

TEACHING STATISTICS IN UNIVERSITIES

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Introduction

August has come and a lot of you have joined ICOTS II, the Second International Conference on Teaching Statistics. Some may attribute credit to "Footie", but we are indebted to the ISI Task Force for Conferences on the Teaching of Statistics and to the conference Organizing and Program Committees.

ICOTS I and this conference have been preceded and interlocked with various other conferences, workshops, and meeting sessions on the teaching of statistics and statistical consulting. This attests to our concerns with the teaching of statistics and the training of statisticians, concerns healthy for the discipline and suggestive of a continuing search for excellence. One may wonder what remains to be said, but reminders and reappraisals are helpful and the nature of our discipline and its setting continue to evolve.

Perhaps the most renowned and most cited article on the teaching of statistics is the early paper by Hotelling (1940). He referred to statistics as "one of the most fundamental of subjects", and addressed such topics as where statistics should be taught in the university, who should teach statistics, and what mathematical prerequisites are required. Hotelling recognized the need for and motivation from applications of statistics and, apart from the traditional areas of application, recognized needs for statistics in manufacturing, judicial affairs, and meteorology:

The work of W.A. Shewhart has made clear the central importance of sampling theory in the economic control of quality of manufactured articles.

Even judicial activities call for statistical theory of the most recently discovered kinds, . . .

A course on the treatment of time series might appropriately be included in the Department of Statistics, . . . itself serving as a prerequisite for courses in economic and meteorological statistics.

Hotelling looked to the development of departments of statistics for both basic training in statistics and for the training of statisticians. The notion that basic courses in statistics be taught in statistics departments and specialized applications courses in subject matter departments is clear and may be recommended today. There is recognition of the role of statistics in quality and productivity in industry, a matter currently of great concern in America. We see a preview of statistics in the law, although Hotelling may not have anticipated class action litigation.

On the teaching of statistics, Hotelling believed firmly that a good teacher must be thoroughly familiar with recent advances in the field. He regarded participation in research as the major, but not sufficient, qualification of a good teacher of statistics. He was concerned that "students of statistics who are taught rule-of-thumb methods without their derivations are never quite conscious of the exact limitations and assumptions involved . . ." Hotelling recognized the three functions of the university statistician, teaching, research and consulting, and would have applauded the developing effort to provide students with consulting training.

What Fisher's views were on the teaching of statistics is more difficult to ascertain. The only reference to teaching in the index to Contributions to Mathematical Statistics is to his papers on Pearson and the method of moments, Fisher (1950) and (1937) respectively. His view in 1937 was that too much attention was given to the fitting of frequency curves by moments and that other topics were inadequately taught or neglected, the listed topics being finite differences, the exact treatment of small samples, analysis of variance and co-variance, the theory of estimation, and practical computation.

It is difficult to disagree with Hotelling's stated principles; we have recommended the rereading of his paper before, Bradley (1982). However, the teaching of statistical methods without their derivations continues with increasing demand. The mathematical skills of students have not improved on average but there is new awareness of the need for change. Fisher's topics, with the exception of finite differences, have become the core of basic statistical education.

The historical notes above are designed to provide background for the series of seven papers and the workshop of this conference on the training of statisticians. The major objective of this presentation is to present recommendations on core courses for the M.S. and Ph.D. degrees in statistics, thus introducing material for scrutiny and revision. In a final section, some issues are raised that should stimulate discussion.

The Academic Training of Statisticians

Academic training of professional statisticians in North America is essentially at two levels, the Master of Science (M.S.) degree and the Doctor of Philosophy (Ph.D.) degree. Emphases in this section will be on typical core requirements for these degrees, followed by some comments on variations and on the Bachelor of Science (B.S.) degree available in some institutions.

Some of the material below is taken from Bradley (1986), a manuscript prepared for a proposed volume, The Training of Statisticians Around the World, in preparation by the ISI Task Force on Tertiary and Technical Education in Statistics. Our understanding of the motivation for this volume is that it should provide a compendium on statistical education and supply prospective foreign students with information on necessary preparation for study in a given country, the structure of the educational system, and degree requirements. It should assist the student in the selection of a

study program and ease adjustment to a possible new culture. The volume has additional potential benefit for the improvement of the training of statisticians in that comparisons of programs should lead to the correction of deficiencies.

Graduate training in the United States is tied more closely to credits in formal courses than in other parts of the world. The M.S. degree typically requires 48 Quarter Hours or 36 Semester Hours of graduate credits, possibly including thesis credit. Doctoral programs must be approved by individual student supervisory committees and meet general graduate school requirements and any specified departmental requirements. As a rough guide, in statistics, total graduate credits for the Ph.D. degree, including possible prior M.S. credits, is likely to approach 135 Quarter Hours or 90 Semester Hours, up to a third of which may be for dissertation research. It is in this framework that desirable core courses are suggested in subsections below.

(a) Statistics Masters Degrees

Three types of M.S. degrees have evolved in statistics. The first is the traditional program with a substantial thesis and an emphasis on the theory of statistics and probability. The second is a non-thesis degree similar to the first, but with additional course work, perhaps 12 Quarter Hours (9 Semester Hours), replacing the thesis. The motivation for the second type of degree is that it provides more depth of training and permits the student to proceed more rapidly into a doctoral program. The third type of degree is in applied statistics, usually without a thesis requirement, but often requiring a written paper on an applied statistics project. The applied statistics degree permits exposure to a wider range of statistical methods, but should be regarded as a terminal or professional degree. All three types of M.S. programs may exist in a major department of statistics, but only one or two of them may be offered in smaller programs.

The first two types of M.S. degrees both emphasize theory and similar core courses are required. It is assumed that entering graduate students have completed advanced calculus, linear algebra, a course leading to familiarity with at least one computer language, and have had some introduction to mathematical statistics and statistical methods. Without specification of courses or divisions of course sequences, the M.S. degree programs of study should include:

- An academic-year sequence of mathematics courses on real analysis,
- A parallel sequence in probability and statistical inference,
- A sequence in statistical methods and design of experiments,
- A course on linear statistical analysis.

Thus some 30 Quarter Hours or 20 Semester Hours of the M.S. degree program are specified.

It is seen that the thesis-type degree permits quite limited flexibility, perhaps inclusion of two additional advanced courses along with thesis research and preparation. The course-type degree permits inclusion of four to six additional courses, the choice partially determined by whether or not the student expects to continue in a doctoral program. For the continuing student, consideration should be given to starting sequences of courses in advanced probability, advanced statistical inference, and stochastic processes and to the selection of more specialized courses, examples being multivariate analysis, analysis of categorical data, time series, survey sampling, and nonparametric statistics. The student expecting to seek employment with the M.S. degree should give more consideration to supplementing the core program with courses providing breadth of techniques, including specialized courses in statistical methods and additional computing skills. Such students should also seek experience in supervised statistical consulting.

Prerequisite training required to enter the M.S. degree program in applied statistics is less stringent. Prior training should include completion of basic calculus, some introduction to linear algebra, and first courses in statistics and computing. The degree core courses are:

An academic-year sequence in statistical methods and design of experiments,

A parallel sequence in introductory probability and mathematical statistics,

A course on linear statistical analysis,

The equivalent of two quarters of supervised statistical consulting.

Some additional 20 Quarter Hours in course work are available to achieve breadth of training in statistical methods, computer science, or additional probability or statistical theory. Typical methods courses available in departments with this degree option are applied regression analysis, sample survey methods, statistical computing, applied time series, multivariate statistical methods, data analysis, industrial quality control, and methods of operations research.

A desire for discussion may have been stimulated at this point. There are some who will believe that the core courses and suggested elective courses for the theory-oriented M.S. degrees lead to a too narrowly focused degree program. There will be others who believe that the applied M.S. program has too little theory and too much statistical methods, perhaps sharing Hotelling's concern for understanding of the exact limitations and assumptions involved. Some further comments may assist.

The non-thesis, theoretical M.S. degree program is designed to facilitate rapid progress in graduate study through both the M.S. and Ph.D. degrees. The student should develop the tools for research as rapidly as possible and start on dissertation research early. The suggested program is effective in this regard. Breadth of training, study of special methodologies useful in applied statistics, and experience in teaching and statistical

consulting may be acquired in parallel with advanced theoretical study and research as the student progresses in the doctoral program.

The applied M.S. degree program seems to have been generally successful and graduates of such programs are sought by industry, business and government. There is an appeal to graduates with broad training in techniques of statistics. We have had concern for their long-run futures. Have they been given the means to keep up with new developments? It appears that these graduates can assimilate new methodology, and the increasing availability of continuing education courses in statistics assists.

(b) The Ph.D. Degree in Statistics

The Doctor of Philosophy degree in statistics continues to be a research degree. Thus, we believe that the dissertation should represent an achievement in research and a contribution to knowledge. Doctoral programs of study should be planned to facilitate such achievement.

A quality doctoral program should produce dissertations yielding one or more substantial publications in one of the better refereed journals in the field. Dissertation topics may vary greatly, from research on the foundations of statistics and probability to the development of new methodology stimulated by unsolved problems arising in statistical consulting. Dissertations involving some aspect of data collection and analysis seem inadequate unless unusually innovative methods are developed. Doctoral programs in applied or experimental statistics, promoted in the past, now show understanding of need for sound theoretical training in programs of study. We expect substantial agreement on core courses for doctoral programs of study suggested below.

The M.S. degree is not required to enter doctoral programs in statistics. However, some demonstration of skills and ability for such entry is desirable. Some departments have Ph.D. "qualifying examinations", often concurrent with M.S. comprehensive examinations, that are to be passed to enter the doctoral program. This practice is recommended; we do not believe that it is a kindness to permit students to proceed in a doctoral program only to be refused admission to candidacy some two years later because of unsatisfactory performance on the customary Ph.D. comprehensive examination. Immediately following approval of entry into the doctoral program, a tentative student supervisory committee should be formed and a tentative doctoral program of study approved. It should be understood by all that the supervisory committee will be revised as a dissertation topic is selected and a major professor to direct the research is agreed upon. We do find that the program of study is required early to ensure efficient selection and sequencing of courses.

We have noted above that the student supervisory committee is responsible for the doctoral student's progress and the program of studies. However, some departmental requirements may be imposed and this seems appropriate in regard to core courses. It is suggested that doctoral programs of study should include:

The core courses specified above for the theory-type M.S. degree,
A year's sequence in advanced statistical inference, and
A year's sequence in advanced probability.

The doctoral program of study, including graduate courses that may have been included in an M.S. program, should contain total course credits approaching 90 Quarter Hours or 60 Semester Hours. Courses in mathematics, computer science, or allied fields, that will assist the student in preparation for research in a chosen area should be included in the program of studies. Courses should also be included to provide breadth over specialized areas of statistics and/or probability. It is suggested that two areas of probability or statistics be selected for study in depth to the research level, such study perhaps culminating with specialized advanced topics courses or seminars on recent research.

A device found useful at the Florida State University, now being tried at the University of Georgia and perhaps elsewhere, is the requirement that the student prepare a predissertation essay as part of the written examinations of the doctoral comprehensive examination. The essay should demonstrate familiarity with the literature of the proposed research area, report on any preliminary research results obtained, outline the proposed dissertation research, and demonstrate good technical writing ability. The essay provides the student's committee means to effectively evaluate the feasibility of the proposed dissertation research.

Many foreign graduate students enter U.S. graduate programs in statistics. While they may be required to demonstrate functional ability in English, usually through achieving a minimum TOEFL score, many of these students need the additional instruction available in most universities. Counseling in this regard is an important responsibility of the department.

The discussion above is limited to the training of statisticians to the M.S. and Ph.D. levels. A number of Bachelor degree programs exist, some of which at least meet prerequisite and core requirements of the applied M.S. degree, and employment opportunities exist. There are also M.S. and Ph.D. statistics programs with special orientations, programs in biometry or biostatistics, educational statistics, and business and economic statistics. We are inclined to argue that most of the suggested core requirements should apply also to these programs, but more dissent would be encountered. Other sessions of ICOTS II deal with industry, government, and business implications for training in statistics, although bio-medical implications seem to be missing. Our suggestions on degree core requirements are intended to provide students with the knowledge that will assist them to keep up with new developments in statistics throughout their careers.

Some Questions For Discussion

A number of questions relating to the training of statisticians merit discussion. We raise a few such questions with minor elaboration.

i) What should be done to give graduate students a broad understanding of statistics as a profession?

We believe that students need to understand that statistics has a central role in the scientific method, that statistics in application deals with the formulation of stochastic models subject to confirmation or modification (Hotelling – "One of the most fundamental of subjects"). Students need information on the structure of the discipline, its societies and publications, information retrieval, sources of and means to research support, the peer review systems of journals and granting agencies, career opportunities, and employment expectations and requirements. Do we leave such information to piece-meal acquisition or should it be provided in some more formal orientation seminar?

ii) How do we stimulate awareness of ethical issues in both statistical practice and research in the training of statisticians?

We suspect that more is done in other professional training, for example, in medicine and law, than in statistics in response to this question. Should we do more? Should students be provided with the American Statistical Association's Committee on Professional Ethics Report (1983)? What about careful referencing and appropriate credits for prior research on a topic? What about objectivity, limitations of methods used, factors that may affect impartiality? Does this question provide another topic for the orientation seminar, supplemented by emphases on responsible statistical advice in supervised statistical consulting?

iii) Where should emphases be made in training in statistical consulting?

There is probably general agreement now that graduate students should acquire some training and experience in statistical consulting. But this is time-consuming and could reduce subject matter training. Some would argue that sound statistical training is all important for good consulting. Others would argue that considerable emphasis should be given to communication skills, interpersonal relations, and management of the consulting session – see McCulloch *et al.* (1985), who also recognized that time constraints exist. How much hands-on experience should be provided in data analysis, particularly the analysis of very large data sets? Can we do more than provide some principles of good consulting and limited experience with a few projects, hoping to instill in the student a positive attitude towards consulting?

iv) Do we modify curricula in statistics effectively as new statistical and computational techniques are developed?

Fisher's concern was with the incorporation of small sample theory in courses in statistics. While core training should not be sacrificed, fads should be avoided, and judgment is required, we should be alert continually for needed curricular change.

It is easier to include new extensions of existing statistical theory and methodology into appropriate existing courses than it is to deal with major new approaches. How do we provide instruction in new computer-intensive techniques such as the bootstrap, the jackknife, predictive sample reuse or cross-validation techniques, and methods of multiple imputation to assist with missing data? Are these topics for new courses, courses in statistical computing, or inclusion in existing

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courses? Can we shorten the lag in the introduction of new ideas? The new Institute of Mathematical Statistics journal, Statistical Science, holds promise for the early identification and presentation of new material for statistics curricula.

We seem to have been effective in the use of computers in research and applied statistics. Are we slower in the use of computers in the teaching of statistical methods? Use of statistical software packages is not the full answer since exposure to the details of statistical computing assists the student in understanding and in gaining "number sense". What is the appropriate compromise? What about simulation to show the effects of failure of assumptions and the benefits, for example, of transformations of data or of robust techniques?

Computing has become useful in theoretical research. Algorithms can be devised to check conjectured conditions and to suggest methods of proof of important theorems. Can students be given insights to such techniques?

v) How do we stimulate interest in research in statistics and probability and show that it is an exciting activity?

One of the great satisfactions of teaching is to have students who successfully develop their own research careers and make significant contributions to the discipline. Some students do this, while others complete dissertation research and regard it as an experience never to be repeated. Is this simply a matter of innate creativity or lack thereof? Has the dissertation advisor carped too much on detail or failed to stimulate creativity in the second case? Research and the direction of research are very personal and the interaction of a doctoral student and the research advisory requires special symbiosis.

These and other questions will enter into discussions in this and other sessions of this conference.

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