Statistics for All : Why, What, and How?

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1.   Why statistics for all?

Statistics has been traditionally thought of as a rather arcane body of knowledge best left to specialists. Society needs statisticians just as we need highway designers and surgeons, but statistics has no more been part of the intellectual armament of most citizens than are the properties of pavements or the physiology of digestion. This is no longer the case, at least if we understand "statistics" as *the science of data and chance*. Statistics in this broader sense is the heart of what is more often called "numeracy" or "quantitative literacy". Numeracy, like literacy, is important not for its own sake but as a medium for expressing reasoning and communicating ideas. Changing trends in most societies will make numeracy as essential as literacy now is.

The increasing presence of numerical information (data) and numerical reasoning in public dialogue in developed countries is too striking to require detailed description. The ability of the public to recognise sound policy in the face of risk and uncertainty is also increasingly important in democracies, nowhere more so than in the United States, where lawsuits now follow every random fluctuation. See Mossman et al. (1990) for a description of how public misperceptions of risk led to bad policy in the case of removing asbestos from buildings, and Zeckhauser and Vicusi (1990) for a more general treatment of perceptions of risk and probability. Thus both data and chance play important roles in informed citizenship.

More compelling to governments is the increasing need for quantitative skills in the labour force. A study done for the US Bureau of Labor Statistics (Johnson and Packer, 1987) noted that "Among the fastest-growing jobs, the trend toward higher educational requirements is striking." The Department of Labor quantifies the level of skill required for various jobs using a six-point scale. Current jobs require on the average math skills at the 2.6 level; the rating for fast-growing jobs is 3.1, for slowly growing jobs 2.3, and for declining jobs 1.6. We are all able to fill in some of the specific cases behind the averages: manufacturing workers must cope with automated processes and quality control, office workers with computerised information systems,

and so on. The most important specific behind the growing average skill required for productive employment is the decline in genuinely unskilled jobs. In the words of the study, "... jobs that are currently in the middle of the skill distribution will be the least-skilled jobs of the future, and there will be very few net new jobs for the unskilled." This fact lends an obvious urgency to the task of improving the quantitative (and other) skills of all members of society. Statistics for all is our social responsibility.

2.   What statistics for all?

We do not learn to read and write in order to become editors or novelists, or (even more) in order to prepare for some later course of study in reading and writing. Yet mathematics has often been taught as though the immediate purpose were to prepare for some later maths course and the ultimate purpose to train mathematicians. Statistics has been consigned to its corner within mathematics instruction and has followed the same instructional practice, much to its detriment. Our social responsibility requires that we not allow pre-professional education to dominate our thinking. It also requires that we participate fully in the reform of mathematics education, to which statisticians have much to contribute. What should we emphasise?

First, *data analysis in the context of basic mathematical concepts and skills.* The ability to use and interpret simple graphical and numerical descriptions of data is the foundation of numeracy. Consider, for example, the point-of-sale terminals used by Seven-Eleven, Japan's largest food retailer. The computer notes each item purchased with its price, the age and sex of the buyer, and much else. The *Economist* (March 10, 1990) observed that "Each machine is fitted with a special monitor which displays the information as charts to shopkeepers. Sales of a certain product can be plotted against the hours of the day, days of the week or whatever. Thus patterns can be easily picked out and new products tested." At least in Japan, shopkeepers are assumed to possess basic data analysis skills.

Inclusion of graphical and numerical tools for data analysis in school curricula, until recently quite rare, now has wide support (e.g. NCTM, 1989). Working with data is an important ability in its own right, one that becomes more prominent as we move from basic schooling to vocational or on-the-job training. But that is not the primary justification for so considerable a revision in basic mathematics instruction. Data - that is, numbers with a context - bring meaning to arithmetical operations. Calculating the mean price of oranges in several urban markets and making comparisons across seasons of the year or neighbourhoods in the city is more than an exercise in arithmetic. Meaningful data aid in replacing an emphasis on calculation by the exercise of judgement and a stress on interpreting and communicating results. Thus consistent use of data and data-analytic tools in early mathematics instruction is not statistical imperialism but a contribution to broader reform of mathematics education. See MSEB (1990) for an excellent statement of the goals of reform and Moore (1990) for more detailed comments on the place of data and chance in the schools.

Next, *the design of data production* with emphasis on detecting bias due to improper design. Not all data are equally trustworthy; the design of the data production process is the most important indicator of quality in data. One of the most-noted clinical trials of recent years was the Physicians' Health Study, a randomised, comparative,

double-blind experiment that demonstrated that taking aspirin regularly reduces the risk of heart attacks in middle-aged men. Shortly thereafter, another study observed several thousand residents of California retirement communities and found that men who chose to take aspirin had no lower risk of heart attacks. The physician who directed the PHS replied (*New York Times*, November 18, 1989) that the authors had "gone beyond the ability of the kind of study they did to draw such conclusions of cause and effect" and went on to describe the advantages of controlled experiments over observational studies. A similar appreciation of the principles of data production is a major goal of statistics for all.

Third, *an appreciation of the role of variation and uncertainty*. Statisticians recognise the omnipresence of variation. Individuals vary, repeated measurements on the same individual vary, the domain of determinism is narrowly circumscribed. Not all variation is significant in either the practical or the statistical sense. Unfortunately, there is every indication that chance is a much harder topic than is data. Our anecdotal classroom experience suggests this; research confirms the anecdotes. Psychologists (e.g. Tversky and Kahnemann, 1983) have documented the surprising extent to which intuitive thinking about uncertainty conflicts with the rules of probability theory. Our intuition

(i)   expects random phenomena to be regular even in the short term, so that runs in coin tossing (for example) are taken as evidence of some causal influence;

(ii)   disregards the effect of after-the-fact selection, so that when one of very many possible "coincidences" occurs, a causal explanation is again sought;

(iii)   cannot comprehend or compare very small probabilities, a weakness with serious consequences in assessing risks;

(iv)   has great difficulty with conditional probability, commonly confusing $P(A|B)$, $P(B|A)$, and $P(A \text{ and } B)$.

As this list suggests, the difficulties are conceptual rather than mathematical. Education researchers have looked intensely at students' understanding of probability and at attempts to improve their learning. They find that our students, even those who can successfully solve most textbook problems, have a very limited understanding of probability. Garfield and Ahlgren (1988), after a useful survey of this research, conclude that "teaching a conceptual grasp of probability still appears to be a very difficult task, fraught with ambiguity and illusion." Statistics for all, concentrating on concepts rather than mathematics, must face this task.

Even history testifies to the difficulty of probabilistic concepts. The history of probability and statistics has received a great deal of scholarly attention in recent years. I recommend *The Empire of Chance* (Gigerenzer et al., 1989), in which six randomly ordered authors give a narrative overview more accessible than the specialised histories. The struggle of better minds than ours to understand and quantify uncertainty is fascinating, full of interplay with social patterns, and with the ideas of determinism and indeterminism. Full also of what can only be called confusion among differing concepts of chance and between the specific "application" and mathematical and statistical ideas that eventually proved portable across applications.

Yet there is some hope. Let me cite the evidence summarised by Nisbett et al. (1987). They demonstrate, among much else, that the study of even quite academic

statistics does improve the ability to recognise the role of chance and variability in a variety of settings, while even graduate study of deterministic disciplines has no such effect. If we concentrate on concepts rather than mathematics in teaching basic probabilistic facts, we should do yet better.

3. How statistics for all?

The answer to the question "How statistics for all?" is certainly "By every available means." We will often find ourselves cooperating with the efforts of others to improve education or to offer training to wider groups of citizens. Statistics, even in the broader guise of numeracy, is but one component of basic education and of more specialised training. Our task is not to invent new delivery systems but to work cooperatively to use and improve existing structures.

Schools, especially the primary grades, are the traditional vehicle societies use not only to teach but to acculturate the young. Schools are everywhere the most important means for increasing over time the numeracy of the general population. Pupils gain from their schooling a structure of thought that persists even when the details are forgotten, and forms a basis for later recall or new learning. We hope that in the future pupils will bring away from their schooling a structure of thought that whispers "Variation matters ... Why not make a graph?" The movement to increase the role of data and chance in the early years of schooling, well represented in other ICOTS sessions, is the centerpiece of statistics for all.

Other vehicles for reaching a wide audience, while they lack the universal reach of early schooling, can be effective in different social settings. *Universities* in most nations concentrate on quite specialised education, in which technical statistics plays a role as needed. In the United States, however, it is traditional to devote the early part of college or university study to "general education" intended to present a broad culture and general intellectual tools. Here is an opportunity to acquaint a sizable audience (about 60% of US high school graduates continue into post-secondary education) with statistical ideas. At least one large public university has decided to require data analysis as part of general education (Ohio State University, 1988). I believe that general education requires both much more (in breadth of topics) and much less (in technical detail) than traditional statistics courses. My ideas appear in detail in a text (Moore, 1991) for this audience.

On-the-job training has the advantage of reaching workers in their job setting, where motivation is often higher than in schools. Workplace training is widespread. In the US, the corporate training system is roughly the same size in both number of students and dollars spent as the entire four-year college and university system. In some other countries, government and industry cooperate in structured apprenticeship and training programmes. These varied vocational programmes, often neglected by academics, are a proven means of imparting practical skills. Can we increase and improve the role of data analysis and statistical thinking in on-the-job training?

Mass media, perhaps especially television, offer another means of reaching a large number of citizens, though the actual audience for things statistical will be very much smaller than the potential audience. Early childhood programmes (such as *Square One* and *Three-Two-One-Contact* in the US) attempt to influence children's attitudes

toward mathematics and to present some basic facts. Telecourses bring tertiary instruction to learners who are remote from university campuses and usually employed. Examples are the products of the Open University in Britain and the US Public Broadcasting System course *Against All Odds : Inside Statistics*, for which I was content developer. The use of video recorders has given new life to telecourses in developed nations, where distant learners typically study alone. (Over two-thirds of US households now have a video recorder.) In developing societies, television can bring instruction to groups of learners in remote locations. Finally, television is widely used for post-graduate education of technical workers. Many US engineering schools, for example, present extensive offerings of technical courses that are transmitted by satellite and viewed by graduate engineers at their work locations. The National Technological University, operated by a consortium of American universities, now offers post-graduate degrees to students who select from televised courses taught by the schools in the consortium.

Beyond these structured suggestions, we ought surely to brainstorm, to search for original ideas for calling statistics to the attention of the public. Here are some examples. Video games commonly display the top ten scores achieved. Why not rather display a histogram of all recent scores? The player can then place himself relative to all other players and learn indirectly the value of effective data display. Displays in science museums would also profit from better presentation of data even when the topic of the display is not statistics. At an exhibit on human physique, enter your height, weight, age, and sex. A screen shows where you stand relative to the bivariate distribution of height and weight for persons of your age and sex. Statisticians are accustomed to working with researchers in other fields. We ought also to cooperate with other scientists when they design museum displays.

4.   Conclusion

It is certainly true that for some developing nations the immediate task is to put in place an independent and efficient system of national economic and social statistics and to train professionals, planners, and managers to operate this system and use its products. Statistics for all, with its emphasis on the wider public, may appear to be a luxury for the developed world. If a greatly increased numerical competence on the part of ordinary citizens seems utopian, consider that even in Western Europe programmes to achieve near-universal literacy were established only in the latter half of the nineteenth century. Developed nations may soon be giving numeracy the same emphasis that they placed a century ago on literacy. Developing societies may wish to telescope the process by simultaneously emphasising literacy and numeracy. Statistics for all may move from the reveries of ICOTS to national policy.

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