STATISTICS FOR EDUCATION

With Data Processing

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STATISTICS FOR EDUCATION

To
WALTER R. BORG,
some of whose work
provided the
incentive for writing
this book

PREFACE

This book is designed to introduce statistics to people having the following characteristics:

1. They have relatively little background in mathematics (a maximum of one year of high school algebra).
2. They are interested in being able to use a few statistical tools (as contrasted with a desire simply to know what statistics is about).
3. Their research interests are primarily educational in nature, and they are oriented toward projects involving relatively large groups of people, rather than small laboratory studies over a period of time with few subjects.
4. They would like to have the basic tools to use computer center facilities for statistical purposes.

To reach this group of people, the following techniques have been employed (the topic numbers correspond to the paragraphs above):

1. Basic arithmetic is taught at the first place in the text where it is needed; hence sections on arithmetic, elementary algebra, and some geometry are interspersed throughout the book.
2. Ability to use statistical tools is developed through the provision of appendixes containing large amounts of raw educational data collected by W. R. Borg. The student will be asked to use his statistical tools by carrying out the following steps:

   a. Translate a research problem into statistical terminology.
   b. Make a sampling plan.
   c. Collect the data, using the sampling plan (from the raw data in the appendix).
   d. Analyze the data.
   e. Interpret the data in the light of the research problem assigned.

   These steps are among those any researcher must carry out in planning and executing a research project; they can be considered important parts of the so-called story problems of an applied statistics course. A heavy emphasis on story problems should enable the conscientious student to gain skill in carrying out his own research projects with some degree

of statistical competence. Basic emphasis will be on the meaning to the researcher of the techniques used.

3. To maintain student interest, the text material is focused on educational problems; statistical methods are introduced as they are needed to help solve these problems. It is hoped that this approach will appeal to those whose primary interest is education rather than statistics itself. The educational data referred to earlier have been provided not only for the experience they permit, but also because of the intrinsic interest education students are likely to have in such data. Any branch of applied mathematics becomes more appealing to the nonmathematician if it is embedded in a topic he truly cares about.
4. To provide training in the use of computer center facilities, the elements of data processing are taught throughout the text at the points where the material is needed, just as for the basic arithmetic. Appendixes K–N are computer programs to use with the statistical methods covered. These are in the FORTRAN language approved by the U.S.A. Standards Institute; thus they may be used at most computer centers.

A word of advice to instructors is in order with respect to the computer program listings provided. Computer centers are different enough to make successful operation of a program on the first try a highly unusual event. Minor changes should always be expected, and the best policy is to submit your listings to one of the resident programmers before you expect to have your class use it, and to let him have the program deck punched and made operational on your equipment. Then, duplicates of his deck can be made by the computer center for distribution to the class members.

Another alternative is available if your computer center has a set of simple and easy to use statistical programs. Such a set should be accompanied by clear instructions that can be made available to your students on how to use the programs. If this is your good fortune, you can—and should—ignore the listings in the Appendix and take advantage of the programs provided by your own computer center. However, it is recommended that you avoid using programs which do many more things than your class needs. Such programs are usually more difficult to use and will tend to "turn off" beginning students who are using computer facilities for the first time.

It should be emphasized here that most of the Experiences with Data do not have a single answer. A question such as "Design and execute a project to determine the degree to which a student's morale is affected by his school" will result in as many different papers as there are class members. The student must define *morale* in terms of available measures, decide such matters as whether deviations in morale can be attributed to socioeconomic differences rather than to the schools themselves, decide on statistical techniques, collect his own data, and analyze and interpret the data. Students inevitably will differ in each of these steps; and papers which differ greatly, will often be of equally high quality. Incidentally, papers reporting projects of this kind turn out to be no more time consuming to grade conscientiously than the more conventional kind—and they are much more interesting.

The text is designed to include sufficient material for one academic year of work if the class meets twice a week and an additional weekly lab period is allotted for reports and class discussion arising from the problems in the Experiences with Data sections. Early chapters can be covered more rapidly than the later ones since the Experiences with Data play a larger role as the student progresses through the book and these problems are more time consuming.

For those who wish to use the text for one semester, Chapters 1 to 5 provide a logical set of topics if the sections marked with an asterisk are omitted. Throughout the text the asterisked sections can be omitted without affecting the continuity of the material. Chapters 6, 7, and 8 are self-contained topics; any one of these can be taken up after Chapter 5 is completed. Chapter 9 assumes that Chapters 7 and 8 have been covered. Exercises marked † are essentially sampling problems designed to familiarize students with the meaning of certain aspects of statistical inference. Exercises marked ‡ require coordination of the results by the instructor as part of a class period. This extra effort will have its reward in the increased understanding that students acquire for confidence intervals, type I and type II errors, and other concepts that the beginning student often has trouble with.

A section appears at the end of each chapter giving solutions to all problems with the exception of those marked † or ‡. Those marked with † have no fixed answer, but in some cases a sample solution is given. The reader is encouraged to use these sections; often computational short-cuts are given there that are not described in the main body of the chapter.

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I am indebted to the Literary Executor of the late Sir Ronald A. Fisher, F.R.S., to Dr. Frank Yates, F.R.S., and to Oliver and Boyd, Edinburgh, for permission to reprint Tables III, IV, and V from their book *Statistical Tables for Biological, Agricultural and Medical Research*. I also wish to express gratitude to McGraw-Hill Book Co., for permission to reproduce material in Tables 16–10 and 16–19 from *An Introduction to Linear Statistical Models*, Vol. I, by F. A. Graybill; and to C. W. Dunnett and M. Sobel and *Biometrika* for permission to reproduce Table 4 from their paper "A Bivariate Generalization of Student's *t*-Distribution." Hayden Book Co. has kindly permitted the reproduction of Figures 2-5(a) and 2-5(b) from *Comprehensive Standard Programming* by J. N. Haag; I am indebted to John Wiley and Sons, Gads Forlag, and Skandinavisk Aktuarietidskrift for permission to reproduce the table of logarithms and the normal distribution.

I wish to call particular attention to the effectiveness of the editorial staff at Harper & Row. Editorial recommendations have been uniformly good; and the speed with which production details were completed has been especially appreciated. My association with the company has been a distinct pleasure.

The final version of the manuscript was typed with much patience and attention to detail by Nola White, Ann White, and Susan Walk, and the answers to the problems in the first six chapters were worked out by Ann White and Lorraine Flynn; I am most grateful to them for their efforts. I owe my greatest debt of gratitude to my wife, Thelma, who has provided constant support through the years during which this book has been in preparation.

CONTENTS

CHAPTER 1
RANDOM SAMPLING WITH MATHEMATICAL PRELIMINARIES

The goal of this book is to make statistics useful and interesting for the student who is pursuing a career in education. Statistical techniques are important tools for educational research and for decision-making at the district level. One of the ways in which we can learn to use these tools is through the study of specific educational problems in a quantitative setting—this is the approach of this text. In this chapter you will be introduced to a research project that is of current educational interest. Data from this project will be used throughout the book to explain the proper use of statistical techniques.

The topics covered in this chapter are (1) how to obtain a random sample; and (2) a review of the mathematics needed for this text. The random sampling comes first, so that you will have some concrete experiences with educational data to apply your symbols to; then the mathematics can be related to these experiences.

Some hints to the student are in order here as you begin your work.

1. Answers to all exercises in a chapter are at the end of the chapter. There is no known substitute for working problems to ensure understanding; students are encouraged to (1) work the examples in the book as though they were problems; (2) do some of the problems at the end of each section.

2. There is a glossary at the end of the book giving all math symbols used in the text, how to pronounce each, and the section where it is first explained. Make a practice of referring to it, if you have forgotten the meaning of a symbol.

3. A review of all concepts and formulas introduced appears at the end of each chapter, to help you to periodically summarize the material you have read.

We next turn to a description of our educational research project. In December 1965 a report entitled "Ability Grouping in the Public Schools" by W. R. Borg appeared in the *Journal of Experimental Education*. The circumstances surrounding this study were a bit unusual; two Western school districts of comparable socioeconomic background and rural-urban characteristics were considering a change to ability grouping, such that children in any given classroom would be at the same ability level. One of the districts decided to change to ability grouping; the other elected to stay with the conventional type of classroom organization. Borg was responsible for conducting a study that obtained both social adjustment and academic achievement measures for a large proportion of the children in both districts. The goal was to detect any genuine differences between the two districts that could con-

FIGURE 1-1
Ability grouping vs. random grouping in two school districts.

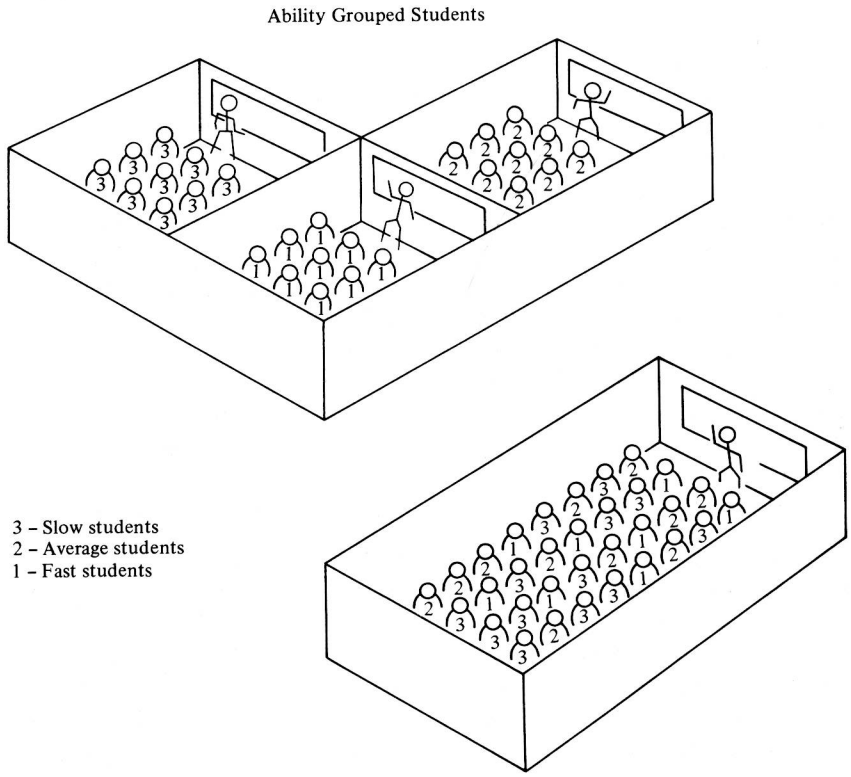
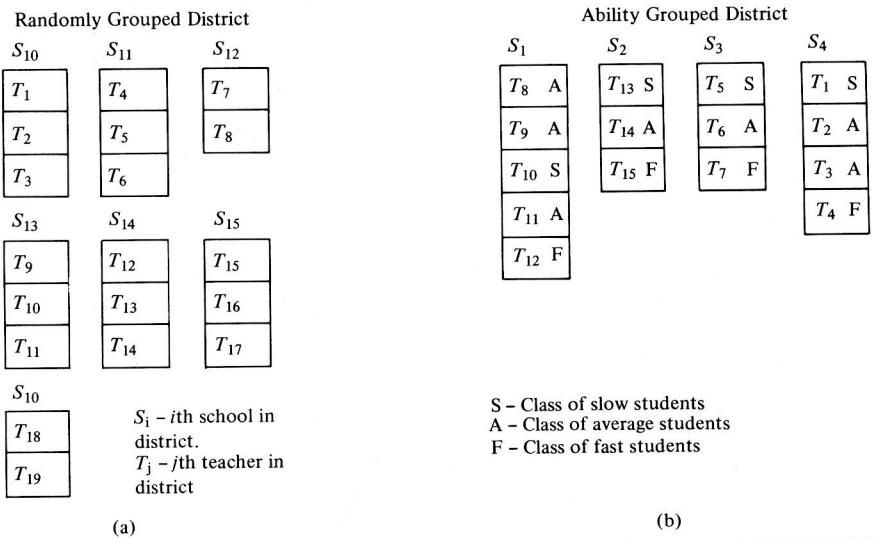


FIGURE 1–2
Layout of schools in two districts. (a) Students grouped randomly; (b) Students grouped by ability levels.



ceivably be due to ability grouping, and also to determine whether these differences were large enough to be meaningful in the educational sense.

Part of the "raw" data (the original measurements) appears in Table A of the Appendix; a brief consideration of it will be useful at this point. At the beginning of Table A is an explanation of the meaning of the data in the body of the table; we will find these pages useful later.

The table itself is divided into two parts, one for each of two different school districts. The classes in the first district (starting on page AR1) were organized in the conventional manner—that is, there are approximately equal numbers of bright, average, and slower children in each classroom. We will call this the "randomly grouped" district. The children in the second district (beginning on page AA1) were grouped according to ability. Their achievement scores for the preceding year were used as a basis for dividing them into three groups: (1) above average, (2) average, and (3) below average children. Each class taught in this district had children from only one classification; this will be termed the "ability grouped" district. The students were all in the fifth grade, 447 of them in the ability grouped district, and 544 in the set of randomly grouped students from the other district. Figure 1–1 is an illustration of the situation for a few of the classrooms in the two districts; Figure 1–2 illustrates the actual arrangement diagramatically presenting an overview of the entire set of data provided in the text.

Now turn to page AR1 of Appendix Table A. This is the set of data for the 25 children from one classroom. Each row corresponds to one child; each column corresponds to a particular type of information. The first four columns

contain sampling numbers, which will be explained later. The next column, headed PL, gives the pupil level for each child; 1 for above average, 2 for average, and 3 for below average. Note that the tests used for classifying the students were given each year to the children of *both* districts, and the students in the randomly grouped district were classified also, for purposes of comparison. The column headed "S" is for the sex of the student; the code used is 1 for boys, 2 for girls. The remaining columns are for achievement and social adjustment scores, and they are described in the first three pages of the table.

SIMPLE RANDOM SAMPLING

Throughout this book, our purpose is to draw conclusions about large groups by selecting a certain small number from each group and using this more limited set of observations to draw conclusions about the larger groups. We begin with

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DEFINITION 1.1

A list of numbers is considered "random" if it consists of consecutive digits from 0 to 9 and has the following properties:

1. *There is no systematic way in which the digits are written: that is, a given digit cannot be predicted from preceding digits.*
2. *In the list, the digits occur with relatively equal frequencies.*

Appendix Table B is a list of this type; it will be used throughout the text. It is designed to give numbers of the type that could be obtained, were one to put 10 bingo-type disks, numbered 0 to 9 in a hat, and draw one out, record it, replace it, and repeat this process thousands of times. This set was generated on a computer, to save labor. The list can be used to generate larger numbers by considering the table as a set of consecutive numbers, each containing three digits, for example, so that beginning at the upper left-hand corner of the first page of Table B and going down, we get 041, 504, 947, . . . , instead of 0, 5, 9.

We now describe how to use this list to select observations at random from a large group. Let the larger group be Part I of Table A (the randomly grouped fifth grade students). Note that each student has been assigned an identification number from 1 to 544. To allow each ID number to appear, we must use consecutive sets of three digits each. To illustrate, we begin at the top left-hand corner of the first page of Table B and work down. On reaching the bottom, we return to the top of the page, using the next three digits, and continue in this fashion. Numbers greater than 544 *and numbers that have already been chosen* are ignored. From this procedure comes the list in Table 1–1. Note that in the table the number 246 (fourth from the end) was deliberately changed to illustrate the ignoring of ID numbers already selected; we are pretending that 246 actually occurred where 130 is.

TABLE 1–1
Selection of a Random Sample of Size 10 from 544 Students, without Replacement

NUMBER IN TABLE OF RANDOM NUMBERS	NUMBERS SELECTED	NUMBERS IGNORED	REASON FOR IGNORING
041	41		
504	504		
947		947	Greater than 544
602		602	Greater than 544
595		595	Greater than 544
855		855	Greater than 544
021	21		
246	246		
746		746	Greater than 544
987		987	Greater than 544
383	383		
372	372		
752		752	Greater than 544
146	146		
483	483		
354	354		
246		246	Already selected
709		709	Greater than 544
778		778	Greater than 544
447	447		

DEFINITION 1.2
The method of selecting students from a list in the manner described above is called "simple random sampling without replacement."

DEFINITION 1.3
If the foregoing method of selecting students is changed to allow numbers already selected to be selected again, the procedure is called "simple random sampling with replacement."

When the method outlined in Definition 1.3 is used, ID numbers already selected are not ignored but are included as many times in the list as they appear, as though they were separate individuals.

EXERCISES

1.1 Select a simple random sample without replacement of ten students from the ability grouped population and make a list of the STEP science scores for each of these students. Obtain the average STEP science score.

1.2 Do the same for the randomly grouped students.

1.3 Can you draw any conclusions from your two random samples about the relative merits of random grouping and ability grouping with respect to science achievement? Describe your reasoning.