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AN ANALYSIS OF CRITICAL THINKING IN A

COLLEGE GENERAL ZOOLOGY CLASS

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CHAPTER I

INTRODUCTION

In recent years increased attention has been directed toward the product of our schools, and there is evidence of increased concern regarding the development of critical thinking abilities of students. With regard to college students, Dressel and Mayhew state that:

> As a starting point in consideration of critical thinking, it perhaps can be accepted that students, as one result of their education experience, should be able to carry on types of mental activity more complicated than simple recall and restatement of ideas, facts, principles, etc., given in the textbook or presented by the instructor in his lectures. . . .
>
> A major aim of general education is for the student to acquire and use the skills and habits involved in critical and constructive thinking.[1]

Similarly, Osborn states: ". . . it is assumed that development of thought power is one of the major aims of all education."[2]

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[1] Paul L. Dressel and Lewis B. Mayhew, _General Education: Explorations in Evaluation_ (Washington: American Council on Education, 1954), p. 153.

[2] Worth J. Osborn, "Testing Thinking," _Journal of Educational Research_, XXVII (February, 1934), p. 402.

Wood and Beers insisted that, "It is impossible to teach pupils to think, and therefore, development of the ability to do critical thinking is not a legitimate objective of the schools."[1] However, Edwards pointed out that "development of the ability to do critical thinking is generally regarded as one of the most important aims of education at all levels and in all areas."[2]

It appears that little is known of the extent to which critical thinking abilities are developed in educational institutions; therefore, an analysis of the relationships among aptitudes, achievement, and critical thinking is highly appropriate.

Background of the Problem

Members of the faculty of the Department of Zoology at The University of Oklahoma are concerned with the development of critical thinking abilities and attitudes on the part of students enrolled in that department. For the staff in the introductory zoology course, critical thinking and an appropriate scientific attitude, as well as the learning of an extensive quantity of factual information, are particularly pressing goals. The course has been designed to promote

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[1]Benjamin D. Wood and F. S. Beers, "Knowledge versus Thinking," Teachers College Record, XXXVII (March, 1939), pp. 487-99.

[2]T. Bentley Edwards, "Measurement of Some Aspects of Critical Thinking," Journal of Experimental Education, XVIII (September, 1949 - June, 1950), p. 263.

the attainment of these goals by the students.[1]

Examinations used in the introductory zoology course (hereinafter referred to as Zoology I) are devised by the teaching staff and are departmental in nature. They are designed to test critical thinking, scientific attitude and the mastery of facts. Some members of the Zoology I teaching staff desire more information on how well these departmental examinations measure critical thinking in comparison with the measurement of this factor by standardized tests of critical thinking (to be described later).

Permission was granted the writer by members of the Zoology I teaching staff to ask their students to participate in this study. Those students who volunteered to take the critical thinking tests and who were qualified within the limits of this study were used. When the fall semester of the 1958-1959 academic year ended, the Zoology I instructors made available the total accumulated raw scores of the students who took the tests.

Operational Definitions

For the purposes of this experiment the following terms are operationally defined:

Critical Thinking. Critical thinking is the process

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[1]Paul R. David and Harley P. Brown, "Objectives and Content of an Introductory Course in Zoology," Proceedings of the Oklahoma Academy of Science, XXXVI (1955), pp. 129-33.

of examining both concrete and verbal materials in the light of related objective evidence, comparing the object or statement with some norm or standard, and concluding or acting upon the judgment then made. In the process the person involved will withhold or suspend judgment until adequate facts have been accumulated; he will examine all available data and apply methods of logical inquiry or scientific analysis.[1] Action will be taken in the light of this analysis or reasoning.[2]

Variable. A variable is a quantity which may assume different values. In this experiment the dependent variable, the quantity which is to be held constant, is the total accumulated raw-scores of the students who qualify within the limits of this experiment on the Zoology I examinations. The independent variables, those which may be manipulated in relation to the dependent variable, are the total raw scores of the same students on five tests, which are: (1) *Watson-Glaser Critical Thinking Appraisal, Form AM*,[3] (2) *Test of*

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[1]David H. Russell, *Children's Thinking* (Boston: Ginn and Company, 1956), p. 285.

[2]David H. Russell, "Reading for Critical Thinking," *California Journal of Elementary Education*, XIV (1945), p. 83.

[3]Goodwin Watson and Edward M. Glaser, *Watson-Glaser Critical Thinking Appraisal, Form AM* (Yonkers, N. Y.: World Book Company, 1952).

Critical Thinking, Form G,[1] (3) The University of Oklahoma Mathematics Placement Test, Form 3,[2] (4) The Iowa High School Content Examination, Form L,[3] and (5) The Ohio State University Psychological Test, Form 23.[4]

Success in Zoology I. Success in Zoology I refers to the degree to which a student accomplishes the required tasks in that course of study in relation to the accomplishment of other members of the class-group.

Need for the Study

The assumption is made by many persons associated with most of the areas of science that students who study in the fields of science develop a more critical attitude of thinking than they possessed before beginning that particular study. Raths, in this connection, stated: "Mathematics teachers have been contending for many years than an important objective of their teaching is the development in their

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[1]The American Council on Education, Test of Critical Thinking, Form G (Washington: American Council on Education, 1954).

[2]Department of Mathematics, University of Oklahoma, The University of Oklahoma Mathematics Placement Test, Form 3 (Norman: The University of Oklahoma Press, 1950).

[3]D. B. Stuit, H. A. Greene, and Giles M. Ruch, Iowa High School Content Examination, Form L (Iowa City: Bureau of Educational Research and Service, State University of Iowa, 1943).

[4]Herbert A. Toops, The Ohio State University Psychological Test, Form 23 (Chicago: Science Research Associates, 1947).

students of what is loosely called 'thinking'."[1]

It appears that critical thinking should be a major objective of all teaching, and Russell suggested that "observation and some indirect evidence suggest that most children do not learn to think critically by themselves; they need help in becoming critical thinkers."[2] The ability to think critically is an important one for all people, especially in a democracy, and would seem to be one of the first requirements of a conscientious and full-fledged citizen. Modern techniques of propaganda and high-pressure salesmanship in a setting of increased leisure time should give all persons cause for understanding the principles of critical thinking and its practice.

Critical thinking has been mentioned by many authors in several connections, but very few published reports of experiments relating to this type of thinking exist. It is probable that many teachers at both secondary and collegiate levels encourage and promote critical thinking, but the extent of success is unknown. In general, it seems that precise work in the field of critical thinking has been neglected.

There is a special need for this experiment in that the Zoology I teaching staff of the University of Oklahoma

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[1] Louis E. Raths, "Techniques for Test Construction," <u>Educational Research Bulletin</u>, XVII (April, 1938), p. 108.

[2] Russell, <u>Children's Thinking</u>, p. 287.

will utilize the results in an evaluation of that course of study. It will be of general interest and use to all who are concerned with the development and promotion of critical thinking.

Specifically, the Zoology I teaching staff wishes to know: (1) How well do scores on the departmental examinations regularly administered to the Zoology I students correlate with the scores of students on standardized tests of critical thinking? (2) Will scores on tests of critical thinking function as predictors of success in Zoology I? (3) Which of several sets of available scores on standardized tests may be most effectively used as predictors of success in Zoology I?

Statement of the Problem

The purpose of this study is to discover the relationships which exist between students' success in Zoology I and the students' ability to think critically. Further, it is designed to indicate which of several sets of raw-score data, regularly available to the teaching staff, may be most effectively used as predictors of success in Zoology I at the University of Oklahoma. Specifically, this experiment is designed to test the following null hypotheses: (1) There is no significant correlation between the total raw-scores of subjects on the departmental Zoology I examinations and their total raw-scores on tests of critical thinking; (2) Scores of subjects on tests of critical thinking will not be of value as predictors of success in Zoology I; (3) Scores of subjects on three other standardized tests will not be of value as predictors of success in Zoology I.

Limitations of the Study

The subjects involved in this experiment volunteered to participate. Participation was restricted as follows: (1) The subjects' ages were seventeen and eighteen years; (2) The subjects were enrolled in Zoology I at the University of Oklahoma; (3) The fall semester of the 1958-1959 academic year was their first regular university enrollment; (4) Subjects of both sexes and any race were invited to participate. The subjects were assured of absolute confidence, and no coercion of any kind was implied nor applied to cause them to volunteer.

Major Assumptions

The following assumptions were made: (1) The tests, to be described later, measured the factors which they are purported to measure; (2) Since the Zoology I sections follow a departmental schedule and outline and the Zoology I students take departmental examinations, all the students have an equal opportunity to develop critical thinking abilities and to score accordingly on the Zoology I examinations. It is further assumed that these critical thinking abilities will be equally well encouraged by the several instructors, each of whom is a specialist in some area of zoology.

Zoology I

> Zoology One at the University of Oklahoma is the only introductory course in zoology offered. It is a one-semester course conducted on the practicum-discussion plan, in which from three to five hundred students per semester have been enrolled. The class is divided into sections each of which (in full charge of a single instructor) contains twenty-four to thirty students and meets for one fifty-minute period five times a week . . . The course is required of departmental majors and pre-medical students, and may be taken by non-majors to satisfy their requirements in biological science.[1]

Five semester-hours credit accrue to students who satisfactorily complete the course. Classical laboratory work is held to a minimum, although dissection, use of the microscope and observation of living specimens and other experiences are liberally provided.

The grading system is based upon the normal distribution curve of point-totals accumulated by students of all sections. The points are derived from four one-hour examinations, the final examination, and classwork scores; the latter being based largely upon daily quizzes. The examinations are completely objective in form and include many "thought questions." They are prepared by committees of three, each staff member being on at least one examination committee. A set of approximately 1300 study questions is available to the students.

A major requirement of the students is that they

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[1]David and Brown, op. cit., pp. 129-30.

learn the habits of scientific reasoning. According to David and Brown,

> The students must learn that the value of accurate observation and of critical thinking is not restricted to the scientist in the laboratory; that objectivity and logical rigor are indispensable aids in every area of human activity. We do not undertake to teach habits of critical thinking by presenting rules of logic or formalized schemes of scientific procedure; but we do try in every phase of the course to impress on the student that the validity of any statement rests wholly on the strength of the evidence which supports it. On every possible occasion we try to raise, in one form or another, such questions as, 'What is the evidence?' 'Is the conclusion reached consistent with the evidence?' 'Are there alternative conclusions which would also be consistent with the evidence?' 'If so, what kind of observations or experiments would be needed to decide among the alternatives?'[1]

Other major objectives of the course are: (1) to stress the interrelations of biology with other sciences; and (2) to integrate all the phases or subdivisions of zoology within a general field.

Review of Selected Related Literature

Critical thinking apparently is elusive of definition, and accordingly authors differ in the application of the term. Russell presented as nearly a complete discussion of critical thinking as is known to exist. He listed it as one of the activities essential to problem-solving and as a phase of creative thinking.[2] Russell suggested that critical thinking ordinarily involves four conditions: (1) a knowledge

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[1]*Ibid*., p. 130.

[2]Russell, *Children's Thinking*, p. 282.

of the field or fields in which the thinking is being done, (2) a general attitude of questioning and suspending judgment; a habit of examining before accepting, (3) some application of methods of logical analysis or scientific inquiry, and (4) taking action in light of this analysis or reasoning.[1]

Anderson, Marcham, and Dunn have listed such items as selecting and organizing relevant facts, making inferences, distinguishing between fact and opinion, and recognizing insufficient evidence as parts of critical thinking.[2]

Glaser listed the attributes of a person who thinks critically:

> (1) . . . an attitude of being disposed to consider in a thoughtful way the problems and subjects that come within the range of one's experience, (2) the knowledge of the methods of logical inquiry and reasoning, (3) some skill in applying these methods.[3]

Fawcett listed seven steps for persons doing critical thinking about printed materials. They are:

> (1) He will select the significant words and phrases in any statement that is important to him and ask that they be carefully defined. (2) He will require evidence in support of any conclusion he is pressed to accept. (3) He will analyze that evidence and distinguish fact from assumption. (4) He will recognize stated and unstated assumptions essential to the conclusion. (5) He

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[1]Russell, "Reading for Critical Thinking," p. 82.

[2]H. R. Anderson, F. G. Marcham, and S. B. Dunn, "An Experiment in Teaching Certain Skills of Critical Thinking," Journal of Experimental Education, XXXVIII (1944), pp. 241-51.

[3]Edward M. Glaser, "An Experiment in the Development of Critical Thinking," Contribution to Education No. 843 (New York: Columbia University Press, 1941).

> will evaluate these assumptions, accepting some and rejecting others. (6) He will evaluate the argument, accepting or rejecting the conclusion. (7) He will constantly re-examine the assumptions which are behind his beliefs and which guide his actions.[1]

McBurney and Hance listed two causes, personal and social, of uncritical thinking. As factors relating to the personal cause it is suggested they may be unintentional or intentional, with inability to observe, lack of memory, inability to organize or form hypotheses, gullibility, stereotyped behavior, and excessive emotion as examples of unintentional causes. As intentional causes they listed the desire to bolster self-esteem, to imitate and to convert, along with the influence of prejudice and the tendency to rationalize. They listed under the second or social cause of uncritical thinking group pressures such as traditions, creeds, dogmas and parties.[2]

Development of tests of critical thinking has apparently been the objective in most of the experimental work done in this area to date. A number of such tests exist, some devised for elementary school-age children, some for secondary schools and others for college-level use. Edwards developed four tests of critical thinking from seven preliminary tests for grades ten, eleven, and twelve. The tests,

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[1]Harold P. Fawcett, "The Nature of Proof," Thirteenth Yearbook, National Council of Teachers of Mathematics (1938), pp. 11-12.

[2]H. H. McBurney and K. G. Hance, Principles and Methods of Discussion (New York: Harper and Brothers, 1939).

standardized on 2,000 students in these grades, were on judging opinions, matching facts and principles, detecting good and bad arguments, and judging the worth of conclusions based on facts. In reporting on Forms A and C Edwards indicated a split-half coefficient of reliability of .80 and .32 respectively. He found that validity coefficients of correlation with the Otis Quick-scoring Test of Mental-Abilities ranged from .00 to .17 and .06 to .15 for Forms A and C.[1]

The "absurdities" tests, parts of the Revised Stanford-Binet Tests of Intelligence,[2] are considered to be tests of critical thinking. Form L of this test includes picture absurdities at the seventh-, tenth-, and fourteenth-year levels, and verbal absurdities at the eighth-, ninth-, eleventh-, and twelfth-year levels.

Although critical thinking is not defined nor discussed in exactly the same way by any two authors, it can probably be defined to the satisfaction of most persons by incorporating those points which appear to be most applicable. A concise definition of the term is essential to continued research in this area. Most of the research in the area of critical thinking done to date has been directed toward the development of tests of critical thinking, and research on other facets is needed.

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[1]Edwards, op. cit., p. 266.

[2]Lewis M. Terman and Maud A. Merrill, Intelligence (Boston: Houghton-Mifflin Company, 1937).

CHAPTER II

EXPERIMENTAL DESIGN AND PROCEDURE

Design of the Experiment

This experiment is designed to analyze the relationships of critical thinking with success in Zoology I at the University of Oklahoma. Total raw-scores of the subjects on two tests of critical thinking and three other standardized tests (to be described later) constitute five independent variables. The dependent variable is the total accumulated raw-scores of the experimental subjects in Zoology I.

Simple or zero-order coefficients of correlation between pairs of total raw-score data relating to the six variables involved are computed. These coefficients of correlation indicate the extent of relationship among the variables. Coefficients of correlation for the two tests of critical thinking with the independent variable are the primary objectives, but the other coefficients are included for purposes of comparison.

Partial or net coefficients of correlation of the first order are computed for all combinations of the six variables. The correlation coefficients resulting from this procedure indicate the relationship between two variables when that relationship is relieved of the influence of another variable. Partial coefficients of correlation of the second order are also computed, but they involve only the relationship between the dependent variable and one of the independent variables when that relationship is relieved of the influence of two of the independent variables in turn.

A coefficient of multiple correlation, with the five independent variables simultaneously correlated with the dependent variable, is computed. This coefficient represents the highest correlation coefficient obtainable between the combination of independent variables on the one hand and the dependent variable on the other.

In all instances regression equations are presented. From these one may predict, for a prospective Zoology I student of some future semester, the probable total accumulated raw-score in Zoology I if that prospective student is from the same population as are the subjects of this experiment. The prospective student's total raw-score or raw-scores on the tests from which the independent-variable data are derived may be substituted in the regression equations, thus providing an estimate of the student's success in Zoology I.

Subjects

The subjects of this experiment were 93 freshmen regularly enrolled in Zoology I in their first regular semester at the University of Oklahoma during the fall semester of the 1958-1959 academic year. There were 37 male and 56 female subjects, all of whom participated on a strictly voluntary basis. The subjects, 92 white and one Negro, were 17 and 18 years of age.

At least one subject represented each of the twelve class-sections of Zoology I which were available to students for that semester. The 93 subjects listed a wide variety of prospective major fields, although they were all enrolled in the University College.[1]

Sources of Data

In the course of a semester each Zoology I student may accumulate a maximum of six hundred score-points. These points may be obtained from four one-hour examinations and the final examination, prepared by a committee of three Zoology I instructors, and a series of class-work scores. The examinations are designed to test for factual information, critical thinking, scientific attitude and understanding of biological principles. The distribution, range, and percentages which apply to the entire class (all sections combined) for the fall semester, 1958-1959, are presented in Appendix A. The subjects' total raw-scores, accumulated during the semester, comprise the dependent variable, or

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[1]<u>Bulletin of the University of Oklahoma</u> (Norman: The University of Oklahoma Press, 1958), p. 10.

criterion, in this experiment.

There were two tests of critical thinking administered to the subjects on or immediately after December 3, 1958. This data was selected on the basis that the subjects should have had adequate instruction in Zoology I so that a legitimate portion of their critical thinking abilities which might be derived from the course would have been developed, and that it preceded the possible disturbing influence of the end-of-year holiday season and semester-end turmoil. The tests of critical thinking used were the Watson-Glaser Critical Thinking Appraisal, Form AM,[1] and the Test of Critical Thinking, Form G.[2] These tests will hereinafter be called "WG-CTA" and "ACE-CT," respectively.

The WG-CTA is composed of five sub-tests with a total of ninety-nine items. The sub-tests--Inference, Recognition of Assumptions, Deduction, Interpretation, and Evaluation of Arguments--are directed toward the testing of critical thinking which a citizen is expected to do generally. Form AM of the test is reported to have a mean reliability coefficient of .85, based upon the split-half method with 400 adults, 100 college and 135 high school students as samples. No validity coefficients were reported.[3]

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[1]Watson and Glaser, op cit.

[2]The American Council on Education, op. cit.

[3]Goodwin Watson and Edward M. Glaser, "Manual," Watson-Glaser Critical Thinking Appraisal, Form AM (Yonkers, N. Y.: World Book Company, 1952).

The ACE-CT consists of fifty-two objective-type questions. There are five sub-tests: Ability to Define Problems, Ability to Select Pertinent Information, Ability to Recognize Unstated Assumptions, Ability to Invent and Evaluate Hypotheses, and Ability to Make Valid Inferences and to Judge the Validity of Inferences, with the questions of the first, second, and fifth sub-tests intermixed. A coefficient of reliability, using the split-halves technique with a sample of ninety-seven college freshmen subjects, was reported to be .84. Coefficients of validity for this test were reported to be from .65 to .85, with an approximate mean of .73, based on sub-test intercorrelations of data from several colleges.[1]

Other data were obtained from records in the office of the University Testing Service, University of Oklahoma. These data were derived from a series of tests administered to freshman students either during the freshman orientation period at the beginning of the fall semester or in the summer pre-enrollment program, June to August, 1958. The three tests provided raw-score data which were utilized throughout this experiment and are described below.

The University of Oklahoma Mathematics Placement Test, Form 3,[2] is reputed to provide data concerning the

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[1]Dressel and Mayhew, op. cit., pp. 190-92.

[2]Department of Mathematics, op. cit.

student's understandings and skills related to basic mathematical principles. The test, composed of forty problems, provided a total raw-score which is equal to the number of correct responses made by each student. There are no coefficients of reliability nor of validity available, although the mean raw-score for the university is 12. This test shall be called "OU Math" in this experiment.

The Iowa High School Content Examination, Form L,[1] hereinafter called IHSC, has as its major purpose the prediction of success in college. There are four sub-tests relating to English Grammar and Literature, Mathematics, Science, and History and Social Studies, with a total of 235 items. A reliability coefficient of .91 (N = 300) and a coefficient of validity of .50 to .60, correlated with academic grades of twelfth- and thirteenth-year students have been reported.[2]

The Ohio State University Psychological Test, Form 23,[3] is intended for use in evaluating that aspect of general intelligence known as scholastic aptitude. The test is in three parts, Same-Opposite, Word Relationships, and Reading Comprehension. In this experiment this test will be called

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[1]Stuit, Greene, and Ruch, op. cit.

[2]Maurice E. Troyer, "Review of Iowa High School Content Examination," The Third Mental Measurements Yearbook, ed. Oscar K. Buros (New Brunswick: Rutgers University Press, 1949), p. 10.

[3]Toops, op. cit.

OSPE.

Although sub-test scores of these examinations were recorded, along with the total raw-score data, only the total raw-scores were used since the value of the sub-test scores for purposes of prediction and evaluation was questioned by the builders of the tests.

CHAPTER III

PRESENTATION AND ANALYSIS OF DATA

This experiment is concerned with the relationship of critical thinking as measured by two standardized tests of critical thinking and by the departmental examinations used in Zoology I at the University of Oklahoma. The primary objective is to discover whether the Zoology I examinations, which are devised in part to test for critical thinking, do measure critical thinking on the part of the subjects. The total accumulated raw-scores of the subjects, for the fall semester of the 1958-1959 academic year, in Zoology I constitute the dependent or criterion variable (see Appendix A for the range, distribution and percentage-distribution of these scores). The WG-CTA and the ACE-CT, taken by the subjects during the semester in which they were enrolled in Zoology I, provided raw-score data for two of the five independent variables, with the OSPE, IHSC, and OU Math, taken by the subjects as part of their freshman orientation program, providing data for the remaining variables.

To discover the relationship between the dependent and independent variables, simple or zero-order correlation coefficients are computed, as are first- and second-order partial coefficients of correlation. A multiple correlation coefficient is calculated, and from the groups of correlation data regression equations are derived. The regression equations are presented as means of predicting the success of future students in Zoology I on the basis of their total raw-scores on the tests which comprise the group of independent variables in this experiment. The utilization of the regression equations will be restricted to those cases in which the student is from the same population as the subjects of this experiment.

To simplify the computations and to conserve space, the variables involved in this experiment have been assigned symbols. An accepted procedure in statistical writing is that of assigning the symbol "X" with appropriate subscripts of numbers, as follows:

X_1 = Total accumulated raw-scores of subjects in Zoology I,

X_2 = Total raw-scores of subjects on the OSPE,

X_3 = Total raw-scores of subjects on the OU Math,

X_4 = Total raw-scores of subjects on the IHSC,

X_5 = Total raw-scores of subjects on the WG-CTA, and

X_6 = Total raw-scores of subjects on the ACE-CT.

The primary and basic statistical treatment of the data in this experiment is that of correlation. Tate mentions the basic underlying assumption in computing the coefficient of correlation as a measure of relationship between two variables as being that of "linearity," or the tendency of the data, when plotted, to follow generally a straight line.[1] As a check on the normality of the samples, that is, whether or not the frequencies in the specific class intervals for each of the six sets of raw-score data are compatable with the frequencies expected if the distribution is normal, the chi square test for "goodness of fit,"[2]

$$\chi^2 = \Sigma \frac{(f_o - f_e)^2}{f_e} ,$$

where χ^2 = chi square,

f_o = observed frequency,

f_e = expected frequency, and

Σ = summation,

was applied. The hypothesis that the universe has a normal distribution was tested. Since the observed chi square value of 8.05 is smaller than the tabled value of 11.070 for 5 degrees of freedom at the .05 level of significance, the hypothesis that the distribution of frequencies is normal in the case of the Zoology I total raw-scores is accepted.

The observed chi square values of 4.68 and 3.36 are smaller than the tabled value of 9.488 for 4 degrees of freedom at the .05 level of significance. The hypothesis that

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[1]Merle W. Tate, Statistics in Education (New York: The Macmillan Company, 1955), p. 242.

[2]*Ibid*., p. 263.

the distribution of frequencies is normal, in the case of the IHSC and OSPE, respectively, is accepted (see Appendices E and C). The observed value of .28 is smaller than the tabled value of 7.815 with 3 degrees of freedom at the .05 level of significance; therefore the hypothesis that the frequency distribution of the OU Math raw-scores is accepted. (See Appendix D.)

Since the observed value of 12.43 is larger than the tabled chi square value of 9.488 for 4 degrees of freedom at the .05 level of significance, but smaller than the tabled value of 13.277 for 4 degrees of freedom at the .01 level of significance, the normality of the distribution is questioned but not rejected in the case of the WG-CTA.[1] The observed value of 11.88 is larger than the tabled value of 9.488 for 4 degrees of freedom at the .05 level of significance, but not as large as the tabled value of 13.277 for 4 degrees of freedom at the .01 level of significance. Therefore, the normality of the frequency-distribution of the ACE-CT raw-scores is questioned but not rejected. (See Appendices F and G.) Despite the fact that the observed chi square values for the WG-CTA and the ACE-CT data indicate that the frequency-distribution is abnormal at the .05 level of significance, the data are used in the computations in this experiment since they are not significantly different

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[1]Quinn McNemar, Psychological Statistics (New York: John Wiley and Sons, Inc., 1955), p. 213.

from the normal distribution at the .01 level of significance.

Simple Correlation

Since the data utilized were all raw-score data, the formula recommended by Tate for use in computing the Pearson product-moment coefficient of correlation (designated as r_{xy}) is[1]

$$r_{xy} = \frac{N \Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}},$$

where N = number of subjects in the sample,

ΣX = sum of original scores in one variable,

ΣY = sum of original scores in another variable, and

ΣXY = sum of cross-products.

Intercorrelations among the six variables were calculated and the coefficients of intercorrelation are presented in Table 1.

If the possible influence of other factors, measured or not by others of the tests considered, is ignored, the coefficient of correlation between the OU Math and the WG-CTA ($r_{35} = .62$) shows the strongest relationship. This is understandable if one accepts a proposition that critical thinking and analysis of mathematical probiems have many factors in common. It is apparent that the OU Math, WG-CTA, ACE-CT,

[1]Tate, op. cit.

TABLE 1

MATRIX OF INTERCORRELATIONS OF RAW-SCORE DATA FOR THE SIX VARIABLES AND 93 SUBJECTS

Variable	X_2	X_3	X_4	X_5	X_6	X_1
X_2	---	.33	.13	.55	.56	.41
X_3		---	.20	.62	.42	.55
X_4			---	.09	.13	.11
X_5				---	.41	.38
X_6					---	.52
Mean:	83.3	15.9	189.1	67.3	34.6	424.3
Sigma:	23.4	6.9	35.6	10.7	6.6	53.98

and Zoology I examinations (X_1, X_3, X_5, and X_6) intercorrelate highly ($r_{13} = .55$, $r_{35} = .62$, and $r_{36} = .55$), as is also true of the Zoology I, ACE-CT, and WG-CTA tests ($r_{15} = .38$, $r_{16} = .52$, and $r_{56} = .41$). One may assume that the OU Math, WG-CTA, ACE-CT, and Zoology I tests measure many factors commonly. It may well be that these factors relate to or are phases of critical thinking.

Fisher's "t" test, a test of significance of coefficients of correlation, was applied to the coefficients listed in Table 1. The formula[1]

[1]J. P. Guilford, Fundamental Statistics in Psychology and Education (3rd ed.; New York: McGraw-Hill Book Company, Inc., 1956), p. 219.

$$t = \sqrt{\frac{N - 2}{1 - r^2}},$$

where r = obtained coefficients of correlation, and

N = number of pairs of observations,

estimates the required "t" values needed for significance in testing whether the obtained coefficient of correlation is different from the population correlation of zero. The findings are reported in Table 2.

TABLE 2

VALUES FOR FISHER'S "t" APPLIED TO INTERCORRELATIONS OF THE SIX VARIABLES LISTED IN TABLE 1

r	"t"	r	"t"	r	"t"
r_{12} = .41	4.30*	r_{23} = .33	3.29*	r_{35} = .62	7.59*
r_{13} = .55	6.25*	r_{24} = .13	1.20	r_{36} = .42	4.37*
r_{14} = .11	1.05	r_{25} = .55	6.33*	r_{45} = .09	.90
r_{15} = .38	3.78*	r_{26} = .56	6.36*	r_{46} = .11	1.27
r_{16} = .52	5.81*	r_{34} = .20	2.00*	r_{56} = .52	4.26*

*Significant at the .05 level of significance.

The minimum tabled value for "t" at the .05 level of significance, with N - 3, or seven degrees of freedom, is 1.666. The intercorrelation coefficients are significant at the .05 level of significance except those involving X_4, which represents the IHSC. A possible explanation for the non-significance of four of five coefficients of correlation involving variable X_4, or the IHSC, may be that this test, although designed to predict success of students in college, has as its basis the testing of students' stores of knowledge and skills only. Whereas this is true for the IHSC, the other tests attempt to measure some aspect of critical thinking (WG-CTA, ACE-CT, and Zoology I examinations), scholastic aptitude (OSPE), or mathematical skills and understanding (OU Math). The IHSC did correlate significantly at the .05 level of significance with OU Math ($r_{43} = .20$); therefore, one would assume that the IHSC and OU Math more nearly measure the same factors than do the IHSC and the other variables.

The prediction of a total accumulated raw-score in Zoology I (X_1') from another raw-score value on any of the five tests functioning as independent variables may be accomplished by using the formula suggested by Tate,[1]

$$X_1' = r_{xy} \frac{\sigma x}{\sigma y} (Y - \overline{Y}) + \overline{X},$$

where X_1' = score-value to be predicted,

Y = total raw-score of student on one of the five independent variables on which prediction is based,

$\overline{Y}$ = mean of scores for the population, and

$\overline{X}$ = mean of Zoology I scores for the experimental subjects (424.3).

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[1]Tate, op. cit., p. 272.

For example, if a first semester freshman student had scored 90 on the OSPE (X_2), the predicted score for that student in Zoology I (X_1') would be

$$X_1' = r_{12} \frac{\sigma X_1}{\sigma X_2} (X_2 - \bar{X}_2) + \bar{X}_1.$$

Upon substituting values from Table 1, the equation becomes

$$X_1' = (.41) \frac{53.98}{23.4} (90 - 83.3) + 424.3$$

$$= (.41)\ (2.307)\ (6.7) + 424.3 = 430.64.$$

This predicted Zoology I score of 430.64 would be the best prediction and would be expected if the potential Zoology I student were representative of the same population as the subjects of this experiment, and if other non-measured factors were equal. There is, however, little likelihood of all the predicted values following precisely the line of regression. It is possible to predict the extent to which the predicted values will deviate from the straight line of regression, and the formula, which describes the standard error of estimate is[1]

$$\sigma_{x.y} = \sigma_x \sqrt{1 - r^2_{xy}}\ .$$

Applied to the data previously used, where $\sigma x = \sigma X_1 = 53.98$ and $r_{12} = .41$, the standard error of estimate becomes

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[1]Tate, <u>op. cit</u>., p. 277.

$$\sigma_{1.2} = \sigma_1 \sqrt{1 - r^2_{12}}$$

$$= 53.98 \sqrt{1 - (.41)^2}$$

$$= 53.98\ (.912) = 46.88.$$

That is, the predicted value for the Zoology I score may be expected to vary as much as 46.88 above or below the line of regression. In discussing the meaning of a regression equation, Guilford states:

> The main use of a regression equation is to predict the most likely measurement in one variable from the known measurement in another. If the correlation between Y and X were perfect (with a coefficient of 1.00 or -1.00), we could make predictions of Y from X or of X from Y with maximum accuracy; the errors of prediction would be zero. If the correlation were zero, prediction would be futile. Between these two limits, predictions are possible with varying degrees of accuracy. The higher the correlation, the greater is the accuracy of prediction and the smaller the errors of prediction.[1]

The same regression equation and the same formula for finding the standard error of estimate were applied to the other coefficients of correlation between X_1 and independent variables. The standard errors of estimate ($\sigma_{1.3} = 44.80$, $\sigma_{1.6} = 45.88$, $\sigma_{1.2} = 46.88$, $\sigma_{1.5} = 49.93$, and $\sigma_{1.4} = 53.10$) follow the principle of higher coefficients of correlation producing smaller standard errors of estimate since the coefficients of correlation ($r_{13} = .55$, $r_{16} = .52$, $r_{12} = .41$, $r_{15} = .38$, and $r_{14} = .11$) follow a reverse order of sequence from the higher coefficients to the lower. This

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[1]Guilford, _op. cit._, p. 367.

may be taken to indicate that all these variables may be used in predicting total accumulated raw-scores in Zoology I, although with varying degrees of accuracy, for students of the same population as the experimental subjects.

Partial Correlation

To calculate the partial or net coefficient of correlation between a dependent variable and an independent variable with this relationship relieved of the influence of a second independent variable, Tate proposed the formula[1]

$$r_{12.3} = \frac{r_{12} - r_{13}r_{23}}{\sqrt{(1 - r^2_{13})(1 - r^2_{23})}} ,$$

in which the simple or zero-order coefficients of correlation between these pairs of variables may be substituted. Upon substituting from Table 1, the equation becomes

$$r_{12.3} = \frac{.41 - (.55)(.33)}{\sqrt{[1 - (.55)^2][1 - (.33)^2]}}$$

$$= \frac{.2285}{\sqrt{.622}} = \frac{.2285}{.789} = .29$$

This formula has been applied to the possible combinations of independent variables with variable X_1, Zoology I total raw-scores, the criterion, and the results are recorded in Table 3.

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[1]Tate, op. cit., pp. 297-303.

TABLE 3

THE PARTIAL OR NET COEFFICIENTS OF CORRELATION OF VARIABLE X_1 ON VARIABLES X_2, X_3, X_4, X_5, AND X_6, WITH VARIABLE X_y HELD CONSTANT

Variable X_1 on X_m	Partial $r_{X_1 m.y}$ when y is:				
	X_2	X_3	X_4	X_5	X_6
X_{12}	---	.29	.44	.26	.17
X_{13}	.48	---	.54	.43	.43
X_{14}	.07	.00	---	.08	.05
X_{15}	.20	.05	.37	---	.21
X_{16}	.39	.39	.52	.44	---

Interpretation of partial coefficients of correlation is not different from the interpretation of simple coefficients of correlation, except that the coefficient is a numerical expression of the relationship of two variables when that relationship has been freed of the interference of the influence of a third variable. For example, the relationship of variable X_1 on X_2 in the simple coefficient of correlation calculations ($r_{12} = .41$) is considerably larger than it is after the relationship has been relieved of the influence of X_3 ($r_{12.3} = .29$).

In the zero-order correlations the relationship of Zoology I scores and the WG-CTA (r_{15} = .38) was moderate,[1] and after the influence of the IHSC has been removed it remains essentially the same ($r_{15.4}$ = .37). This may be construed to indicate that the measurement of those factors which the Zoology I examinations and the IHSC measure in common is influenced (the true relationship is hidden) by those parts of the two tests which measure critical thinking as the WG-CTA also measures critical thinking. However, the measurement of critical thinking which the Zoology I examinations and the WG-CTA have in common is not influenced by the IHSC.

The relationship between Zoology I scores and the ACE-CT (r_{16} = .52) as indicated by the zero-order coefficient of correlation is not altered when the relationship is relieved of the influence of the IHSC ($r_{15.4}$ = .52). The relationship between Zoology I scores and the IHSC (r_{14} = .11) in the case of the zero-order coefficients is only slightly altered when the relationship is relieved of the influence of the ACE-CT ($r_{14.6}$ = .05). It is probable that no one of these three variables interfere with the measurement function of the others in this case.

The prediction of a total accumulated raw-score in Zoology I, for a prospective freshman student representing

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[1]Guilford, op. cit., p. 145.

the same population as that of the subjects involved in this experiment, from a regression equation expressing the best-fit plane, may be accomplished by the use of the formula proposed by Tate, as follows:[1]

$$X_1' = \beta_{12.3}\frac{\sigma_1}{\sigma_2}X_2 + \beta_{13.2}\frac{\sigma_1}{\sigma_3}X_3 + (\bar{X}_1 - \beta_{12.3}\frac{\sigma_1}{\sigma_2}\bar{X}_2 - \beta_{13.2}\frac{\sigma_1}{\sigma_3}\bar{X}_3)$$

where $\beta_{12.3} = \dfrac{r_{12} - r_{13}r_{23}}{1 - r^2_{23}}$, and

$$\beta_{13.2} = \frac{r_{13} - r_{12}r_{23}}{1 - r^2_{23}} .$$

These beta coefficients are partial regression coefficients, referring, for example, to the partial or net regression of variable X_1 upon X_2 with X_3 held constant. To find the equation of the plane of regression of Zoology I raw-scores on the raw-scores of the student on the OSPE and OU Math, data from Table 1 are substituted:

$$\beta_{12.3} = \frac{.41 - (.55)(.33)}{1 - (.33)^2} = \frac{.23}{.89} = .26, \text{ and}$$

$$\beta_{13.2} = \frac{.55 - (.41)(.33)}{1 - (.33)^2} = \frac{.41}{.89} = .46.$$

If the values, $X_2 = 90$ and $X_3 = 19$, are assigned arbitrarily, the general regression equation then becomes

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[1]Tate, <u>op. cit</u>., pp. 304-05.

$$X_1' = (.26)\frac{53.98}{23.4}(90) + (.46)\frac{53.98}{6.9}(19) + 424.3$$

$$- (.26)\frac{53.98}{23.4}(83.3) - (.46)\frac{53.98}{6.9}(15.9)$$

$$= 53.98 + 68.35 + (424.3 - 57.20) - 439.46.$$

As in the case of the regression equation developed for the simple coefficients of correlation, this predicted raw-score for a prospective Zoology I student would be the best prediction, and would be expected if there were no deviation from the straight line of regression. Since it is improbable that the predicted Zoology I scores would all follow precisely the regression line, it is necessary to discover the standard error of estimate of X_1' by applying the formula:[1]

$$\sigma_{1.23} = \sigma_1 \sqrt{1 - r^2_{12}} \sqrt{1 - r^2_{13.2}} \quad .$$

Upon substituting values from Tables 1 and 3, the equation becomes:

$$\sigma_{1.23} = 53.98 \sqrt{1 - (.41)^2} \sqrt{1 - (.48)^2}$$

$$= 53.98 \sqrt{.83} \sqrt{.77}$$

$$= 53.98\ (.91)\ (.88) = 43.24$$

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[1]Henry E. Garrett, Statistics in Psychology and Education (5th ed.; New York: Longmans, Greene and Company, 1958), pp. 409-11.

This standard error of estimate is the extent to which the predicted Zoology I scores, estimated from the three-variable regression equation, would be expected to vary, above or below the straight line of regression.

To calculate the partial or net coefficient of correlation between two variables with two other variables held constant ($r_{12.34}$) Tate suggested the formula:[1]

$$r_{12.34} = \frac{r_{12.4} - r_{13.4}\, r_{23.4}}{\sqrt{(1 - r^2_{13.4})\,(1 - r^2_{23.4})}} .$$

It is apparent that the computation of correlation coefficients of the zero-order and of the first-order must be made before proceeding to these second-order coefficient computations. The second-order coefficients of correlation have been calculated, and the results are reported in Table 4. By substituting data from Table 3 in the formula above, the equation becomes:

$$r_{12.34} = \frac{.44 - (.54)\,(.31)}{\sqrt{[1 - (.54)^2]\;[1 - (.31)^2]}}$$

$$= \frac{.27}{\sqrt{.64}} = \frac{.27}{.80} = .34.$$

The prediction of a raw-score in Zoology I, X_1, from another variable, X_2, with two remaining variables held

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[1]Tate, op. cit., p. 303.

TABLE 4

THE PARTIAL OR NET COEFFICIENTS OF CORRELATION OF VARIABLE X_1 ON X_2, X_3, X_4, X_5, AND X_6, WITH VARIABLES Xyz HELD CONSTANT

Variable X_{1X_m} on	Partial coefficients of correlation of variable X_1 on variable X_m, when y and z are:									
	X_{23}	X_{24}	X_{25}	X_{26}	X_{34}	X_{35}	X_{36}	X_{45}	X_{46}	X_{56}
$X_{12.}$	---	---	---	---	.34	.31	.13	.25	.17	.09
$X_{13.}$	---	.47	.46	.42	---	---	---	.32	.43	.38
$X_{14.}$	.02	---	.06	.04	---	.01	.02	---	---	.04
$X_{15.}$	.09	.18	---	.15	.05	---	.03	---	.21	---
$X_{16.}$	.29	.37	.37	---	.39	.39	---	.43	---	---

constant may be accomplished by using the formula[1]

$$X_1' = \beta_{12.34}\frac{\sigma_1}{\sigma_2}X_2 + \beta_{13.24}\frac{\sigma_1}{\sigma_3}X_3 + \beta_{14.23}\frac{\sigma_1}{\sigma_4}X_4$$

$$+ \left(\bar{X}_1 - \beta_{12.34}\frac{\sigma_1}{\sigma_2}\bar{X}_2 - \beta_{13.24}\frac{\sigma_1}{\sigma_3}\bar{X}_3 - \beta_{14.23}\frac{\sigma_1}{\sigma_4}\bar{X}_4\right)$$

where the beta coefficients are defined as:

$$\beta_{12.34} = \frac{r_{12} + r_{14}r_{23}r_{34} + r_{13}r_{24}r_{34} - r_{12}r^2_{34} - r_{13}r_{23} - r_{14}r_{23}}{1 + 2r_{23}r_{24}r_{34} - r^2_{23} - r^2_{24} - r^2_{34}},$$

$$\beta_{13.24} = \frac{r_{13} + r_{12}r_{24}r_{34} + r_{14}r_{23}r_{24} - r_{13}r^2_{24} - r_{12}r_{23} - r_{14}r_{34}}{1 + 2r_{23}r_{24}r_{34} - r^2_{23} - r^2_{24} - r^2_{34}},$$

$$\beta_{14.23} = \frac{r_{14} + r_{13}r_{23}r_{24} + r_{12}r_{23}r_{34} - r_{14}r^2_{23} - r_{12}r_{24} - r_{13}r_{34}}{1 + 2r_{23}r_{24}r_{34} - r^2_{23} - r^2_{24} - r^2_{34}}.$$

By substituting values from Table 1 the beta coefficient equations become:

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[1] *Ibid.*, pp. 306-07.

$$\beta_{12.34} = \frac{.41 + (.41)(.13)(.20) + (.11)(.33)(.13) - (.41)(.20)^2 - (.55)(.33) - (.11)(.13)}{1 + 2(.33)(.13)(.20) - (.33)^2 - (.13)^2 - (.20)^2} = \frac{.22}{.85} = .26,$$

$$\beta_{13.24} = \frac{.55 + (.41)(.13)(.20) + (.11)(.33)(.13) - (.55)(.13)^2 - (.41)(.33) - (.11)(.20)}{1 + (.33)(.13)(.20) - (.33)^2 - (.13)^2 - (.20)^2} = \frac{.40}{.85} = .47, \text{ and}$$

$$\beta_{14.23} = \frac{.11 + (.55)(.33)(.13) + (.41)(.33)(.20) - (.11)(.33)^2 - (.41)(.13) - (.55)(.20)}{1 + 2(.33)(.13)(.20) - (.33)^2 - (.13)^2 - (.20)^2} = \frac{-.015}{.85} = -.018.$$

On substituting these values, with others from Table 1, the basic formula then becomes:

$$X_1' = (.26)\frac{53.98}{23.4}X_2 + (.47)\frac{53.98}{6.9}X_3 + (-.018)\frac{53.98}{35.6}X_4$$

$$+ 424.3 - (.26)\frac{53.98}{23.4}(83.3) - (.47)\frac{53.98}{6.9}(15.9)$$

$$- (-.018\frac{53.98}{35.6}(189.1) .$$

If a raw-score value of 90 is assigned as X_2, 19 for X_3, and 190 for X_4, the equation becomes

$$X_1' = (.26)(2.307)(90) + (.47)(7.823)(19) + (-.018)(1.516)$$
$$(190) + 424.3 - (.26)(2.307)(83.3) - (.47)(7.823)(15.9)$$
$$- (-.018)(1.516)(189.1) = 483.66.$$

This value, 483.66, the predicted total raw-score in Zoology I for a student of the same population as the subjects of this experiment but of some future semester, is the best prediction from the score-values arbitrarily assigned. One would expect to encounter a standard error of estimate, however, and the example which follows, involving X_2, X_3, and X_4 as predictors of a Zoology I raw-score has been calculated from a formula proposed by Garrett.[1]

$$\sigma_{1.234} = \sigma_1 \sqrt{1 - r^2_{12}} \sqrt{1 - r^2_{13.2}} \sqrt{1 - r^2_{14.23}} \ .$$

Substituting from Tables 1, 3, and 4, the equation becomes:

$$\sigma_{1.234} = 53.98 \sqrt{1 - (.41)^2} \sqrt{1 - (.48)^2} \sqrt{1 - (.02)^2}$$
$$= 53.98\ (.91)\ (.88)\ (.999) = 43.18.$$

The standard errors of estimate which one would encounter as different combinations of independent variables are employed in predicting Zoology I total raw-scores from the three-variable partial coefficients of correlation are presented in Appendix G. Similarly, the standard errors of estimate expected with different combinations of independent variables in the four-variable regression equations are presented in Appendix H. By reference to these appendices one may observe that in those instances in which the correlation coefficients (Tables 1, 3, and 4) used in computation of the values are large the standard errors of estimate are small.

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[1]Garrett, <u>op. cit</u>., p. 411.

The reverse is true for the standard errors of estimate when the coefficients of correlation are small.

As the variable X_1 is freed of the influence of an increasing number of variables, the standard error of estimate is progressively slightly reduced. The standard errors of estimate ($\sigma_{1.2}$ - 46.88), ($\sigma_{1.23}$ = 43.24), and ($\sigma_{1.234}$ = 43.18) show this to be true. However, the values recorded in Appendices G and H suggest that the coefficients of correlation used in computation of the standard errors of estimate determine the trend, not the number of variables used in the regression equation.

Coefficient of Multiple Correlation

Guilford[1] suggests that in computing the coefficient of multiple correlation (usually represented by the symbol R) when more than three variables are involved the Doolittle method, utilizing zero-order coefficients of correlation, should be employed. This method involves the use of a work-sheet with progressive steps which result in values which, when substituted in a series of equations, will produce beta coefficients. The work-sheet and the beta-coefficient formulae are presented in Appendices J and K, respectively.

The beta coefficients from Appendix K and the coefficients of correlation from Table 1 are used in the solution of the regression coefficients for the multiple-

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[1]Guilford, op. cit., pp. 405-11.

regression equation. In Table 5 the steps necessary to derive the coefficient of multiple correlation ($R_{1.23456}$) from data in the work-sheet, as well as the constant (a) which is used in the regression equation for the prediction of X_1, are presented.

The work-sheet for the Doolittle method of computing a coefficient of multiple correlation has a check column, which permits a worker to maintain a check on the accuracy of the work being done. In completing the work-sheet in this study the widest margin of error at any point, one ten-thousandth, is attributed to rounding-error.

To predict a total accumulated raw-score in Zoology I for a future student of the same population as the experimental subjects the regression equation, proposed by Guilford,[1] is employed, as follows:

$$X_1' = a + b_{12}X_2 + b_{13}X_3 + b_{14}X_4 + b_{15}X_5 + b_{16}X_6$$

where a = a constant, functioning in assuring coincidence with the mean of the X_1 values.

b_{1y} = coefficients, derived from beta coefficients, from column six of Table 5.

X_n = values arbitrarily assigned independent variables.

Upon substituting from Table 5 and assigning the values: $X_2 = 90$, $X_3 = 19$, $X_4 = 190$, $X_5 = 69$, and $X_6 = 36$, the regression equation becomes:

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[1]Guilford, op. cit., p. 411.

TABLE 5

SOLUTION OF THE REGRESSION COEFFICIENTS FOR THE MULTIPLE REGRESSION EQUATION, INVOLVING THE SIX VARIABLES IN THIS EXPERIMENT, WITH VARIABLE X_1 AS THE CRITERION

(1) Variable:	(2) β_{1y}	(3) r_{1y}	(4) $(\beta_{1y})(r_{1y})$	(5) $\frac{\sigma_1}{\sigma_y}$	(6) b_{1y}*	(7) $\bar{y}$	(8) $(-\bar{y})(b_{1y})$
X_2	.0777	.411	.0319	2.3068	.1792	83.3	-14.9274
X_3	.3320	.548	.1819	7.8231	2.5973	15.9	-41.2971
X_4	-.0169	.110	-.0019	1.5163	-.0256	189.1	4.8410
X_5	.1127	.376	.0424	5.0449	.5686	67.3	-38.2668
X_6	.2969	.522	.1550	8.1788	.4269	34.6	-14.7707
			Σ = .4093				Σ = -104.4210
			= R^2				$\bar{X}_1$ = 424.3
			R = .6398				a = 319.8790

*$b_{1y} = (B_{1y})(1/y)$. The symbol "y" indicates the independent variables in turn.

$$X_1' = 319.9 + (.1792)(90) + (2.5973)(19) + (-.0256)(190) + (.5686)(69) + (.4269)(36)$$

$$= 439.98$$

The value, 439.98, which is the predicted Zoology I score of a prospective student from the same population as the experimental subjects, is the score which would lie on the regression line at the point or level at which the independent variables might fix the score as their influence assumes a common factor. It is not likely that the scores of a large number of Zoology I students would all fall precisely on the straight line of regression, however. The extent to which they would be expected to vary from the straight line of regression may be calculated by the formula proposed by Tate, as follows:[1]

$$\sigma_{1.23456} = \sigma_1 \sqrt{1 - R^2_{1.23456}}$$

$$= 53.98\ (7686) = 41.49.$$

The standard error of estimate has been further reduced ($\sigma_{1.2} = 46.88$), ($\sigma_{1.23} = 43.24$), ($\sigma_{1.234} = 43.18$), and now ($\sigma_{1.23456} = 41.19$) through the application of the Doolittle multiple correlation method. This increase of accuracy in prediction of a theoretical Zoology I total accumulated raw-score, with the influence of variables X_2, X_3, X_4, X_5, and X_6 held constant, has been accomplished at the expense

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[1]Tate, op. cit., p. 310.

of extended labor, and is not a great improvement over the limit of accuracy suggested for the prediction of X_1 from X_2 in the case of the zero-order regression equation (46.88 - 41.19 = 5.69 score-points improvement).

The coefficient of multiple correlation is the product-moment coefficient of correlation between the observed values of variable X_1 and the theoretical values given by the equation of linear regression of X_1 on (in this study five) other variables. That is, it is a measure of the extent to which X_1 is associated with the joint variation of the five independent variables, X_2, X_3, X_4, X_5 and X_6. The multiple coefficient is not a sum nor is it a mean of the simple coefficients of correlation of the independent variables with the dependent variable. The multiple coefficient of correlation ($R_{1.23456} = .64$), since it is larger than any of the simple coefficients of correlation (see Table 1), involves over-lapping of relationships among the intercorrelations of the six variables. The IHSC, although not correlating very well with the criterion ($r_{14} = .11$), contributes to the multiple coefficient through its correlation with other variables which do correlate highly with X_1. Such a variable, since its function in a regression equation is to suppress whatever variance in other independent variables may not be represented in the criterion but which may be in some variable that does otherwise correlate with the criterion, is called a suppression variable.[1] The suppression variable (X_4) also is apparent in the partial coefficients of correlation.

Summary

The hypothesis that there is no significant correlation between the Zoology I examination total raw-scores and the total raw-scores of the subjects on the WG-CTA and ACE-CT (tests of critical thinking) may be rejected. All the simple coefficients of correlation resulting from combinations of these three variables are significant at the .05 level of significance (r_{15} = .38), (r_{16} = .52), and (r_{56} = .41).

Sample-problems involving the simple coefficients of correlation and the first- and second-order partial coefficients of correlation have been worked out. Although others may be worked out by using the same applicable formulae it was not considered necessary in this instance, since only theoretical raw-score values for prospective Zoology I students are available. The same relationship applies in the case of the regression equations, which are presented as the basic equations to be used in real prediction situations wherein the prospective students represent the same population as that of the experimental subjects.

Essentially all the coefficients of correlation may be of useful value in regression equations used in predicting

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[1]Guilford, op. cit., p. 403.

Zoology I total accumulated raw-scores, the only coefficients which would not be of value would be those of zero, although the degree of accuracy of prediction will vary according to the extent to which the variables correlate.

The OU Math is the best single predictor of success in Zoology I (r_{13} = .55; $\sigma_{1.3}$ = 44.80). The ACE-CT (r_{16} = .52; $\sigma_{1.6}$ = 45.88) would be the second-best basis for the prediction of Zoology I scores from zero-order coefficients of correlation. The WG-CTA (r_{15} = .38; $\sigma_{1.5}$ = 49.93) is the fourth-best basis of prediction of Zoology I scores from zero-order coefficients of correlation.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

This experiment, involving 93 subjects who volunteered to participate, has been designed to test the null hypotheses that: (1) There is no significant correlation between the total raw-scores of subjects on the departmental Zoology I examinations and their total raw-scores on two tests of critical thinking, the WG-CTA and ACE-CT; (2) Scores of subjects on tests of critical thinking will not be of value as predictors of success in Zoology I; (3) Scores of subjects on three other standardized tests will not be of value as predictors of success in Zoology I.

Coefficients between the criterion, X_1, and the independent variables, X_2, X_3, X_5, and X_6 are significant at the .05 level of significance, while the coefficient of correlation between X_1 and X_4 is not significant at the .05 level of significance. The IHSC, X_4, was used in computations, however, since the frequency distribution was normal.

Coefficients of correlation of the zero-order, partial correlation coefficients of the first- and second-order, and a multiple correlation coefficient involving all the variables have been computed. The coefficients of correlation are substituted in regression equations which are used in predicting total accumulated raw-scores for future students of the same population as the experimental subjects. Essentially all the coefficients of correlation may be utilized in the regression equations, although the degree of accuracy of prediction of Zoology I total raw-scores is directly proportional to the extent to which the variables correlate with each other in the instance of the zero-order coefficients of correlation. The only coefficient of correlation which may not be used in the regression equations for predicting Zoology I total raw-scores ($r_{14.3} = .00$) is the result of holding one independent variable constant. The accuracy of prediction, that is, the extent to which the predicted Zoology I scores deviate above or below the straight line of regression, in the instance of the partial coefficients of correlation depends upon the particular zero-, first-, and second-order coefficients of correlation which are combined in the regression equation.

The coefficient of multiple correlation, with its associated beta and (a) coefficients, may be utilized in predicting Zoology I total accumulated raw-scores ($R_{1.23456} = .6398$) with a standard error of estimate of 41.49 score-points above or below the straight line of regression.

According to the first-order partial coefficients of correlation, in which the influence of one variable is removed from the relationship between the criterion and one other independent variable, the Zoology I examinations more nearly measure the same factors as the OU Math ($r_{13.2} = .48$; $r_{13.4} = .54$; $r_{13.5} = .43$; and $r_{13.6} = .43$). It is improbable that the Zoology I examinations measure critical thinking as critical thinking is measured by the WG-CTA, since ($r_{15.2} = .20$), ($r_{15.3} = .05$), ($r_{15.4} = .37$), and ($r_{15.6} = .21$). The Zoology I examinations and the ACE-CT more nearly measure the same critical thinking factors, since ($r_{16.2} = .39$), ($r_{16.3} = .39$), ($r_{16.4} = .52$), and ($r_{16.5} = .44$).

Conclusions

On the basis of the evidence presented it is concluded that there is significant correlation at the .05 level of significance between the dependent or criterion variable, X_1, which represents total accumulated raw-scores in Zoology I for the experimental subjects, and the two tests of critical thinking, the Watson-Glaser Critical Thinking Appraisal, Form AM and the Test of Critical Thinking, Form G. Therefore, the null hypothesis that there is no significant correlation between the total raw-scores of subjects on the departmental Zoology I examinations and their total raw-scores on the two tests of critical thinking may be rejected.

Coefficients of correlation of the total raw-scores of the subjects on the two tests of critical thinking with total raw-scores of the subjects on Zoology I examinations, (r_{16} = .52; $\sigma_{1.6}$ = 45.88) and (r_{15} = .38; $\sigma_{1.5}$ = 49.93), are the second- and fourth-best of the five independent variables for use in predicting future Zoology I total raw-scores from zero-order coefficients of correlation. The OU Math, X_3, is the best of the independent variables (r_{13} = .55; $\sigma_{1.3}$ = 44.80), while the OSPE, X_2, is third-best (r_{12} = .41; $\sigma_{1.2}$ = 46.88).

The prediction of Zoology I total raw-scores from first-order coefficients of correlation may be accomplished by substituting any of the coefficients in the regression equation except that of X_1 on X_4 with X_3 constant ($r_{14.3}$ = .00). The combinations of these partial coefficients of correlation which result in the most accurate predictions, proceeding from the best, are: ($\sigma_{1.32}$ = 39.66), ($\sigma_{1.56}$ = 39.95), and ($\sigma_{1.53}$ = 41.02). Other combinations result in errors of estimate ranging generally from 43 to 53 Zoology I score-points above or below the straight line of regression.

In predicting Zoology I total raw-scores from the second-order coefficients of correlation, variable X_1 on any combination of the independent variables except those involving the coefficient equal to zero previously mentioned may be utilized. Degrees of accuracy will be encountered as before, and the best combinations resulting in the smallest standard errors of estimate are: ($\sigma_{1.436}$ = 40.51), ($\sigma_{1.623}$ = 41.02) ($\sigma_{1.356}$ = 41.02), and ($\sigma_{1.326}$ = 41.28).

Other combinations result in standard errors of estimate ranging from 42 to 48 Zoology I score-points.

On the basis of these data, it is concluded that the null hypotheses that the total raw-scores of the subjects on the five tests which constitute the independent variables will not be of value as predictors of success in Zoology I may be rejected.

The coefficient of multiple correlation and the associated beta and (a) coefficients may be used in predicting future Zoology I total raw-scores, but with a larger standard error of estimate than in the instances of the best partial coefficients of correlation data. The multiple correlation data ($R_{1.23456} = .6398$; $\sigma_{1.23456} = 41.49$) result in relatively accurate predictions when compared with the majority of the results from the zero-, first-, and second-order correlation coefficient data.

Recommendations

The teaching staff of the Zoology I class may most advantageously utilize the OU Math total raw-scores, among the zero-order coefficients, as predictors of success in Zoology I, if the student for whom the degree of success is being predicted is of the same population as the experimental subjects. The total raw-scores of the ACE-CT, OSPE, WG-CTA, and IHSC, in that order, may also be utilized in predicting students' success.

On the basis of the data presented in Tables 3 and 4 it is recommended that the Zoology I examinations be re-examined, since they apparently measure that which is measured by the OU Math ($r_{13.2} = .48$; $r_{13.4} = .54$; $r_{13.5} = .43$; $r_{13.6} = .43$) and ($r_{13.24} = .47$; $r_{13.25} = .46$; $r_{13.26} = .42$; $r_{13.45} = .32$; $r_{13.46} = .43$; $r_{13.56} = .38$) more than they measure critical thinking. The Zoology I examinations do measure critical thinking as it is measured by the ACE-CT, however ($r_{16.25} = .39$; $r_{16.3} = .39$; $r_{16.4} = .52$; $r_{16.5} = .44$) and ($r_{16.34} = .39$; $r_{16.35} = .39$; $r_{16.45} = .43$).

The selection of the regression equation to be used in predicting success in Zoology I for future students of the same population as the experimental subjects may be left to the discretion of the individual. Generally, the multiple correlation data and the first-order partial correlation data result in predictions of slightly greater accuracy.

It is recommended that one or two other comparable samples be made of the Zoology I students and the data be either incorporated or compared with the data presented in this study. Such a follow-up would provide much more substantial data for comparing the measurement of critical thinking by the standardized tests of critical thinking and that done by the Zoology I examinations.

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APPENDICES

APPENDIX A

GRADE-DISTRIBUTION, FREQUENCY-DISTRIBUTION, AND PERCENTAGE-DISTRIBUTION FOR 365 ZOOLOGY I STUDENTS, FALL SEMESTER, 1958-1959, THE UNIVERSITY OF OKLAHOMA

Grade	Accumulated Score-Point Range	Number of Students	Percentage Distribution
A	516 - 574	32	8.8
B	467 - 515	69	19.0
C	399 - 466	150	41.1
D	350 - 398	82	22.3
F	265 - 349	32	8.8
Total		365	100.0

APPENDIX B

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL ACCUMULATED RAW-SCORES FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS IN ZOOLOGY I, THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 25	Observed Frequency f_o	Expected Frequency f_e	Regrouped Frequencies f_o	f_e	$\frac{(f_o - f_e)}{f_e}$
525-549	4	1.95	8	6.50	.35
500-524	4	4.55			
475-499	8	8.86	8	8.86	.08
450-474	13	13.35	13	13.35	.01
425-449	21	16.69	21	16.69	1.11
400-424	9	16.75	9	16.75	3.59
375-399	14	13.63	14	13.63	.01
350-374	14	8.97	14	8.97	2.82
325-349	3	4.70	6	6.74	.08
300-324	3	2.04			
	N = 93				$\chi^2 = 8.05$*

*Not significantly different from the normal population distribution at the .05 level of significance, with five degrees of freedom.

APPENDIX C

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL RAW-SCORES ON THE OHIO STATE UNIVERSITY PSYCHOLOGICAL EXAMINATION FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 13	Observed Frequency f_o	Expected Frequency f_e	Regrouped Frequencies f_o	f_e	$\frac{(f_o - f_e)}{f_e}$
129-141	2	1.79	8	7.07	.02
116-128	6	5.28			
103-115	11	11.25	11	5.28	.01
90-102	21	17.79	21	11.25	.58
77- 89	15	20.58	15	20.58	1.51
64- 76	21	17.50	21	17.50	.70
51- 63	9	11.00	9	11.00	.36
38- 50	5	5.02			
25- 37	2	1.75	8	7.23	.08
12- 24	1	.46			
	N = 93				$\chi^2 = 3.36$*

*Not significantly different from the normal population distribution at the .05 level of significance, with four degrees of freedom.

APPENDIX D

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL RAW-SCORES ON THE UNIVERSITY OF OKLAHOMA MATHEMATICS PLACEMENT TEST FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS, THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 4	f_o	f_e	Regrouped Frequencies f_o	f_e	$\frac{f_o - f_e}{f_e}$
36-39	1	.17			
32-35	1	.87	12	12.42	.01
28-31	2	3.13			
24-27	8	8.25			
20-23	15	15.52	15	15.52	.02
16-19	21	20.80	21	20.80	.00
12-15	20	20.10	20	20.10	.00
8-11	14	14.00	14	14.00	.00
4- 7	9	6.94	11	9.45	.25
0- 3	2	2.51			
	N = 93				$\chi^2 = .28$*

*Not significantly different from the normal population distribution at the .05 level of significance, with three degrees of freedom.

APPENDIX E

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL RAW-SCORES ON THE IOWA HIGH SCHOOL CONTENT EXAMINATION FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS, THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 20	Observed Frequency f_o	Expected Frequency f_e	Regrouped Frequencies f_o	f_e	$\frac{(f_o - f_e)}{f_e}$
280-299	1	.39			
260-279	1	1.12	8	6.41	.39
240-259	6	4.90			
220-239	7	10.90	7	10.90	1.40
200-219	22	17.73	22	17.73	1.03
180-199	21	20.86	21	20.86	.00
160-179	15	20.66	15	20.66	1.56
140-159	12	11.27	12	11.27	.05
120-139	6	5.01	8	6.71	.25
100-119	2	1.70			
	N = 93				$\chi^2 = 4.68$*

*Not significantly different from the normal population distribution at the .05 level of significance, with four degrees of freedom.

APPENDIX F

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL RAW-SCORES ON THE WATSON GLASER CRITICAL THINKING APPRAISAL FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS, THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 6	Observed Frequency f_o	Expected Frequency f_e	Regrouped Frequencies f_o	f_e	$\frac{(f_o - f_e)}{f_e}$
82-87	5	5.74	5	5.74	.10
76-81	16	12.02	16	12.02	1.31
70-75	21	18.39	21	18.39	.37
64-69	26	20.57	26	20.57	1.43
58-63	11	16.81	11	16.81	2.01
52-57	4	10.05	4	10.05	4.80
46-51	7	4.38			
40-45	1	1.40	10	6.15	2.41
34-39	1	.33			
28-33	1	.04			
	N = 93				$\chi^2 = 12.43$*

*Not significantly different from the normal population distribution at the .01 level of significance, with three degrees of freedom, but significantly different at the .05 level of significance.

APPENDIX G

FREQUENCY-DISTRIBUTION AND CHI SQUARE OF TOTAL RAW-SCORES ON THE TEST OF CRITICAL THINKING FOR 93 (37 MALE, 56 FEMALE) FRESHMAN SUBJECTS, THE UNIVERSITY OF OKLAHOMA, FALL SEMESTER, 1958-1959

Raw-Score Interval = 4	Observed Frequency f_o	Expected Frequency f_e	Regrouped Frequencies f_o	f_e	$\frac{(f_o - f_e)}{f_e}$
47-50	1	.25	5	7.55	.86
43-46	4	7.30			
39-42	25	15.13	25	15.13	6.44
35-38	21	21.56	21	21.56	.01
31-34	21	21.33	21	21.33	.01
27-30	11	14.73	11	14.73	.94
23-26	5	6.98	5	6.98	.56
19-22	4	2.33			
15-18	0	.00	5	2.33	3.06
11-14	1	.00			
	N = 93				$\chi^2 = 11.88$*

*Not significantly different from the normal population distribution at the .01 level of significance, with four degrees of freedom, but significantly different at the .05 level of significance.

APPENDIX H

STANDARD ERRORS OF ESTIMATE EXPECTED WHEN PREDICTING ZOOLOGY I TOTAL ACCUMULATED RAW-SCORES (X_1') FROM THREE-VARIABLE PARTIAL COEFFICIENTS OF CORRELATION

		Standard Error of Estimate			Standard Error of Estimate
$\sigma_{1.23}$	=	43.24	$\sigma_{1.45}$	=	49.66
$\sigma_{1.24}$	=	49.12	$\sigma_{1.46}$	=	45.88
$\sigma_{1.25}$	=	48.26	$\sigma_{1.52}$	=	48.04
$\sigma_{1.26}$	=	45.34	$\sigma_{1.53}$	=	44.94
$\sigma_{1.32}$	=	39.66	$\sigma_{1.54}$	=	52.90
$\sigma_{1.34}$	=	- --*	$\sigma_{1.56}$	=	39.95
$\sigma_{1.35}$	=	44.94	$\sigma_{1.62}$	=	45.41
$\sigma_{1.36}$	=	41.47	$\sigma_{1.63}$	=	41.02
$\sigma_{1.42}$	=	48.15	$\sigma_{1.64}$	=	46.04
$\sigma_{1.43}$	=	45.00	$\sigma_{1.65}$	=	44.80

*The coefficient of correlation ($r_{14.3} = .00$) is not useable in regression equations.

APPENDIX I

STANDARD ERRORS OF ESTIMATE EXPECTED WHEN PREDICTING ZOOLOGY I TOTAL ACCUMULATED RAW-SCORES (X_1') FROM FOUR-VARIABLE PARTIAL COEFFICIENTS OF CORRELATION

		Standard Error of Estimate			Standard Error of Estimate
$\sigma_{1.234}$	=	43.18	$\sigma_{1.435}$	=	44.70
$\sigma_{1.235}$	=	42.80	$\sigma_{1.436}$	=	40.51
$\sigma_{1.236}$	=	41.56	$\sigma_{1.456}$	=	45.02
$\sigma_{1.245}$	=	48.34	$\sigma_{1.523}$	=	42.64
$\sigma_{1.246}$	=	45.69	$\sigma_{1.524}$	=	48.04
$\sigma_{1.256}$	=	44.80	$\sigma_{1.526}$	=	44.80
$\sigma_{1.324}$	=	43.18	$\sigma_{1.534}$	=	45.07
$\sigma_{1.325}$	=	42.64	$\sigma_{1.536}$	=	41.46
$\sigma_{1.326}$	=	41.28	$\sigma_{1.546}$	=	44.91
$\sigma_{1.345}$	=	-- --*	$\sigma_{1.623}$	=	41.02
$\sigma_{1.346}$	=	-- --*	$\sigma_{1.624}$	=	45.34
$\sigma_{1.356}$	=	41.02	$\sigma_{1.625}$	=	44.80
$\sigma_{1.423}$	=	42.54	$\sigma_{1.634}$	=	41.56
$\sigma_{1.425}$	=	47.39	$\sigma_{1.635}$	=	41.56
$\sigma_{1.426}$	=	44.80	$\sigma_{1.645}$	=	44.64

*The coefficient of correlation ($r_{14.3} = .00$) is not useable in regression equations.

APPENDIX J

WORK-SHEET FOR THE SOLUTION OF A MULTIPLE CORRELATION PROBLEM*

Row	X_2	X_3	X_4	X_5	X_6	X_1	Check
A	1.0000	.3260	.1250	.5540	.5550	.4110	2.9710
B	-1.0000	-.3260	-.1250	-.5540	-.5550	-.4110	-2.9710
C		1.0000	.2030	.6230	.4160	.5480	2.7900
D		-.1063	-.0408	.1806	-.1809	-.1340	-.6425
E		.8937	.1622	.4424	.2351	.4140	2.1475
F		-1.0000	-.1814	-.4952	-.2636	-.4632	-2.4028
G			1.0000	.0940	.1320	.1100	1.3360
H			-.0156	-.0693	-.0694	-.0514	-.2056
I			-.0294	-.0803	-.0426	-.0751	-.2274
J			.9550	-.0556	.2000	-.0165	.9030
K			-1.0000	.0582	-.0209	.0173	-.9455
L				1.0000	.4070	.3760	1.7830
M				-.3069	-.3075	-.2277	-.8421
N				-.2191	-.1164	-.2050	-.5406
O				-.0032	.0012	-.0010	-.0030
P				.4780	-.0157	-.0577	.3974
Q				-1.0000	-.0333	-.1226	-.8440
R					1.0000	.5220	1.5220
S					-.3080	-.2281	-.5361
T					-.0620	-.1091	-.1711
U					-.0004	.0003	-.0001
V					.0005	.0019	.0024
W					.6301	.1871	.8171
Y					-1.0000	-.2969	-1.2969

*Data are drawn from Table 1, representing zero-order coefficients of correlation for six variables. The criterion is Variable X_1.

Directions for steps involved in the completion of this work-sheet are as follows:

Row A. Record coefficients of correlation of all variables with variable X_2. Sum all coefficients and record the sum in the check column.

Row B. Divide the numbers in row A by minus B2, and record in corresponding spaces of row B. Include check column.

Row C. Record remaining coefficients of correlation with variable X_3. Sum all coefficients and record sum in check column.

Row D. Multiply the numbers in row A by the number in B3, beginning with column 3 and proceeding to the right. Subtract A2 from the check value before multiplying.

Row E. Sum algebraically the values in rows C and D.

Row F. Divide all numbers in row E by that found at E2, with sign changed.

Row G. Record the remaining coefficients of correlation with variable X_4. Sum these values and record the sum in the check column.

Row H. Multiply the values in row A by B4, proceeding from column 4 toward the right. Subtract the value at A2 and A3 from the value in the check column before multiplying that value.

Row I. Multiply values in row E by the number at F4, proceeding to the right. Subtract the value at E3 from the check column value before multiplying it by this number.

Row J. Sum algebraically the values in rows G, H, and I.

Row K. Divide numbers in row J by number, with the sign changed, at J4.

These steps, with the appropriate modifications, will apply to the remaining procedures in the work-sheet.

APPENDIX K

FORMULAE FOR SOLUTION OF BETA COEFFICIENTS FROM A WORK-SHEET IN THE DOOLITTLE METHOD (SUBSTITUTE VALUES FROM APPENDIX J)

$$\beta_{16} = -(Y1) = \underline{.2969}$$

$$\beta_{15} = -(Q1) + \beta_{16}(Q6)$$
$$= .1226 + (.2969)(-.0333) = \underline{.1127}$$

$$\beta_{14} = (K1) + \beta_{16}(K6) + \beta_{15}(K5)$$
$$= (-.0173) + (.2969)(-.0209) + (.1127)(.0582)$$
$$= (-.0173) + (-.0062) + (.0066) = \underline{-.0169}$$

$$\beta_{13} = -(F1) + \beta_{16}(F6) + \beta_{15}(F5) + \beta_{14}(F4)$$
$$= .4632 + (.2969)(-.2636) + (.1127)(-.4952)$$
$$+ (-.0169)(-.1814)$$
$$= (4632) + (-.0783) + (-.0558) + (.0031) = \underline{.3320}$$

$$\beta_{12} = -(B1) + \beta_{16}(B6) + \beta_{15}(B5) + \beta_{14}(B4) + \beta_{13}(B3)$$
$$= (.4110) + (.2969)(-.5550) + (.1127)(-.5540)$$
$$+ (-.0169)(-.1250) + (.3320)(-.3260)$$
$$= (.4110) + (-.1648) + (-.0624) + (.0021) + (-.1082)$$
$$= \underline{.0777}$$