SESSION II

COMPUTER-ASSISTED INSTRUCTION IN QUANTITATIVE METHODS

Microcomputer-based tutorials for teaching statistics

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A set of computational and exploratory exercises is described for teaching and remediation in undergraduate statistics. The materials consist of an ensemble of BASIC programs written for the use of a variety of popular microcomputers and a system-independent workbook.

Many instructors believe that the key to mastery of statistics is the successful completion of many sample problems. However, pressures of all sorts frequently infringe upon instructors' implementing programs that might provide opportunities for students to engage in such activities. In addition, the drudgery students typically associate with working the problems and the difficulty instructors have in expeditiously giving individualized feedback to large numbers of students also contribute to making this approach often infeasible. Recently, Bill Froming, Marcia Belcher, and I have worked to develop a set of computer-based exercises that address these issues.

The statistics we focused on were determined by our need to provide undergraduate students with both practice and remediation on techniques that they would have to use in our advanced laboratory courses. This pragmatic orientation limited us to treatments of chi square, means and standard deviations, correlation, z , t , and analysis of variance.

Our materials presently consist of a set of computer programs stored on a flexible disk and a student workbook. The programs were written in BASIC, using, whenever possible, graphics created from the vendor-supplied character set. This has made it possible for us to migrate these materials to several microcomputers fairly easily. Currently, we have versions of the programs running on the IBM personal computer, Apple II, Atari, and Terak systems. The ensemble of run-time, nondocumented programs consume about 100 KB of disk space, but each of the modular components executes in 3-16 KB of main memory.

The workbook portrays the rationale for each statistic and demonstrates its use with a detailed example. It also presents a series of problems for the student to complete using the computer programs. The workbook and the disk are interdependent in the sense that one is of little use without the other. In another sense, they are independent of each other: Because we made portability and migration important design criteria, one workbook may be used for all of the microcomputer versions.

The design of our programs was heavily influenced by insights that emerged as we developed other courseware during the last decade. For example, because so many students lacked typing skills, it seemed important to insure that they were required to make only the minimum number of keystrokes. This implied that complex log-on procedures should be omitted, and that the RETURN key should be used only when absolutely necessary (e.g., to terminate multicharacter numeric entries).

A related design consideration was that the software would have to include routines whose sole function was to help reduce the opportunities for students to make errors, especially those that cause unpleasant surprises such as an abnormal program termination or evocation of an obscure error message. These events can occur for an unfortunately large number of reasons. When illegal arithmetic operations (e.g., division by zero) are attempted, BASIC programs usually stop cold. Similarly, if BASIC anticipates a numeric entry but receives input that it cannot evaluate, some error message will probably be delivered, but the program may or may not continue with another request for the entry.

We found these constraints intolerable. So we set things up in such a way that students could make no entry that would stop a program or cause an unwanted error message to be delivered. After all, one cannot

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jump a wall in PAC MAN or, short of unplugging it, stop the program in the middle of play. A limited-use manipulandum helps achieve these ends in a video game, but we were forced to accommodate a much more complex keyboard. Thus, in our programs, when a student intends to enter "345.6" but somehow types "34jh5W;+6!" instead, and if the program is expecting numeric input at that juncture, it will accept and display only what was intended, namely "345.6". This bit of user-friendliness is accomplished by examining each character as it is typed, checking it for legality, and then accepting and displaying only appropriate characters.

The programs, in addition, exert further paternalism when it appears that students are risking destruction of their recent efforts. In particular, the letter "Q" is used in all programs for the student to indicate a desire to quit work on the current program and branch to the table of contents. Since such branching destroys all intermediate data and calculations, the programs insist that the student make an affirmative response to the query "Are you sure you want to quit?" before the quit instruction is obeyed.

The programs contain two broad categories of exercises. One category includes multiple computational problems for each statistic. These are in the same family of exercises found at the end of the chapter of most statistics textbooks, but they were designed to provide the guided practice our students needed to appreciate the process of determining the correct solution.

The second category of exercises is dubbed "exploratory problems." These were developed to meet a student deficiency that did not surface until we conducted a formal evaluation of some early versions of the computational programs: We discovered then that, even after demonstrating mastery of the rationale and techniques for calculating the statistic, many students had no intuitive grasp of much of the material with which they were dealing. When they encountered the statistic in a different context, for example, they were often unable to interpret it adequately. The exploratory problems that emerged from these concerns encourage students to tweak the statistic in various ways and observe the outcomes. Students work through these exercises in a discovery mode, but they are not left entirely on their own to search for underlying principles; the workbook provides considerable guidance, direction, and prodding to keep the exploration focused.

To use the materials effectively, the student must first read the description of the statistical technique in the workbook, addressing the detailed instructions provided for the computation of the statistic and considering a set of experimental problem descriptions. Subsequently, the student selects the appropriate computational statistic from the computer-driven table of contents and is provided a unique, but constrained, set of data. The student uses one or more built-in

process options to compute whatever intermediate values the workbook prescribes, as well as to determine the final answer. Our process options include the arithmetic operators available on most good calculators plus several special operators, including, for example, one for computing cross-products and one for creating a graphical display of the data. When the student has made the necessary computations and offered a solution, appropriate praising feedback is delivered if the answer is acceptable. More interesting from a pedagogical perspective are the events that occur when a student does not solve the problem. The program steps the student back thorough the computations, requesting all intermediate results and providing immediate feedback as to their accuracy. After this error analysis, the student may attempt to solve the problem again (as often as is necessary to reach an acceptable solution). Because students may perform arithmetic rounding differently from the programs, each program calculates a range of acceptable answers. (The range of tolerance may be altered by the instructor, but in the default mode, it is set to $\pm 2\%$. Employing this "range-of-tolerance" concept also solves all those vexing floating-point arithmetic problems associated with certain systems in which, for example, $2/2$ is reported to equal .999 or the square of 2 is indicated to be 3.999.)

Thus, in contrast to traditional textbooks and manuals in which only solutions to problems are usually provided, the present approach allows the students to determine if and when they are making errors. This seems to eliminate much of the frustration students associate with imperfect performances and, moreover, helps them to formulate better questions when they run into difficulty.

As indicated earlier, we also developed a set of exploratory programs. An explicit effort was made here to incorporate special features that would make moderately deep levels of processing nearly unavoidable. We accomplished much of this by directing students to "play with" the statistical techniques and manipulate the raw data in order to answer "what-if" sorts of questions. Examples of such inquiries include: What will happen to the variance if I add a constant to each score? What if I multiply each score by a constant? What will happen to the standard error of the means when N increases? What will happen to the correlation if one more set of observations is obtained, and they are extremely different from the others? Or, what will happen to F if the variance in one group falls to zero? Providing students with opportunities to discover for themselves the answers to such questions helps make many of the abstract theoretical issues concrete, and hence, more memorable.

In a very literal sense, the student "gets a feel" for the statistic by interactively manipulating displayed data points and observing the consequences for the statistic. The exploratory correlation program, for

example, initially displays a pair of data points in the X-Y space defined by the coordinates. The student is given a series of problems of the form: "Place on the graph the smallest number of data points for the correlation to be -0.8 ." Later, the student might be asked to "add the fewest number of data points to make the value of the correlation equal zero." As each new data point is positioned, the student estimates the current value of r , and the actual value is then revealed. The student repeats this procedure, adding additional data points, until a satisfactory representation is achieved. Then the student may erase all that has just been done and try the same problem again, proceed to another problem that has different initial parameters, or quit.

In many of our exploratory programs, the keyboard is used as an asynchronous device. This technique allows executing programs to peek at the keyboard every so often to see if the student has made an entry and shift their focus accordingly when a keypress is made. This makes it easy to set up activities that have at least a family resemblance to the popular video games. In one exploratory program, for example, students view

a continuously changing display of a large number of digits that represent a continuous sampling from an underlying distribution but in certain respects look like a bank of slot machines gone berserk. The display will be in this state of flux until the student makes an overt response (in this case, pressing the space bar) in order to momentarily freeze the display and collect the sample composed of all the numbers in view. The obvious appeal of this utilization may be related to the fact that students who often resent using "canned" data feel that they, rather than the computer, are controlling the situation. In practice, their decision/action/decision cycles resemble an ongoing process operation rather than discrete trials. The consequences of each of their actions and failures to act are immediately visible in the graphical display. Such attributes are, of course, very important in the popular electronic arcade games, and it would be foolish not to try to capitalize on their real-time virtues. We have not yet been able to give statistics the attentional demands of FROGGER or the visceral appeal of SPACE INVADERS, but we are working on the problem.