additional year since the student's graduation from college. It further indicates that there is almost a full grade point (.884) difference between the grades earned by students who have had calculus previously and the grades earned by those who have not.

Model 1 suggests some guidelines for deciding which students should be encouraged to take the MA 2305 validation exam. According to the model a student who had previously taken a course in calculus and who had entered NPS within seven years of his graduation from college would be expected to earn a grade not lower than 'A-' in MA 2305. The more recent the officer's graduation from college, the higher would be his expected MA 2305 grade. Especially in view of the effect of previous calculus study - or lack of it - on the performance of students in MA 2305, recent college graduates whose transcripts list one or more courses in calculus should be urged to take the MA 2305 validation exam. The only exception would be a student who had received very low grades in calculus. A transcript analysis worksheet for computing an incoming student's expected MA 2305 grade is contained in the appendix.

Second, variable X_9 was regressed on variables X_1, X_5, X_6 and X_7 . Stepwise regression led to the following form for model 2:

<u>Model 2</u>

<u>Student Performance in MA 2306</u>

$\overline{R}^2 = .540$ $\qquad$ $X_9 = .698 + .554X_5 + .038X_7$

$F_{obs} = 22.13$ $\qquad$ [3.278] $\quad$ [4.750]

The observed t value (with 34 degrees of freedom) for each regression coefficient appears in brackets beneath the coefficient. Each regression coefficient is highly significant at the .05 level and remains significant even at the .005 level. The observed F value is highly significant at the .01 level. The adjusted coefficient of multiple correlation $\bar{R}^2$ equals .540, indicating that variation in variables X_5 and X_7 explains 54.0 per cent of the variation in variable X_9 .

As in MA 2305 whether or not the student has had calculus previously is an important factor in determining how well he will do in MA 2306, contributing on average .554 points to his grade. A one hundred point difference in the student's GRE score would mean on average a .38 grade point difference (roughly the difference between a B+ and an A-). It appears that for MA 2306 mathematics aptitude as measured by the GRE in mathematics is the most important factor influencing student performance in that course. GRE scores alone explained 39.4 per cent of the variation in MA 2306 grades.

Model 2 suggests some guidelines for deciding which students should be encouraged to take the MA 2306 validation exam. A student who has previously studied integral calculus and who has achieved a score of 72 or higher on the GRE mathematics examination should be encouraged to take the MA 2306 validation exam. At the present time students entering NPS are not required to take the GRE in mathematics. It is recommended that incoming students be required to take the GRE, and that these scores be used for placement purposes. A transcript analysis worksheet similar to the one suggested for MA 2305 and based on model 2 is contained in the appendix.

Finally, variable X_{10} was regressed on variables X_1, X_5, X_6 and X_7 . Stepwise regression produced the following form for model 3:

Model 3

Student Performance in MA 2040

$\bar{R}^2 = .221$

$F_{obs} = 6.11$

$$X_{10} = 2.578 - \underset{[2.259]}{.061X_1} + \underset{[1.769]}{.023X_7}$$

The observed t value (with 34 degrees of freedom) for each regression coefficient appears in brackets beneath the coefficient. Each regression coefficient is significant at the .05 level. The observed F value is barely significant at the .01 level. The adjusted coefficient of multiple correlation $\bar{R}^2$ equals .221, indicating that variation in the variables X_1 and X_7 explains 22.1 per cent of the variation in variable X_{10}. Thus the explanatory power of model 3 is weaker than the explanatory power of models 1 and 2.

Unlike models 1 and 2, whether the student had previously taken a course in calculus was not an important factor in model 3. Since only one student in the sample had previously taken a course in matrix algebra and since calculus and matrix algebra require different skills, this result is not surprising. As would be expected, time away from school, X_1, and general mathematics aptitude, X_7, provide a better indication of how well a student will do in MA 2040. In MA 2040 students were able to compete on a more equal basis, with mathematics aptitude and time elapsed since graduation from college affecting student performance to a greater extent in MA 2040 than in either MA 2305 or MA 2306.

Since only one student in the sample had previously taken a matrix algebra course there does not appear to be a need for a matrix algebra validation model at the present time. Moreover, as neither of the variables in model 3 directly represents previous training in mathematics, model 3 would not be useful in deriving a set of validation guidelines for MA 2040 should the need arise in the future. Within the last few years many colleges have begun to offer courses in matrix algebra designed for students not majoring in mathematics. Should the number of students entering the management program with previous training in matrix algebra increase in the future, then the procedures discussed in this study should be used to reformulate model 3 and to develop validation guidelines for MA 2040.

VIII. OVERVIEW OF THE RESULTS

Of the factors considered in this study the three which were most important in affecting a student's performance in the three required mathematics course were: (1) the number of years since the student's graduation from college, (2) whether or not he had taken a calculus course previously, and (3) the student's mathematics aptitude as measured by his Graduate Record Examination score.

While models 1 and 2 are helpful in predicting how well a student will do in MA 2305 and MA 2306 and in deriving guidelines for validation purposes, there are factors other than those which could be considered here that contribute to the grades a student receives. Different instructors use different grading criteria. The use of quantitative skills in duty assignments varies greatly. Motivational factors also exert an influence. None of these factors could be incorporated in the models due to a lack of data. While the omission of these and other factors undoubtedly affected the statistical results, it was felt that this effect was small enough so as not to affect materially the study's conclusions.

The omitted factors together with the clustering in the grade distributions, which was discussed in Section VI, are at least partially responsible for the relatively low $\bar{R}^2$ values for the three models. The variation in $\bar{R}^2$ values from .221 for model 3 to .540 for model 2 reflects the importance of prior course work in mathematics in determining how successful management students will be in their mathematics courses. In both MA 2305 and MA 2306 those students who had previously studied calculus held a tremendous advantage over their classmates who had not. This factor accounted for a large portion of the variation in final grades, and both model 1 and model 2 had $\bar{R}^2$ values significantly higher than the $\bar{R}^2$ value for model 3, in which previous training in mathematics was not a significant factor.

IX. CONCLUSIONS AND RECOMMENDATIONS

The regression results suggest the need for a change in the method of assigning management students to mathematics courses, as well as other changes which would enable and indeed, encourage, the student to make better use of his time on board:

1. Those students capable of validating one or more mathematics courses should be identified prior to their arrival at NPS. Criteria should include: (1) whether the student has had calculus previously, (2) the number of years since the student's graduation from college, and (3) the student's Graduate Record Examination mathematics score.

2. Every prospective management student should be required to take the Graduate Record Examination in mathematics.

3. Course objectives should be sent to incoming students along with recommended study materials. The incoming student should be informed as to the possibility of validating mathematics courses, and he should be given guidelines so that he can determine whether he could qualify for validation after a reasonable amount of individual study.

4. Students in MA 2305 and MA 2306 should be segregated according to whether or not they have taken calculus previously.

5. More individual attention should be paid to each student and to his academic background. Each student should be advised and placed in courses commensurate with his background and ability.

6. A more individualized and more flexible instructional approach, like the PSI method of instruction, might prove highly beneficial due to the variety of backgrounds and abilities of management students.

7. More background information should be obtained on each student. The content of mathematics courses previously taken, job history, and personal objectives should be made known to each student's academic advisor. A sample worksheet to aid the advisor in transcript analysis is presented in the appendix.

8. Greater effort should be devoted to making students aware of the opportunity to validate, to encouraging the student to validate, and to developing alternate courses so that he will be motivated to validate.

9. Since mathematics courses are preparatory courses for later work, a pass/fail grading system should be considered. Changing to a pass/fail system would ease competitive pressures in the classroom and would encourage more able students to validate.

10. Further study of the factors relevant to academic success, and in particular those factors affecting student performance in MA 2040, MA 2305 and MA 2306, is strongly recommended. This would lead to further improvements in both curriculum and course design.

X. APPENDIX

TRANSCRIPT ANALYSIS WORKSHEET

MA 2305

(Calculus: yes = 1, no = 0	______	X .884	=	______
(Years since graduation)	______	X(-.076)	=	______
				3.332
Expected MA 2305 grade				______

Predicted grade of 3.7 or higher (previous calculus course plus not more than seven years since graduation) indicates that the student should be encouraged to take the MA 2305 validation exam.

MA 2306

(Integral Calculus: yes = 1, no = 0)	______	X .554	=	______
(GRE score in mathematics*)	______	X .038	=	______
				.698
Expected MA 2306 grade				______

*Raw score divided by ten.

Predicted grade of 3.7 or higher (previous integral calculus course plus a GRE score of 72 or higher) indicates that the student should be encouraged to take the MA 2306 validation exam.

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