Chance, Statistics, and Statisticians
Leslie Kish

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Statisticians and statistics deal with the effects of chance events on the treatment of empirical data. I am not attempting to add still another definition to the many already in print; Kendall ([1], p. 1) notes that "Willcox listed well over a hundred definitions" in 1935. I merely hope my description is neither too narrow nor too broad to describe your own activities as statisticians. Some of your other activities may not be well covered because the statistician's work so often penetrates other fields, a feature of statistics I shall emphasize. My aim today is to illuminate the consequences of that description for the practice, for the writing, and for the teaching of statistics. Also I shall relate its consequences to the structure and activities of our Association [the American Statistical Association].

I perceive it as both my task and privilege to present here a broad and philosophical view, rather than the kind of narrow, technical exposition we statisticians usually give in our sessions. I want to entertain not only my fellow statisticians but also their husbands – or their wives.

All of us think, perhaps daily – or at least once a year – about what we statisticians do – and why. Indeed you have often been stimulated to do so from this platform. Even if my contribution adds little to what you already know, it may suggest a new way of putting it all together and stimulate you to do the same. Here then is my apologia, plea, justification for statistics and statisticians. I am not deliberately seeking controversies, but neither am I avoiding them.

I know that emphasizing the central role of chance in all aspects of statistics is controversial. Does that emphasis exclude the collection and tabulation of censuses, of health and of other similar data? Not at all. Those activities' gave birth and name to our field and they still occupy central and vital areas. But in those areas also it is the recognition of the effects of chance, of variability, of fluctuations, that distinguishes the work of statisticians from the neighboring fields of accounting, bookkeeping, and inventory taking.

Controversy also exists about the sources of chance effects. We may agree about the prevalence of errors of sampling and of measurements, and also about errors due to our current ignorance of disturbing factors. However, many of us, but not all, also postulate a fundamental source of indeterminacy that underlies all empirical work, and a basic role for such indeterminacy in our outlook, models, and designs.

Furthermore, the remedies I suggest for closing the gaping wound between academic mathematical statisticians and practicing empirical statisticians are bound to be especially controversial.

Statistics Contrast with Other Sciences

Statistics is a peculiar kind of enterprise of contradictory character because it is at the same time so special and so general. Statistics exists *only* at the interfaces of chance and empirical data. But it exists at *every* such interface, which I propose to be both necessary and sufficient for an activity to be properly called statistics. It has a special and proscribed function whenever and wherever empirical data are treated; in scientific research of any kind; in government, commerce,

industry, and agriculture; in medicine, education, sports, and insurance; and so on for every human activity and every discipline. This widely spread yet specialized character differs from other disciplines, which tend to cover in depth all aspects of their special domains.

Thus statistics differs fundamentally from other sciences. The data of other scientists come chiefly from their own disciplines – though they may also take side trips into other fields. In stark contrast, statisticians have no fields of their own from which to harvest their data. Statisticians get all their data from other fields, and from *all* other fields, wherever data are gathered. Because we have no field of data of our own we cannot work without others, but they also cannot do without us – or not very well, or for very long.

Ours is a symbiotic way of life, a marginal and hyphenated existence. We resemble the professional harvesters of wheat and grains on our Great Plains, who own no fields of their own, but harvest field after field, in state after state, and lead a useful, rewarding, and interesting life – as we do.

Instead of the word chance we could use probability, except that today I would rather avoid the theological controversies surrounding that word. Yet we can agree that statistics does not claim to deal with all kinds of uncertainties. Not, for example, with the uncertain aspects of unique historical events such as brought on the American, French, Russian, Mexican, or Chinese Revolutions. (Nor, for a more humble example, with the uncertain events that brought me to this platform tonight.) Statistics deals with chance effects in empirical data concerned with classes of events, not single historical events; it treats numerical data from classes, from populations [1]. I also believe that we should deal chiefly with large classes of many events, and not with classes of size 2, 3, or 6.

My aims are entirely pragmatic: to describe what we statisticians do in our practice, in our teaching, in our writing – and what we should be doing; also what our Association tries to encompass, and in what directions we should plan to move. The descriptions and plans are not simple because statistics is such a diffuse enterprise. At one end it has vital roots in abstract mathematical theories of probability and stochastic processes; it shades without definable boundaries into several profound areas within mathematics proper. At the other, it branches into procedures for collecting and analyzing empirical data of all kinds; thus it gets embedded in the methods and interpretations of all substantive fields of measurement.

Statistics and statisticians must remain in touch with both ends, but they can neither encompass nor reside exclusively in either end. Without data we are within the deductive arena of mathematical probability. Without chance effects we are in one of the many areas where mankind has learned to observe, measure, and count. All types of counting, all processes of observation, collection, tabulation, and analysis of data are subject to variability, to errors, and to mistakes. But statistics does not necessarily include all kinds of counting, such as those found in accounting, banking, voting, or scoring in sports. When dealing with measurements, experts in the specific substantive fields concern themselves with refining instruments, and with eliminating mistakes and cheating. Statisticians also get involved in those efforts, but the statistician brings a different and special view to the study of errors of observation: an explicit recognition of chance effects, a probabilistic view and treatment of them, and especially the incorporation of that view into the research design and the interpretation of observations. Note then that to err is human, to forgive divine but to include errors in your design is statistical.

In any scientific enterprise one can distinguish a hierarchy of four problems and decisions. First comes the choice of variables to consider, second the design of the model for relations between the variables. These two decisions belong to the scientist or expert in the substantive field. Third comes the estimation of parameters, and fourth the assessment and analysis of the variability of errors of those estimates. For these latter two stages statisticians are needed, and they must be either bought or borrowed. (Otherwise, the role is taken by the scientist; and he may perform it well, but he may not.) Consider, for example, the model $d = (1/2) \, gt^2$ for the distance covered in t seconds by an object falling freely to the earth's surface. The constants 1/2 and 2 come from the physicist's model, but the statistician gets involved in designs for measuring $d, t,$ and especially $g,$ the gravity parameter. Furthermore, to measure the distribution of g may pose a formidable challenge for the sample design, requiring both a background in the relevant variables and foresight about future uses of the model.

The situation is similar in more complex models, whether physical, biological, or social. Consider, for example, the highly controversial separation of an IQ test into components for genetic heritability, environment, situational factors like age and culture, interactions, and error terms. I maintain that the basic difference between the social sciences and the "exact sciences" lies not in the magnitudes of the error terms, but in the multivariate nature inherent in the models. In the social sciences, most models must be multivariate because disturbing variables cannot be excluded as the physicist excludes air resistance and wind from his *freely* falling body.

Statistics and Philosophy

We may agree then that statistics, in both its theory and its practice, plays important roles in many or in most human activities. We generally also agree that it requires as much learning, experience, and intelligence as any other profession. Still, is it an interesting and noble occupation? Is it an exciting activity for a young person and is it dignified for a mature person? Would you want your daughter to become a statistician? Or your son to marry one?

It may seem like a humble task to hunt for and measure errors while the search for the main patterns and variables belongs to other scientists. I believe and shall argue that statistics is the *most mature* of the sciences. Learning to live with the inevitable uncertainties of chance effects and to include them in our patterns, plans, designs, assessments, and inferences is among the latest and most mature products of the human mind. We shall note that the late arrival of statistics among the sciences has important consequences for its position among university departments and for its problems today.

In all her (his) endeavors the statistician cannot avoid the basic philosophical problem of empirical science: to make inferences from limited sets of empirical data to large finite populations and to infinite super populations of random variables induced by causal systems. Survey samplers, in particular, cannot avoid the basic questions posed by David Hume, then by Karl Popper ([2]) and by Wesley Salmon ([3]). The fundamental ideas of statisticians like Fisher, Neyman, and Savage are not only mathematical but profoundly philosophical. The converse is also true: in the current philosophy of science you find fundamental ideas coming from statisticians and from the theory of statistics.

A closer link between the disciplines of statistics and the philosophy of science, at least in joint seminars, would be stimulating to both. The diverse schools of inference – frequentist, fiducial, Bayesian, likelihood, and others still to come – may be viewed as valiant efforts to capture within a mathematical framework the "Hume-an" problem of inference from variable empirical sample data to universal statements.

The powerful emergence of the new ideas may be seen in Darwin's theory of evolution through natural selection, and in the later developments of the theory. Consider genetics from Mendel to Morgan and to Watson. Scardovi ([4], p. 35) writes:

> Mendel's was the first explicit indeterministic paradigm in the history of science, .. . [and in 1866] . . . was thirty years ahead of the philosophy and science of his time. The complete lack of recognition accorded him by his contemporaries can thus be explained. Mendel also surprises us with his statistical insight: he was capable of seeing in his numerical data random oscillations about a limiting value, and thus was able to extract the ideal proportion toward which the outcomes in the combined heredity of several traits tend. . . .

All biological diversity of species and of individuals may now be viewed as the results of many throws of the DNA dice interacting with the environment. Monod ([5], p. 118) writes:

> Even today a good many distinguished minds seem unable to accept or even understand that from a source of noise natural selection alone and unaided could have drawn all the music of the biosphere. In effect natural selection operates upon the products of chance and can feed nowhere else; but it operates in a domain of very demanding conditions, and from this domain chance is barred. It is not to chance but to these conditions that evolution owes its generally progressive course, its successive conquests, and the impression it gives of a smooth and steady unfolding.

Synthesis of Chance and Necessity

Statistics is ubiquitous because events everywhere involve chance factors. All nature and all human activities resemble games like bridge, baseball, football, or tennis in combining chance with skill or causal factors. Bjorn Borg said on winning at Wimbledon in 1977, "I think I am number 1 for the moment."

The structure and language of sports show people's widespread intuitive knowledge of combining chance with skill. In football the top team must win about 8 of 10 games, and we speak of "upsets." I liked the sophistication of a simple headline one Friday in our *Michigan Daily*: "Upset Unlikely." But in baseball games we see no "upsets," and winners average perhaps 60 percent of about 160 games. Examples abound in sports and games of sophisticated designs for combining chance with skill.

Yet statistical views are still emerging in new fields, when mature minds discover the effects of chance. Those views come late, because (as Monod said) "minds are unable to accept or even understand" the *joint roles,* instead of mutually exclusive roles, for pure chance and for natural laws. Einstein, the wisest mind of our century, is quoted ([6], p. 193) as saying, "God does not play dice with the universe." Yet the Einstein-Bose statistics define a basic game of chance for elementary particles.

The delays in the synthesis of chance effects with causal systems present a paradox whose examination is fruitful for us. Primitive man's fascination with chance, fate, and fortune was

early and widespread. He was first filled with wonder and awe of hidden powers, magic, miracles, and ad hoc explanations. Only after discovering rules for connecting cause and effect, and formulating natural laws, did he learn to *counterpose* chance effects to explain deviations from the rules. Much later came the combined view of causal laws with chance effects. "At the end of the seventeenth century the philosophical studies of cause and chance. . . began to move close together," and were developed in sciences like astronomy and demography in the eighteenth and nineteenth centuries

> This development had an important impact on the theory of chance itself. Previously chance was a nuisance, at least for those who wished to foresee and control the future. Man now began to use it for other purposes, ... to bring it under control, to measure its effect, and to make due allowance for it. [7]

A similar development of the idea of chance in children was investigated in 1951 by Piaget ([8]). At first the child does not distinguish the possible from the necessary. During the first period there is no differentiation between what is deducible and what is not because the intuitive anticipation remains halfway between operation and chance itself. During the second period [after seven years] there is differentiation and hence an antithesis between chance and operations… chance defines… the unpredictable. In the course of stage III [after eleven years], on the contrary, there is a synthesis between chance and operations...

Thus the complementary roles of chance and necessity appear basic and ubiquitous. That the discoveries of the diverse syntheses occur late to mature minds has several consequences. First, I believe that this vital outlook should belong to the philosophical, humanistic, and moral heritage of all scientists, and further of all citizens; also I believe that statisticians have natural responsibilities for teaching it. Consider the broad implications of several recent discoveries about the role of chance: the genetics of individual health, intelligence, and behavior; the statistics of population genetics (for which Fisher has been called the foremost biologist of our century); the occurrence of cancer; the lengths of our lives.

Appreciating the pervasiveness of chance should help us cope better with diverse aspects of life. About success in affairs, in business, even in science, we may say: "Fortune favors the prepared mind." The winners of millions of dollars or of Nobel prizes tend to accent the prepared mind, the losers emphasize fortune. This tendency for biased judgment, between winners and losers, is also found in national surveys of attitudes (and these self-protective biases may be psychologically healthy).

The tragic biblical Job might have been happier and wiser if he knew that his plagues were due to chance. The triumphs or the problems of your children may be due to chance, not only to your behavior – despite what Freud may say; a statistical view may protect parents against false pride or against guilt and despair. But we are not mere helpless puppets of chance, and we can improve our chances – for example, by quitting smoking, with regular exercise, and by losing weight. Recognition of the interplay of chance with discernible causes may yet lead us to a better way of life and to a better moral philosophy. Somebody may even start a new religion of Statisticology!

Recent Developments of New Fields

A second consequence of the late recognition of chance effects may be found in recent discoveries of new fields for statistics. Within the past two generations, field after field has been laid open with the statistical recognition or introduction of chance effects. For example: Fisher with randomized experimental designs; Neyman with randomized designs for complex samples; Shewhart with statistical control for quality of products; stochastic analysis for many fields; time series and spectral analysis; Monte Carlo simulation; response surface analysis; and so on. There will be still more as our era of statistical discoveries continues.

Within the major fields many new techniques were also developed. In survey sampling, for example: multiphase sampling, interpenetrating samples, jackknifes, balanced repeated replications, controlled selection, measurements of interviewer variance, randomized response techniques, randomization for confidentiality, etc. Each of these techniques uses chance and randomization to tackle some problem in application. In addition, new procedures are designed as survey sampling penetrates new fields such as anthropology, archeology, and geology.

I view the entire field of survey sampling as another synthesis of chance and structural effects. It is a set of strategies for representing actual populations of variables, which are ill-defined mixtures of the two components. Instead of assuming a well-mixed urn of random variables, the sampler designs a complex randomized design over the frame population, and controls the chance effects through stages of randomized operations of selection.

Many other problems and fields still remain to be conquered with new statistical techniques and theories to capture and to tame the wild errors of chance. For example, modern epidemiology has created many new ideas; McNeill ([9]) used those ideas to write a new interpretation of world history!

Statistics in Universities Today

But even if we grant broad importance to it, does the discipline of statistics need autonomy? Does statistics need separate departments in our universities? The question is being asked by financially pressed universities, which notice that students elect most of their statistics courses outside the statistics departments. With one foot in mathematics, a second in computing, a third in philosophy, and seventeen more in other departments, do we have a leg to stand on?

I say YES – BUT… Yes enthusiastically, because a statistician trained in the theory and in the applications of, for example, survey sampling and experimental design, can design better surveys and experiments in just about any field of application than either a mathematical statistician or an expert within his (her) own field. The knowledge and the approach of the statistician are reasonably portable from field to field.

But I also believe that departments of statistics must change drastically from their present narcissistic concentration on abstract theory. Research and teaching, in many departments, have become divorced from applications, from empirical data, from the real world. This centripetal academic disease is chronic and contagious, and is also common in other disciplines and in other countries (although British statistical tradition seems less affected even today). Typically the teaching of statistics in universities is based on the assumption that graduates with good theoretical backgrounds can readily learn applications afterwards, while "on the job." But, "on

the job training" for unprepared statisticians can be very expensive both to graduates and to their clients and employers. Teaching applications within an academic setting may be more difficult than teaching theory, but with care it can be provided, and ultimately it should be much cheaper than the total costs of "sink or swim on the job" for unprepared graduates. Would you accept a physician or surgeon with only theoretical training?

At the same time, I also believe universities should offer more theoretical statistics as continued education for statisticians – and for others who practice statistics without statistical degrees. The practitioners working on applied problems will bring their own experienced views and, needs to their studies of theory. To satisfy their needs, to answer their questions, and to help solve their problems should also provide the stimulation that academic departments of statistics need. I believe those efforts hold great promise for universities.

The history of our discipline exhibits significant paradoxes in autonomy. Our Association was founded in 1839 – only the second national scientific body after the Philosophical Society. [10] Yet more than 100 years passed before the first department of statistics was established in a university. In the 30 years since then more than 100 departments have mushroomed. The late arrival of this mature science was not accidental; after Galton, Pearson, and Fisher it was bound to come. But the portentous accident was the coincidence of its arrival with the historically unique explosion of American universities, which just now ended. Consequently our academic statisticians have been nurtured in a fantasyland that they mistook for normalcy. Departments concentrated on turning out academic Ph.D.'s, and imported others to fill the hungry pipelines. One had the curious situation where the highest objective of the teacher of statistics was to produce a student who would be another teacher of statistics. It was thus possible for successive generations of teachers to be produced with no practical knowledge of the subject whatever. [11]

But this geometric explosion had to end, and statistics departments must now reform their teaching strategies accordingly. I doubt that the future lies in concentrating exclusively on mathematics and theory, and having students find their own way to applied statistics in other departments. Some biostatistics departments have done remarkably well in teaching applied statistics to students in all fields, but this service function interferes with their primary responsibilities to the biomedical sciences. Also the mislabeling is a hindrance to students and graduates in other fields.

Reformation must come and it will probably take diverse forms. One solution consists of one large department having many joint appointments with departments of application, of mathematics, and of computing. In one university I visited, a good and happy department consists entirely of joint appointments.

Many statistics departments should change, I propose, from their primary concentration on self-contained and self-perpetuating theoretical Ph.D. degree programs. Instead they should develop strong Master's level programs in applied statistics, designed first for statisticians in government, industry, and other applications, and second as vital components of Ph.D. programs in other fields.

If a statistics department insists on confining itself to mathematical statistics, then a decent regard for truth to its clients, the students, demands that it re-label itself accordingly.

Better Theory and Methods in Statistical Offices

In asking for changes both in universities and in work situations I agree with Bjerve's ([12]) presidential address to the ISI [International Statistical Institute], and his "worries about the wide gap existing between official statisticians and academic statisticians. Professionally, these two groups seem to be living in two different worlds without communication in between. "

The time has come for better integration of theory with application. Theory should improve the quality and efficiency of applied work. Simultaneously, applications must be the testing ground for statistical theory and methods, and must provide the motivation for further advances. Several paths toward integration are possible.

1. Programs of continued education should be encouraged. They can transmit new techniques and also satisfy needs discovered on the job by practitioners. Beyond the traditional devices such as books, journals, and sessions at annual meetings, we need more special and short courses both at universities and elsewhere (note the very successful short courses at our ASA meetings). J\10re short courses, seminars, workshops, and meetings should also be organized within the offices themselves. ("Offices" refer to places – in government, industry, hospitals, etc. – where applied statistics are being performed.)

2. Consultations of practitioners with academic experts on current problems can be beneficial and stimulating to both parties. It seems to me that the offices could profitably increase those contacts and the sizes of their consulting budgets. Incidentally, such consultations may help to redress the imbalance between giant organizations that have their own specialists and small ones with none.

3. More statisticians strong in theory and methods are needed in offices. These positions, when created, should be filled better and more easily in the coming job market than in the past – especially if universities prepare their graduates for practical work. In many cases part-time positions for academics, or visiting or rotating positions for one or two years, may be preferable for both parties. All these situations exist, but they are underutilized because they run against the rigid structural habits both of offices and of academia.

4. More internships for students are badly needed and can greatly benefit all three parties (students, universities, and offices) and society. Because of conflicting drives of the three parties, the programs need care, skill, and empathy – and finances. But the outlook for the coming years is more propitious than in the past.

5. Better recognition is also needed for the status and roles of statistical methodologists. In too many offices the ladder of promotion takes good statisticians out of technical positions into largely administrative roles.

Our Association and Publications

What should our Association do to close the great gap, to better serve our discipline and all statisticians? I throw this question back to you. Write to our Board, try reforms in our sections, chapters, and committees.

I note only that the coming years are propitious for bringing our mathematical colleagues back into the Association. But our main efforts should be directed to bringing in all hyphenated statisticians from other fields who have strayed from our fold. Their presence and activities are needed for vigorous development in our field and in our Association. Our sections, chapters, and committees must help. A central role in this unifying task must be played by our publications.

We are proud of our publications, but here again I appeal to you to help restore a better balance toward applications. Our editors and the Publications Committee are working toward those aims, but we need your help. We face several major obstacles:

1. We all respect mathematics because we each have had some, but we also fear mathematicians. I find that the more mathematics one has, the more one craves (an insatiable desire in accord with psychological reward systems). Statistical publications have been flooded with mathematical virtuosity, and that flood has been permitted to impede statistical creativity.

2. We must work against a common but false double equality whereby methods are equated with theory and then theory with mathematics. Both equalities are only partly true – and misleading and harmful. Statistical theory needs strong philosophical foundations and orientation toward empirical data. And methods are valuable only insofar as they are applicable. I would strongly prefer that methodological contributions be actually ap plied to empirical data to prove (probe, test) them. That, I believe, was Karl Pearson's demand as editor of *Biometrika.*

3. Academicians have more time, experience, and motivation to write, edit, and referee than most practitioners. They deserve our gratitude for performing-very well on the whole – a difficult task and a necessary evil. But papers on applications and methods too often suffer from lack of understanding by the referees. The imbalance can be redressed with more help for, and more pressure on, our publications from our practitioners.

What can we do about the gaping chasm between the statistics departments and statistics in the applied world? The very words statistics and statisticians seem to have entirely different meanings in the two worlds. Some friends say that it is too late and hopeless to try to reunite the two. Some favor surrendering the very name statistics in universities, and starting out fresh in new departments with names like "Data Analysis" or "Statistical Computing." Others even dare to deprive the practicing, applied statistician of the name of statistics and to appropriate it exclusively for their own academic mathematical pursuits. I disagree with those pessimists. Iago may be talking of statisticians when he says to Othello:

> Who steals my purse steals trash; . . .
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> But he that filches from me my good name
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> Robs me of that which not enriches him,
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> And makes me poor indeed.

We need the good name of statistics for our field and our Association, and we need it to unite the efforts of theoretical and applied statisticians. There is a common chain that links

mathematical probability with statistical theory, then with our methods, and these with our applications. To weaken or break that chain anywhere is harmful to all.

But I shall not end on a pessimistic note. As a statistician I am an optimist, with a statistical definition of the species: "An optimist is a person who thinks the future is uncertain."

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