Jour. Ind. Soc. Ag. Statistics
Vol. XXXIX, No. 2 (1986), pp. 107-120

TEACHING OF STATISTICS AND STATISTICAL CONSULTING*

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I feel highly honoured to be invited to give "Dr. V. G. Panse Memorial Lecture" this year. Although my direct association with Dr. Panse was brief, I had the distinct privilege of attending his lectures and even playing bridge once with him as his partner. He represented the best among his peers in research, academics and administration. His elloquence is legendary and he provided highly distinguished leadership as Statistical Adviser to the Indian Council of Agricultural Research after Dr. P. V. Sukhatme assumed the leadership of statistics at the Food and Agricultural Organization of the United Nations.

While I was a Visiting Assistant Professor of Statistics at the Michigan State University, East Lansing during the academic year 1957-58, Sir Ronald A. Fisher, the founder of modern statistical inference, design of experiments and so many other things in statistics and genetics, was also a Visiting Professor of Statistics there for one quarter. It was my great privilege to have met Fisher under whom Panse studied. Sir Joseph Hutchinson, whose work with Panse on the use of progeny row breeding (of cotton) of experimental techniques involving replication, randomization, and local control is well known, mentioned Panse to Fisher when the latter was in India in January, 1938. 'Later that year, Panse, in turn came to Galton Laboratory to study under Fisher' Joan Fisher Box in her book on '*R. A. Fisher : The life of a scientist*' provided the above anecdote among many others on Fisher's association with statistics in India.

*Dr. V. G. Panse Memorial lecture delivered on 24th July, 1987 at I. A. S. R. I., New Delhi.

My own interest in statistics developed as a result of my summer job as a Computor under Dr. P. V. Sukhatme in 1944 when he was Statistical Adviser to the Imperial (Indian) Council of Agricultural Research (ICAR). Through his support, this led to my doctoral degree in statistics at Stanford University. I owe a great debt to Dr. Sukhatme for my statistical career. Through the years my association with the Indian Agricultural Statistics Research Institute has remained active and I have visited here for longer periods of time in 1969 and 1980. The visits of several of its Directors including Drs. P. V. Sukhatme, G. R. Seth, Daroga Singh and Prem Narain to The Ohio State University for varying periods of time has enhanced this relationship.

1. Introduction

The topic of teaching of Statistics and Statistical Consulting has been of special interest to me. I with Douglas Wolfe of The Ohio State University organized the first conference of its kind in 1980, in honour of Professor D. Ransom Whitney on his 65th birthday. The proceedings of this conference were published by Academic Press in 1982. Since then, several conferences on teaching of statistics have been organized by the International Statistical Institute and their proceedings are available.

Teaching of Statistics has been of major concern of top statisticians. R. A. Fisher, in a presidential address in 1937 delivered at the opening of the Statistical Conference in Calcutta said the following :

'Responsibilities of teaching statistical methods in our universities must be entrusted, certainly to highly trained mathematicians but only to such mathematicians as have had sufficiently prolonged experience of practical research and of responsibility for drawing conclusions from actual data, upon which practical action is to be taken'.

In the book, *R. A. Fisher* : *Life of a scientist*, Joan Fisher Box (1983) gives the above. The quote is from E. S. Pearson (1956).

'University teachers are unique among professional men having no training whatsoever in their profession. They have to learn by experience and some of them never do learn. One would expect that in such circumstances, a good deal of thought would have been given to the technique by which statistical ideas should be introduced to students', Rustagi and Wolfe (1982).

Harold Hotelling in 1940 wrote a long article on teaching of statistics and emphasized the importance of foundations of probability and statistical Inference with considerable depth as well as exposure to real problems before a student graduates. Many departments of Statistics in the United States and abroad were formed on the basis of his recommendations.

Professor Jerzey Neyman is known to have developed a unique method

for teaching statistics students at the University of California, Berkeley. He proposed a problem or a theorem at the beginning of the class. The students then went to the blackboard to provide solution to the problem or prove the theorem. He kept on providing hints for the students so that by the end of the class hour, some problems have been solved and some theorems have been proved. This method of teaching provides an extremely important education to students for research. However the method requires highly seasoned teachers.

2. Statistics at the Ohio State University

My own experience of teaching statistics has accumulated at The Ohio State University over the past 25 years. Many of my observations on teaching of Statistics and statistical consulting, therefore, are direct outcome of that experience. It would be of interest to keep in view that The Ohio State University (O.S.U.) is one of the very few comprehensive universities in the world. It has almost all professional schools such as Medicine, Optometry, Dentistry, Nursing, Allied Health Professions, Veterinary Medicine, Agriculture and Law. The University has colleges of Business, Engineering, Physical, Biological and Social Sciences, Music, Theatre and Home Economics with other allied enterprises such as hospitals including Cancer Institute, Psychiatric Hospital and Animal Hospital as well as an Airport, an Agricultural Experiment Station, a University Bus System, a Police Department and Residence Halls for more than 20,000 students. It has about 55,000 regular students in a given year, has 3000 full time faculty and about 4000 part time faculty. Part time faculty consists of Graduate Teaching Associates who also study for master and doctoral degrees. It is a huge enterprise,-a city within a city. The Department of Statistics at The Ohio State University was created in 1974 and the statistics faculty teach undergraduate, graduate and service courses. It is obvious that with a comprehensive university of this size and make up, a large number of courses in Statistics will be taught by departments other than Statistics. Statistical Consulting is also provided by other units in the University. We have large classes, sometimes having 600-700 students in one course in a given quarter. We deal with the teaching of these service courses in different ways, depending upon the nature of the course.

3. Statistics Teaching

By teaching of Statistics, we mean teaching all the areas of statistics; theoretical or applied, medical or agricultural, industrial or sociological, economic or biological and so on. All these areas of statistical study

only differ in their fields of applications—the theory is the same. Basically a student of statistics must be introduced to the theory and practice of statistics, must know data management and analysis. He/She should have experience of consulting with people in the subject area of some field.

The basic questions about teaching of statistics and statistical consulting are :

1. What to teach?
2. How to teach it?
3. Who should teach it?
4. To whom, statistics should be taught?

Statistics is now taught at all levels of schooling, starting from elementary school to graduate school. We shall only concentrate on teaching statistics at the College level here. At the high school level, teaching of statistics has also been of concern to the International Statistical Institute. A Task Force appointed by the International Statistical Institute on the Teaching of Statistics at school level has prepared a report under the editorship of Professor Vic Barnett (1982). The report describes and comments upon the prevailing situation in a large number of countries in the world. Education in statistics is a necessity for the modern man. The concepts of randomness, chance variation and its measurement are fundamental to a person's understanding of the real world. Every experimental scientist needs to analyze his data, every businessman needs to make decisions under uncertainty and every administrator requires digestion of information to plan his actions.

4. Graduate Programme

Advanced Theory of statistics is essentially a subject of graduate study leading to master's and doctorate degrees. The theory of statistics needs the language of mathematics and hence a firm grounding in basic concepts of calculus and linear algebra has become a necessity for graduate work in statistics. Students with majors in fields other than statistics, study statistics through graduate level *service courses* and they will be discussed later. Since statistics is the science and art of decision making under uncertainty, it is imperative that the mathematical models of uncertainty, that is, the theory of probability should be necessary for the graduate work in statistics. The foundations of the statistical inference can be built upon the concepts of probability. A graduate student of statistics should be made aware of a large number of available statistical

methods such as those of sampling, design of experiments, multivariate analysis, regression analysis, and nonparametrics.

Master's level programme must also include a course on statistical computing including methods of optimization and simulation. Programmes producing various kinds of statisticians, such as industrial statisticians, should include courses on statistical reliability and quality and productivity improvement statistics. Programme for training a biostatistician should include courses on survival analysis and design of clinical trials. Similarly agricultural statistician needs training in agricultural survey methodology, statistical genetics and so on. To cover a wide variety of applications, many universities have developed one major with a master of applied statistics programme. Of course the student must be trained in providing consultations to the subject matter scientist and hence should know how to deal with clients. The art of teaching consulting is still in its early development and there are very few books dealing with this topic. Boen and Zahn (1982) have made one of the few attempts in this direction. The training obtained through internships in statistical consulting operations, found in various institutions, provide a way to develop client-consultant relationships.

Graduate students should be made aware of the current literature in statistics through special courses of this type. This training allows the student to remain current in developing statistical literature. Through field work in certain type of graduate programme, the enrichment of statistical training can be achieved. Such programmes, for example, were part of the training at the Indian Agricultural Statistics Research Institute in its certificate and diploma programme. Rade (1982) regularly conducts such field trips for his graduate students in statistics to banks, pharmaceutical companies, agricultural experiment stations, where students actually learn how data are obtained and what kinds of problems exist in consultations on statistics. Internships in various organizations for longer periods of time have been required as a part of the graduate degree programmes at some universities in the United States. Field work and internships are accepted as a regular part of training in engineering, medicine and public health programmes. In statistics, their use will definitely enhance the quality of training.

The curriculum of graduate programmes must be kept uptodate. In view of the introduction of new techniques, and the limited amount of time the student has, it is necessary that topics which no longer are current, be dropped. The strength of a programme depends to a great deal on the speed with which it can adjust to the needs of society and changing emphasis on the core of the field and its applications.

5. Service Courses

Service Courses in Statistics are generally given to non-majors at the graduate and undergraduate level. For example, at the Indian Agricultural Statistics Research Institute, courses given to agriculture science majors are service courses. They perform an extremely important function. To undergraduates, the service courses provide the introduction to uncertainty in the real world and how statistics can be used in many situations for making decisions and reaching conclusions. These survey-type of courses have to be taught with extreme care. The basic purpose here is to convey the fundamental concepts rather than the techniques. Many times, these courses deteriorate into 'cook book'—type courses. That is, a catalog of methods is given without any explanation. At graduate level, the students in experimental sciences take these courses so that they can use the statistical methods in their research. Extreme care is needed in developing the contents as well as the method of teaching, since we are trying to give basic concepts of a field without providing the theory. Most of the service courses do not require calculus and have become a necessary part of many graduate programmes in sciences and engineering. We find sometimes, majors from 40 different fields taking a given service course. The business statistics course required of undergraduate business majors at The Ohio State University attracts about 2000 students during the year. It is a major undertaking to teach basic service courses. They require association of several faculty and graduate assistants with the programme and besides teaching, an efficient management of the course is required.

6. Undergraduate Major in Statistics

One of the main reasons of dearth of undergraduate statistics programmes, is that the admission to graduate programmes in statistics essentially requires a mathematics degree. The undergraduate major in statistics tends to be a terminal degree programme. As a rule, therefore, these programmes are not attracting students, at least in the United States and we shall not comment further on the topic of undergraduate teaching of statistics.

7. Presentation of Classroom Material

Through the ages, teachers have imparted knowledge to their pupils on one-to-one basis. However, to educate the masses, there is no substitute to the one-to-many method. The pressure to teach large number of

students effectively such as in the Department of Statistics, at The Ohio State University, we are constantly on the lookout of new methods. Modern technology with television and computers, is being introduced in the classroom. These methods of teaching are constantly being evaluated. To manage large classes, the lecture-recitation method is commonly used. For a five hour per week class, an experienced teacher gives the lecture in a big class, three days a week, say, of 200 students and then graduate teaching assistants teach the recitation in smaller groups on the other two days a week. This way, the contact with individual student can be made. The instructors in recitation sections essentially act as tutors. In order to teach large number of students, many universities employ this method all over the world. Care has to be used in managing the course. For such large courses, one should have a course manager who can coordinate the course with various instructors.

To keep the quality of teaching at the same level, same examinations are given to classes taught by different instructors. The coordinator is responsible for examinations, grading and managing the course. These methods have proved cost-effective and are used not only by statisticians but also by other departments. The Department of Mathematics, for example teaches calculus at The Ohio State University to about 4000 students in one quarter. Teaching by television has been used in the past. In this method, the lecture is videotaped by some experienced teacher for about half of the class hour. Then graduate assistant conducts the class for the other half hour. This method has now been discontinued by the Department of Mathematics since the supply of qualified mathematics teachers has increased. There is no substitute to a human teacher as the main lecturer in the class.

Large number of service courses in statistics are taught by Departments other than statistics. Even at the present time, many such courses are taught by unqualified and unprepared teachers whose areas of interest are in fields other than statistics. The practice of statistics is so widespread that it is impossible to design teaching methods for all possible fields. However, the following desirable characteristics are universally accepted for an effective teacher. A good teacher,

1. Meets his/her classes on time,
2. Prepares his/her lectures well,
3. Provides students outline of the course, schedule of tests and quizzes and the policy about grading the course,
4. Gives home assignments and provides correct solutions to students,
5. Receives student evaluation of teaching and modifies his teaching

strategy based on suggestions,

6. Is available to students for consultations, and has regular office hours,
7. Has good communication skills,
8. Is enthusiastic about his field and has sympathetic attitude towards learning, gives examinations and tests so as to enhance learning,
9. Is familiar with modern developments in the field and keeps current,
10. Meets requirements of syllabus etc.
11. Devotes time to keep his course material current,
12. Develops new course material as needed.

The above is only a partial list and definitely can be improved upon. Developing an effective teaching strategy is a long term process and this effort should continue during teacher's life time.

8. Measurement of Teaching Effectiveness

There is a well known statement that "A teacher who teaches well is a bad teacher". This paradoxical statement only reflects the difficulty of defining good teaching. The results of good teaching are not easy to measure. Sometimes a teacher becomes popular by using methods which please the audience. A popular teacher can create a wrong impression of being a good teacher. If the teacher makes the students learn through his/her technique of teaching then he is regarded as an effective teacher. The results of good teaching are known after long periods of time.

The recent emphasis in student evaluation of teaching is a partial answer to the measurement of good teaching. However, students do not know as to the depth of the class discussion, implication of what has been learnt and the importance of concepts introduced during the course of their study. Their evaluation definitely can point out certain weaknesses in the teaching methodology. In statistics teaching, the measurement of good teaching is still more difficult since we are unable to measure easily the impact of teaching on students who are learning the statistical concepts. It is difficult to assess if they can use these concepts in an unfamiliar situation. In evaluation of teaching effectiveness, not only we need student evaluation of teaching but also we need peer input, the performance of students in later life and the impact of teacher on attracting new and retaining old students. We have already mentioned the characteristics of a good teacher and the effectiveness of a teacher would be related to the vigor with which the teacher adheres to their guidelines. In brief, good teaching can be measured only by a combination of several things such as evaluation by students, evaluation by peers and by those who

have had a chance of using what they had been taught.

9. Examination and Tests

The contributions of examination in the learning process is well known and statistics is no exception. Obviously the traditional method of examination, written or oral, where emphasis is only the reproduction of facts learnt in the classroom, fails to develop the basic understanding of the course. In statistics, there is no need to examine students on word by word reproduction of formulas or theorems. It is rather the innovative applications of these facts and models to real problems, which should be tested. A good examination, most often, is an open-book examination. Alternatively the student should have a supply of important results and formulas in the examination. Most of our courses at The Ohio State University in the Department of Statistics both at graduate and undergraduate level follow the above format.

10. Clinical Approach to Training Teachers for Statistics

With the shortage of statistics teachers at College level, in mind, at least in the United States, an attempt can be made to train teachers of mathematics and other sciences for teaching statistics. Suppose a College teacher is well prepared in his field, say mathematics. It is required that he be trained in the philosophy of statistics. Sometimes it is not difficult to learn the mathematics of statistics but to understand the philosophy of data analysis and the application of a model to the real phenomenon, one needs to understand the nature of statistical science.

We have earlier emphasised the importance of clinical approach in training such teachers, Rustagi (1983). In addition to the student-teacher being exposed to statistical theory and methods through regular courses, the student is exposed to the real problems of statistics through attendance in a consulting clinic. Just as the medical doctor learns the practice of medicine through internship in hospitals and clinics, it is proposed to train the statistics teacher, as an intern in the real exercise of client-statistician setting. Several times during the quarter, each student-teacher attends meetings between the client and the consulting statistician. First few meetings are devoted to observing the consulting process and then he/she participates in the formulation and the ultimate solution of the client's problem. This method of teaching problem formulation, and actual participation in client-consultant relationship over several occasions prepares the student to deal with practical problems of statistics. Development of motivation for the study and teaching of statistics also is the by product of this approach. It seems that this teaching strategy is expensive

to operate but there seems to be no other alternative for the exposure of the student-teacher to real situation in a short period of time. While discussing the role of client-consultant internships, it is interesting to note the following commandments known as Herman Rubin's Command ments, Joiner (1982).

For Client

1. Thou shalt know that thou must make assumptions
2. Thou shalt not believe thy assumptions

For Consultants

1. Thou shalt not make thy clients' assumption for him,
2. Thou shalt inform thy client of the consequence of his assumptions.

A good Consultant should

(a) Be helpful and have resourceful attitude,
(b) Have genuine interest in understanding and solving the problem,
(c) Learn something about the subject,
(d) Ask lot of questions,
(e) Confirm by asking, 'Is that what you mean . . . '
(f) Ask to see laboratory, apparatus or field trials.

Consulting statisticians can be compared to lawyers. They do not need to have all the facts at the tip of their fingers, they must know how and where to locate the facts when needed and be able to understand them. *Current index of statistics* deals with about 8000 articles in the statistical sciences published each year. This addition to our knowledge base is of great importance to research and teaching and should be accessible to the consultant.

11. Computer and Statistics

In the present age of high technology and the nature of data analysis, computer is the essential tool of a statistician. It is, therefore imperative that statisticians' training include some basic knowledge of the computer. The student must have minimum knowledge of one programming language. Several popular statistical packages are available and facility with their use should be required. Of course if statistics courses are taught with lot of numerical exercises which require the use of statistical package, a separate course in statistical packages is not necessary. Since

numerical methods are extensively used in statistical computing, students should be exposed to methods of numerical analysis which form the basis of statistical analyses such as in optimization methods and solutions of equations. For master's degree of applied statistics, at The Ohio State University, a course with elements of the above, is a requirement for graduation. Course on statistical computing is an important part of a graduate statistics programme. An outline of such a course has been suggested by Kennedy (1982) and is given in the Appendix.

12. Experiments in Statistics

Experimentation in the classroom such as in physics, chemistry and geology can also play a very useful role in enhancing the pedagogy of statistics. Statistical aspects of experiments in various areas can be studied. For example some experiments for statistics students are the following.

1. Determination of the local acceleration of gravity by means of a pendulum,
2. Using Geiger—Muller counter, the measurement of absorption coefficient for gamma radiation of lead and aluminum,
3. Determining focal length of a lens using two different methods.

Other examples of simple experiments leading to interesting statistical analysis are

(i) Obtaining several measurements of the length a side walk,
(ii) One's weight measured during different times of the day,
(iii) Measurements of heart rates, blood pressure, oral temperature etc.

To enhance the learning of experimental sciences, usual practice is to combine theory with laboratory exercises. The experiment confirms many results required by the theory, giving the student sufficient confidence. For advanced courses, students sometimes are required to have field experience.

At The Ohio State University, a doctoral degree in Statistics education was awarded to a student who showed that demonstration of concepts improves learning in undergraduate service courses of statistics. Robert Situmeang (1973) conducted experiments in several of his classes to illustrate the theory of statistics. For the control group of students, he just taught as usual. He showed that these two methods of teaching gave significantly different results and that comprehension, retention and motivation improved for those classes of students where experiments were performed in the classroom. It should be remarked that not all subjects

in statistics can be treated this way. The use of numerical exercises to enhance the learning of courses in statistics has been found useful and this practice is quite commonly used everywhere.

13. Technology Classroom

More recently, the Departments of Statistics and Mathematics at The Ohio State University jointly have developed a 'Technology classroom' for teaching Courses where use of Computers is heavy. The room consists of thirty computer terminals connected to the central instructional and research computer of the university. The instructor uses a computer terminal which is projected on a big screen for the class. In this way, the instructor can perform statistical operations, generate data and can compare statistical procedures during the class on real time. Students can try the same techniques on other problems in the presence of the instructor who is available for discussion. The method of teaching—combining theory with practice or numerical illustration of the complicated theoretical concepts can be easily done. Also in the case of service courses or in introductory statistics courses many important concepts can be introduced through the use of the computer. Examples of teaching central limit theorem, derivation of sampling distribution and using simulation to obtain sampling distribution of complicated tests statistics are among the many being taught through the computer.

With the limited success of this classroom during the last year, the university has decided to have several such classrooms. The present dilemma consists of deciding whether to have a central teaching computer to be accessed by the terminals or have stand alone work stations, P.C. etc. The feeling is something like a combination of the two. In any case several classrooms at our university will have at least a computer screen projection equipment so that the instructor can use it for his/her lecture.

The importance of this technology to enhance learning cannot be overemphasized. The instructor can see immediately what a given student is doing without leaving the podium and can address the class if needed for a common point of difficulty. This important feedback to the instructor is a valuable tool in teaching. Such as a blackboard is a necessity in any classroom for science teaching, the student with a computer terminal seem to be a necessity for the future classroom.

Other teaching aids which have become an almost common equipment in big classrooms at our university are overhead projectors. The use of television in lecturing has not really succeeded except in some industrial areas where classes are held at the university and simultaneously at the industrial plant for the benefit of the worker.

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APPENDIX

Outline of a Course on Statistical Computing

1. History and literature of Statistical Computing.
2. Computer hardware operating characteristics.
3. Computer software and programming to include package design.
4. Floating-point arthimetic and introduction to error analysis.
5. Random number generation, testing an introduction to general simulation methodology.
6. Approximations to probability, percentiles and other special functions.
7. Numerical methods in linear algebra with useful methods in statistics.
8. Linear least squares computation—constrained and unconstrained.
9. Nonlinear least squares—constrained and unconstrained.
10. Alternatives to least-squares such as L_1 or Lp optimality criteria.