## Symposium on the Teaching of Statistics

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## How Should We Reform the Teaching of Statistics?

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### 1. Introduction

Over the last 15 to 20 years, in response to the increasing demand for statisticians in research, industry and commerce, the teaching of statistics in the British universities has expanded greatly. Most universities now have a Department of Statistics, and more of the gaps are being filled each year. Many technical colleges offer short courses in statistical methods and more elaborate courses at the Dip. Tech. level are becoming available.

Demand for statistical training at universities comes broadly from two classes of student:

(a) Those aiming at becoming professional statisticians. Most of these will have previous mathematical training and will subsequently become working statisticians of one kind or another, attached to research teams or involved in planning and public administration. Some will be employed by universities and technical colleges where part of their time will be occupied by teaching duties.

(b) Students in other subjects who require a working knowledge of the statistical methods that are of use in their own subject.

Demands at technical colleges are, we believe, essentially similar, but with more emphasis on fully developed and standardized methods, particularly those relevant to industry.

In addition to the requirements of universities and technical colleges there has recently been a move to introduce the subject of statistics into schools. The subject is now included in both the Ordinary and Advanced Levels of the G.C.E., though at present relatively few candidates enter for these papers. In part this is a reflection of the growing recognition of the importance of statistics, in part the consequence of a desire to improve mathematical teaching in schools and introduce subjects which are likely to be of practical interest to the students.

## 2. IS REFORM NEEDED?

It may seem unduly critical, when opportunities for obtaining a training in statistics are being expanded so greatly, to suggest that the training provided is not all that it should be. Certainly, enterprising and stimulating courses are now available at several universities. And if the end-products are sometimes disappointing it may be that this is attributable, at least in part, to the poor quality of the material rather than defects in the courses.

Nevertheless, just because teaching has been expanding, and is likely to expand further, the time seems opportune for an examination of what is at present being taught, and whether this is as effective as it should be in producing competent statisticians. Certainly some courses require drastic revision, and even the best should not be above scrutiny. The need for such examination is, we believe, general, and not confined to our own subject. The issue was well stated by Professor A. G. Lehmann, Dean of the Faculty of Letters, Reading University, in a recent letter to *The Times* (December 27th, 1963):

> Important though these issues are, it may be wondered whether another matter is not even more fundamental, though it has been little enough referred to: namely the need . . . for the actual content of courses in very many faculties to be put under searching scrutiny. . . . Are we so sure that no undergraduate is today being invited to go through long ritual exercises or acquire masses of information of a kind which adds marginally little to a real grasp of his discipline? . . . The matter is not one that can be dealt with by ukase. What is needed is a widespread habit of continuous scrutiny of what it is that really stands at the core of each academic discipline.

Our own experience suggests that all is not well. It is our practice, when interviewing candidates for posts in the Department, to ask them what ground they have covered, and then to see how far they have really grasped the principles by asking a few simple questions. The results have frequently been alarming. Not only have candidates revealed unexpected gaps in their course, but their minds were often in a complete fog concerning matters on which they claimed knowledge. Some, for example, though professing to know about randomized blocks, had not grasped the essential points, that the replicates are arranged in blocks, with randomization within blocks. Others when asked what a two-stage sample was would vaguely describe a two-phase sample, or possibly a stratified sample. Even the *t*-test could be a source of confusion.

These, of course, are the weaker brethren, on whose papers one writes OUT as soon as the door is shut. But at least from their written applications they appeared candidates worth consideration for Assistant Experimental Officer posts. And they were all of them spending or had spent a year or more of their lives being trained in statistics.

It is easy to provide similar examples at a higher level, but perhaps even more revealing is the extent to which we and our colleagues at Rothamsted and elsewhere are approached by university biologists who have been unable to get the help they required, even when their own university possessed a statistics department. Others, finding that their requirements are not met, decide that statistics is of no value. Thus on the leader page of a recent issue of *Science* (May 3rd, 1963) we find the following:

> Sir Alexander Fleming didn't have the benefit of modern instrumentation, a dishwasher and a statistician to tell him what he had found. The latter, of course,

could only tell him whether the results were "significant". I suspect Sir Alexander knew this already, don't you?

Also revealing is the statistical confusion that we encounter in papers on biological subjects submitted for publication (and indeed in some actually published) in scientific journals. It is depressing to find how much good biological work is in danger of being wasted through incompetent and misleading analysis of the numerical results; in many areas there has in fact been little improvement over the last 15 or 20 years. Our profession has here a clear responsibility which it is equally clearly not fulfilling. Our co-workers in other subjects deserve better of us than this.

### 3. RELATIVE EMPHASIS ON THEORY AND PRACTICE

We do not think that anyone, at least in this country, will dispute that statistics is essentially an applied subject. Moreover, of those who take courses in statistics, the great majority do so with the idea of learning how to use statistical methods for the handling of numerical data, "making sense of figures" as Fisher once described it. As with all subjects involving mathematics, however, an ever-increasing body of theory is constructed, and because the developments of the subject are largely in the hands of mathematicians there is a tendency to revise and elaborate this theory, sometimes to unnecessary length.

Some branches of theory which have arisen from statistical needs have general logical interest and appeal to mathematicians who are not interested in their applications. The whole theoretical basis of probability and inductive inference is a matter of wide general interest; the combinatorial theory that has arisen in connection with experimental design has a more restricted but genuine mathematical appeal. Most statistical theory, however, has its justification as a foundation for sound practical methods, and is only of interest in so far as the methods themselves are relevant and useful.

In considering how much theory students should be taught, one must, we think, distinguish clearly between mathematical machinery and basic logical principles. The machinery can be learnt without great difficulty by mathematical students, provided they are sufficiently competent and are prepared to devote adequate time and effort to the matter, but it may present very serious hindrance to other students who are less able mathematically but who can nevertheless become very useful statisticians. A simple example will clarify thought. It will be agreed that every serious student of statistics, whatever his background, should know what the $t$, $\chi^2$ and $F$ distributions are distributions of, in order to have a proper understanding of their uses. But, in order to make use of them, he does not have to know the formulae for the functions which represent them, still less does he require to know how to establish these formulae, or the integrals of the functions, which last are indeed only needed when tabulation of the functions is to be undertaken. It is far more important to appreciate how the three distributions are related, a point about which many non-professional statisticians remain in ignorance.

University courses in statistics for mathematicians have a tendency to start by constructing a general body of mathematical theory and only then proceed to practical examples of the use of this theory. Thus, many courses in statistics are termed "probability *and* statistics", as if probability were a subject which could be profitably taught in its own right, and which must be thoroughly mastered before statistics can be tackled. To us it seems that all statistics (except for statistical summaries obtained by complete enumeration) involves probability, and conversely all applications of

probability theory are essentially statistical in nature. A sound concept of what is meant by probability is best built up naturally in the student's mind in the course of solving and thinking about practical statistical problems. Only then is he capable of appreciating the finer points such as are involved in the logic of inductive inference.

It is, in fact, easy to exaggerate the amount of mathematical expertise that is necessary to the applied statistician. From a study of the literature, it might seem that rather advanced mathematical topics were continually arising, so that a fair degree of mathematical sophistication was an absolute requirement. Multiple regression requires matrix algebra; the design of factorial experiments is related to the theory of finite groups; spectral analysis rests on the concepts of Hilbert space. What is insufficiently realized is that the advanced mathematical topics are often either a luxury that can readily be dispensed with, or else are merely touched upon in their most elementary aspects. Though matrices are convenient in the exposition of least-squares theory, as is the notion of a group in the discussion of confounding and fractional replication, in both instances only the simplest properties are used, and even these can, if necessary, be by-passed without difficulty. An extreme example is provided by Darlington's (1958) presentation of linear least squares smoothing and prediction theory. This topic, as developed by Wiener and Kolmogorov, contains a good deal of formidable mathematics, using such concepts as measurable spaces and generalized Borel fields. Darlington showed that all this could be avoided by making the assumption, perfectly reasonable in practical applications, that all relevant power spectra are rational functions of frequency. We would be interested to learn how many of our colleagues regard this as a brilliant stroke as against those for whom it removes all interest from the topic.

As well as this, the possession of skill in advanced mathematical manipulation provides no guarantee that a man will be capable of understanding and appreciating basic logical principles, much less that he will make a good statistician. One has only to look at the violent disputes that have raged on probability and inductive inference, or to scan the pages of a journal such as the *Annals of Mathematical Statistics*, to realize this. This lack of understanding, we suspect, is in part due to defects in modern training in theoretical mathematics. From an early age, mathematicians are encouraged not to take responsibility for the validity of their assumptions, or for their relevance to the problem they are attempting to solve. They are taught that they cannot be seriously criticized if they clearly state the assumptions they have made.

## 4. CONTENTS OF COURSES FOR PROFESSIONAL STATISTICIANS

We will not attempt here to lay down exact syllabuses for courses. This, we feel, is a matter which requires deliberation by a group of statisticians of wide and diverse experience. But we can give some indication of our own ideas.

The inclusion of a topic in a general course should be judged on the following criteria:

(1) How far the techniques to which it gives rise are likely to be required by practising statisticians

(2) How far its mastery contributes to a general understanding of statistical reasoning and improvement of statistical skill

(3) The ease with which it can be mastered.

The branch of statistics which we believe should form the basis of all general courses is normal error theory, leading to Gaussian least squares. Normal error

theory does not, of course, embrace the whole of modern statistics, but it covers a wide field, including the design and analysis of experiments involving quantitative variates, sampling survey design and analysis, regression, etc. Moreover, it provides an excellent introduction to the general theory of estimation, tests of significance, and inductive inference, and a good foundation for the study of more advanced topics such as the analysis of stationary time series and multivariate analysis.

Of the special topics that are included in least-squares theory we would rank the basic principles of the design of experiments most highly. We believe statisticians should be introduced to this topic at a very early stage. Knowledge of the basic principles of experimental design gives an idea of the importance of planning in an investigation, both for ensuring validity and increasing efficiency, and brings home to the statistician his responsibilities in this matter; it also introduces him to an application of statistics where certain and valid conclusions can be drawn, in contrast to the qualifications that must necessarily hedge most of the conclusions derived from observational data. Clearly, in a general course the more complicated devices cannot be fully covered, but split plots, factorial design, simple examples of confounding ($2^n$ and $3^n$), estimation of error from high-order interactions and fractional replication are basically simple and immensely useful. Personally, we would include reference also to such designs as balanced and partially balanced pairs and incomplete blocks, and change-over designs, without necessarily any attempt to describe their analysis. Complexities such as the estimation of partially confounded effects can be left aside, with reference to textbooks where the solutions can be found if required.

Regression methods and covariance should also be fully treated, including extensions of simple linear regression such as the fitting of parallel regression lines and lines having a common $y$ value for a given $x$ value; the need, when studying the separation of non-parallel regression lines, for taking $y$ values for a common $x$ value near $\bar{x}$; and the bias in $b$ when $x$ is subject to error. Multiple regression is becoming of increasing importance now that electronic computers are enabling the method to be applied without excessive labour; its complexities and particularly its limitations should therefore be thoroughly covered. Multiple regression leads naturally to more general multivariate analysis, such as discriminant functions, principal components, etc., but serious treatment of these can well be deferred until other more elementary matters have been dealt with.

Sampling design is a more specialized topic which need not be dealt with at length in a general course, but is worth introductory treatment. The basic concepts are simple, and most practising statisticians encounter sample surveys or the sampling of material at some time in their career; sampling is also intimately related to quality control. Sampling design also gives good insight into the variance-component approach to correlated material, and is complementary to experimental design. Stratification, variable sampling fractions, multistage and multiphase sampling, and the simpler methods of estimation associated with them, including ratio and regression methods, may well be included; also methods, applicable to the simpler cases, of assessing the relative efficiency of different types of design and size of unit. The interpretation of survey results, including such topics as the adjustment of the strata means of one variate to eliminate the effects of inequalities in the different strata of the frequency distribution of a second variate, and the fitting of additive constants to multiway tables, should be given much fuller treatment than is usually accorded, for many statisticians who are not concerned with the planning of surveys will have to make deductions from published survey results.

Once the handling of quantitative material subject to the normal law of error has been grasped, the analysis of qualitative data can be much more readily mastered. Many qualitative data are appropriately treated by extensions of quantitative methods, e.g. the fitting of probit lines, and the analysis by similar techniques of multiway tables of percentages. For large samples the normal approximation to the binomial or multinomial distribution is frequently adequate, provided the covariances are not forgotten.

Mathematical theory should be introduced as it is required, and excessive generalization avoided. The capable student will do his own generalizing; the less capable will only be confused by it. The emphasis should be on efficient estimation, with proper measures of the accuracy of the estimates obtained. Tests of significance have an important, but subsidiary, place in most practical statistics; they are popular with non-statisticians, who like to feel certainty where no certainty exists, but the present excessive emphasis on them should be discouraged. We question also whether the paraphernalia of general distribution theory, such as moment generating functions and characteristic functions, which are currently introduced at an early stage in many courses, are really necessary in a general course.

The introduction of electronic computers should have considerable effect on statistical courses. A good deal of dead wood, in the form of elaborate routines for desk calculation and inadequate approximations now rendered unnecessary, can be excised. Topics once of no more than academic interest have become of great practical importance, and many are new enough to bring the enterprising student into contact with research actually in progress. Thus the fitting of constants to multiway tables, which was a tedious chore on desk calculators even with quantitative data, and almost impracticable with any exactitude with quantal data, is a routine service which should be expected from any properly programmed computer. Yet how many statisticians are taught the power and utility of these methods, how many, indeed, leave the university believing that quantal tables should be analysed by some elaborate application of $\chi^2$?

In addition to the general course the better students should be given the opportunity of making a more thorough study of particular branches of the subject. Advanced mathematical theory can find its place here, as the subject of specialist courses which would attract the more expert mathematicians. Special topics such as stochastic processes and advanced experimental design and analysis can also be dealt with in this manner.

We consider advanced study of statistical topics preferable to specialization in fields of application, for two reasons. Specialization in fields of application has led in the past to each subject developing its own brand of statistics, with lack of cross-fertilization; it took a long time, for example, for the new ideas on experimental design developed in agriculture to spread to other branches of research, and psychology still seems to have its own brand of multivariate analysis. In addition, good advanced specialized courses will give older statisticians who are still in contact with universities an opportunity for learning new techniques.

## 5. COURSES FOR STUDENTS IN OTHER SUBJECTS

Here, training in the correct use of statistical methods is required. Most of the theory can be taken on trust. Nevertheless, it is important to inculcate an understanding of the basic ideas that underlie the methods used; otherwise they will be mechanically and inappropriately applied. In experimental design, for example, the

function of randomization should be thoroughly taught, as should the way in which the randomization system determines the form of the analysis. Analysis of variance should be introduced via experimental design instead of, as often happens, the other way round. The fact that experiments provide estimates of the treatment effects and of their errors, as well as formal tests of significance, and that the estimates are frequently of more interest than the tests, should also be emphasized; otherwise we shall be confronted (as has actually happened) with reports on experiments such as "the $z$ is not significant" without any numerical results.

The topics included in courses of this nature must be governed by the requirements of the subjects to which they are oriented. Thus a course for biologists will differ markedly from one for economists. We consider, however, that all courses should include the elements of experimental design and sampling, for the reasons given above.

It is important that the student should be made aware of the limitations of the methods he is taught. He should know when to seek professional assistance and should not be ashamed to ask for it. Equally, the world being the imperfect place it is, he should be taught to examine such assistance critically, and should be encouraged to question it if it appears to be erroneous or to miss the point.

Who is to give these courses? In practice they are often given by non-statisticians, either mathematicians whose knowledge of statistics is derived solely from textbooks or workers in the subject concerned who themselves have learnt some statistical methods and hand on their hardly won knowledge. This we regard as a potentially dangerous procedure. It is often a case of the blind leading the blind, with the result that erroneous methods gain currency and are perpetuated. But, unfortunately, the obvious teachers, the professional statisticians employed by the university statistics departments, frequently fail to expound the subject in a sufficiently down-to-earth and realistic manner to be intelligible to their audience; and, let us confess it, many of them are so little aware of practical problems or of the correct methods of handling them, that even when intelligible they are a source of confusion rather than enlightenment. This, we believe, can only be cured by a much more practical outlook in the university statistics departments.

## 6. EXAMINATION QUESTIONS

The primary purpose of examinations is to test the knowledge and ability of the student. The interest in the questions set is not, however, wholly ephemeral. The papers indicate, often much more clearly than the syllabus, what the student is actually taught (or is expected to learn for himself). In so far as there is continuity from year to year—and this is almost essential in examinations which cater for students from several teaching sources, and tends to be fostered also by the employment of "outside" examiners—they largely condition what is actually taught. They have considerable educative influence (for good or bad) on subsequent generations of students, since many students, not unreasonably, spend a good deal of time working through previous papers and discussing with their supervisors and colleagues the solution of questions which defeat them. They are also revealing as indications of what the examiners think is important. Incidentally, may we urge that students be examined on all matters in the syllabus judged to be of importance, and that matters not any longer considered important be promptly deleted. We have been struck by the discrepancies between many syllabuses and the examination papers supposedly based on them.

Apart from general issues of what branches of the subject should be covered by the examinations, we consider it important that questions should be framed so as to

give students a lead in clear thinking, and a sense of their duties and responsibilities as statisticians. Questions starting from false or unrealistic premises and leading to questionable conclusions are particularly to be avoided, as are those in which practical problems are treated unrealistically. Should students in 1963 be confronted in their examination by phrases such as "if the prior distributions of $\mu$ and $\log \sigma$ are independent and both uniform over the whole straight line"? Should they be asked to prove that if $X$ is normally distributed with mean $\theta$ and unit variance the confidence region for $\theta$ of least average size when $\theta = 0$, for say $\alpha = 0.05$, is

$$X - 1.64 \leqslant \theta < 0 \qquad \text{if} \quad X \leqslant -1.64,$$
$$X - 1.64 \leqslant \theta \leqslant X + 1.64 \quad \text{if} \quad -1.64 < X < 1.64,$$
$$0 < \theta \leqslant X + 1.64 \qquad \text{if} \quad 1.64 \leqslant X,$$

with the implication that the statistician is at liberty to say that if $X = 0$ is observed $\theta$ has confidence limits of $\pm 1.64$, instead of the accepted and well-understood $\pm 1.96$? This last is the sort of thing that is bringing the whole science of statistics into disrepute.

On the practical side, one of us (Yates, 1964) gave an example of a recent Diploma examination question on a sequential test for two drugs which, besides being open to criticism on statistical grounds, gave the impression that it was no part of the duty of a statistician to question the premises and procedure put forward by the clinician. A further example, taken from a very recent paper, is the following:

In a large underdeveloped country it is desired to grow corn in a region newly cleared of forest. This region is divided roughly into four areas of different types of soil and an experiment was carried out to investigate the most suitable varieties of corn and most suitable fertilizers for these areas. There were no differences in the costs of the varieties tested or in the costs of the fertilizers.

Four different varieties of corn, A, B, C, D, and four fertilizers $F_1$, $F_2$, $F_3$, $F_4$ were used in the experiment which was carried out in the following way.

In each area a large field was marked out into 32 plots of equal size and each of the 16 combinations of variety and fertilizer were allotted at random to two of the plots, the plots being the same size in each area.

The student was evidently intended to accept this as a good set of trials, as he was given a summary of the results (presumably hypothetical) in the form of an analysis of variance and two-way tables of means (area × fertilizer, area × variety, variety × fertilizer), and was asked to "write a short report making recommendations for the varieties and fertilizers to be used in the future".

The analysis of variance showed that areas (A), fertilizers (F), A × F and F × V were significant at $P = 0.05$, the other mean squares being little greater than the error mean square. Clearly then, accepting the results at their face value, the simple way to determine the best fertilizer–variety combination in a particular area is to take the highest yielding combination *in that area*. But since the three-way A × F × V table of means was not given this cannot be done; the table could be reconstructed on the assumption that the A × F × V interactions are negligible, but there would certainly not be time for this in the 40 minutes or so allotted to the question, even if the student (second-year undergraduate) knew the technique.

Our main objection to the question, however, is that it suggests that positive recommendations *can* properly be made on the basis of these results, whereas the only recommendation that seems appropriate is that the whole investigation should be

started afresh. In the first place, in all cases in which alternative quantitative treatments are to be tested the question "How much?" must be asked, as well as "Which?"; in the case of fertilizers the situation is more complicated since the fertilizers commonly used are mixtures of three quite distinct major plant nutrients, and any proper investigation requires that the responses to varying amounts of these nutrients be determined by a proper factorial design, whereas interactions of the responses with varieties are usually of secondary importance. Secondly, the fact that there was only one experiment on each soil type makes it quite impossible to say whether the differences between experiments are due to soil types or to other differences between the experimental fields which may have nothing to do with soil types. Thirdly, it is well known that both varietal differences and fertilizer responses vary with season, and therefore repetition over years is essential. And fourthly, it might have been indicated as a minimum of good experimental design that the experiments were arranged in blocks.

All this might not matter if the examinees were a thoroughly sophisticated lot and could be relied on to put the examiner in his place. But of course they are not. A number of them may well be foreign students who will in due course become statisticians in underdeveloped countries. It is sad to think that some of them may take the scheme described in this question as a model for what should be done in their own country.

## 7. STAFFING AND FUNCTIONS OF UNIVERSITY DEPARTMENTS

The greatest weakness in the organization of statistics in many universities seems to us to lie in the fragmentation of statistical activities over many departments. The training of professional statisticians and research into mathematical theory is the responsibility of a statistics department, headed by a professor or a reader, but often with only one or two lecturers under him. Much of the practical statistics that is required in the course of research work in other departments is done by workers in those departments, who may or may not be trained statisticians.

As already indicated, we think that this lack of contact of the statistics department with practical statistics is bad for the training of professional statisticians. It also leads to much sterile and unrealistic research into mathematical theory. It is worth remembering that most of the recent advances in methodology and the associated theory which have proved practically useful have been the work of men who have first and foremost been engaged in applying statistical methods to practical problems.

How can university statistics departments attract practical work? First, they must have the will, and also the competence; it is no good offering statistical advice unless it is good advice. But also, we think, they must be able to offer a statistical service (including the provision of computational facilities) to those who require it. This for three reasons. First, many research workers have neither the time nor the ability to undertake large-scale computations themselves, or to organize the work within their own department. Secondly, if such a service is not offered, fragmentation of statistical activities will inevitably result; first, computing staff will be appointed in other departments, then statisticians. Thirdly, many problems have novel features on which sound advice cannot be offered without actual analysis of the data; no statistical "consultant" can, we believe, function properly unless he himself tackles novel problems numerically and has good computing services at his disposal.

This, of course, should not be taken to imply that there should never be statisticians in other departments. For a department with a large and continuing load of

statistical work it may be reasonable to have a statistician within the department, but we would hope that in such cases the person concerned would have close and friendly relations with members of the statistics department and would consult them on special problems. It is important that such persons should also take part in the teaching programme of the statistics department.

The provision of a statistical service requires adequate staff. First, there must be enough research staff to permit reasonable specialization in different branches of statistical methodology and acquaintance with a variety of applied fields; the staff must also have time for the work. Secondly, there must be sufficient intermediate and computing staff; by intermediate staff we mean people, generally graduates, corresponding to the Experimental Officer Class in the Scientific Civil Service, who, though not expected to do original research work, can take charge of and supervise the more routine work. It is in no way essential that the graduate staff should be recruited solely from those with degrees in mathematics. Our experience at Rothamsted has repeatedly shown us the value of employing, as professional statisticians, non-mathematicians who have become interested in statistics.

All this of course costs money. And, if the money is forthcoming, the staff (and the accommodation) must be found. Neither money nor staff will come in a day. But nor can a statistical service be built up in a day. And if from the first small beginnings it is found that other research activities of the university are benefiting, support for further expansion will be forthcoming, often from unexpected quarters.

With the introduction of electronic computers the present time is particularly opportune for development on these lines. For if a computer is to be effective in statistical work good general programmes must be written, and there must be people who know their way around these programmes and can advise on their use. If the Statistics Department does not tackle this work it will be done piecemeal, and probably ineffectively, by people who lack the necessary statistical knowledge.

We also believe that experienced statisticians working at research establishments and in industry could collaborate usefully with universities and technical colleges, and that this would be mutually advantageous to both groups. Secondment is one possibility, but this is likely to be difficult for key workers. Regular participation by part-time lectureships is probably more effective, and might do much to reunite our dangerously fissile subject. The reverse procedure, with university statisticians spending their sabbatical years in research establishments or taking on part-time appointments, should also be encouraged.

## 8. ELECTRONIC COMPUTERS

Many statisticians have been curiously reluctant to recognize the importance of electronic computers; even now there is little serious attempt by university statistical departments to study the ways in which they can best be used in speeding up and facilitating the application of current statistical methods, and in developing new methods which would be impracticable with desk calculators and conventional punched-card machinery.

This reluctance is reflected in the lack of instruction to statistical students in the application of computers to statistical problems, or at least in the failure until very recently, as judged by examination papers, to give students any credit for such knowledge. Thus, in spite of the fact that Cambridge University has had an electronic computer since 1949, no questions were asked on computers in the 1959 and 1960

Diploma examinations, and even in the 1963 examination the only reference to computers was in a particular field of application. Similarly in the 1962 London Diploma in Statistics no question on computers was asked. London University does require those taking the B.Sc. (Special) in statistics to take two papers on Numerical Analysis and Computational Methods, and the syllabus for this topic includes applications to statistical problems, but recent papers contained no questions that were of direct relevance to the analysis of statistical data; nor has there been any mention of magnetic tape. Yet it is a fact that most practising statisticians in the immediate future will have access to large and powerful computer installations and will be expected by their employers to make effective use of them. They will find themselves very ill-prepared for the task.

Lack of lively and up-to-date instruction on the use of computers is also unfortunate in that it tends to divert the more enterprising and go-ahead students from the study of statistics. Instead they take up the study of numerical analysis and computer methods, and are thereby permanently lost to statistics.

Computers are good servants but bad masters. There has been plenty of statistical nonsense produced on desk calculators, but this will be nothing compared with the flood that will emerge from computers if they are not wisely used and firmly controlled. It is up to our profession to direct this use and exercise this control.

### 9. THE PLACE OF TEXTBOOKS IN STATISTICAL TEACHING

We suspect that insufficient reliance is placed on textbooks, and that the wrong textbooks are often recommended. It has always seemed to us that it is much easier to learn mathematical subjects from textbooks than from lectures. Unless a student has a phenomenal memory he must necessarily spend most of his time in lectures taking copious notes of formulae, numerical computations, etc.; even so these notes are often inaccurate and incomplete. The verbal connective tissue is almost certainly so. And, of course, most lecture notes are inevitably untidy, and void of cross-references.

Consequently, lecture notes become progressively less useful as time passes and memory of what was actually said fails. A textbook, on the other hand, becomes more useful as the student gets to know his way about it. Textbooks, also, have the advantage that the student can choose his own pace of study. Points missed at first reading may be comprehended on a second reading, whereas a point missed in a lecture is lost for ever, or at least until recovered later from another source.

All this presupposes that good textbooks exist. It is true that there are many shockingly bad books. But there are some good ones, and more good ones will be written if there is adequate selective demand. It seems to us that one of the lecturer's main tasks should be to recommend appropriate books, set a programme of reading and computational exercises, and use his lecture time (which might well sometimes be reduced) to supplement these books and amplify points he thinks are not adequately dealt with, *after* the relevant sections have been studied. The student should be compelled to acquire personal copies of these books. He will need them later in the exercise of his profession.

We may, of course, be wrong in all this. It may be that laboriously taking lecture notes impresses a subject on the student's memory better than the study of a book. Personally we doubt it, but we would point out that very little serious experimental work on different teaching methods has been done, particularly at university level.

Might it not be appropriate if pioneering work of this nature were undertaken in conjunction with courses of statistics, which are themselves intimately concerned with the inculcation of the experimental method?

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