SOME REMARKS ON STATISTICS AND SCIENTIFIC EXPLANATION

MARLOS VIANA AND BORKO JOVANOVIC

Probability and statistics, as quantitative reasoning tools, determine and are affected by the experimental context. Because reasoning and the communication of reasoning are encoded by one's language, it is surprising that the interplay between statistical reasoning and the language of explanation of natural phenomena is less frequently discussed. In biomedical applications, for example, investigators formulate questions about a biological phenomenon (ω) and observe data $\mathrm{X} = \mathrm{x}$ in accordance to an experimental protocol $\mathcal{M}$ (i.e., experimental design, sampling units, measurement scales, etc). Statisticians then return a statement $\hat{\theta}$ about an abstract parametric structure θ describing a probability law of X, or certain functions of it. The interplay among the language expressing the investigator's initial question about ω, the experimental protocol $\mathcal{M}$ and the statistician's language reporting the resulting inferences about θ (or X) often goes unsuspected. In the following, we briefly comment on explanation and prediction in science, and then concentrate on a few remarks related to our main theme: Increased consideration should be given to the consequences of the fact that the practice of statistics and probability both determines and is affected by the collective of many different cultures of scientific enquiry and corresponding collective of experimental protocols. The goal of a unity of scientific explanation, we argue, will serve to a better understanding of the domain and adequacy of a forcible view of probability and statistics in science.

Explanation in science. John Casti and Anders Karlqvist (1991) suggest that the purpose of science is to provide explanation of perceived events (ω) and to enlarge such explanations with predictions of what future events will be seen next. What distinguishes scientific from other methods is explanation and prediction by rule, characterized by its explicit and public character. Because rules are explicit, they can be taught and used by anyone after appropriate training. Because they are public, they are open to common scrutiny regarding their validity and effectiveness for prediction and explanation of natural events. Of importance to the statistician's dialogue in collaborative projects is learning that the distinction between explanation and prediction can only be appreciated by considering how different corners of science have dealt with each one of them (e.g., explanation by reductionist principles of physics and chemistry in cell biology and the prediction of its evolutionary complexity, reduction vs. synthesis).

The unity of science. With this benchmark of scientific quality in mind, it is common observation that the intrinsic complexity of many biomedical, social or

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behavioral experimental protocols are unfriendly to well-defined and quantifiable laws of prediction. Nevertheless, the same protocols rely routinely on extensive statistical quantification and reasoning. We argue that here, again, the collaboration between statisticians and investigators will only gain by jointly recognizing the interplay of natural phenomena and experimental data, of analysis of data and interpretation of natural phenomena in the collective of all statistical reasoning territories (e.g., biological, sociological). More generally, by considering that fragmentation of knowledge leads to fragmentation of reality. This is conveyed by Edward Wilson (1998), in his contemporary approach to unity of science. He argues that *the ongoing fragmentation of knowledge ...is not reflection of the real world but artifact of scholarship*(p.8). So that we have mathematical, biological, social, educational, economic and many more statistics to read from. During the past thirty years, points Wilson, *the ideal of the unity of learning ... has been largely abandoned. With rare exception American universities and colleges have dissolved their curriculum into a slurry of minor disciplines and specialized courses.*(pp. 12-13). It is opportune to observe, however, that the aggregate of statistical reasoning share many common notions such as quantification, measurement and experimentation.

Geometers who never measure. Field anthropologists would observe that statisticians have the opportunity to *become resident* in the investigator's culture of scientific inquiry - a residency which would affect our own view of statistics and probability, and, consequently, our own ways of teaching statistics and probability. Junji Koizumi (1997) in his study of construction of person and time argues that one's view of time, for example, is profoundly affected by one's own aging process. We contend that, similarly, how one perceives the process of reasoning and experimentation within a research program affects profoundly how one understands the role of statistics and probability within that program. Without contact with experimentation, Dennis Lindley once said[1], we statisticians face the risk of becoming like geometers who study space and never measure it. If statistics is an integral part of the scientific method, then we must be aware that it cannot adequately be discussed if it is divided from the science to which it applies (Barry Gower (1997, p.6)). Again, it is by reaching out to the unity of science (the collective of statistical reasoning) that we may better see the natural dependency among statistics, probability and experimentation.

Entailment. Charles Ruhla (1989, Ch.7) describes a sequence of research protocols $\mathcal{M}_1, \mathcal{M}_2, \mathcal{M}_3, \ldots$ illustrating the interplay among experimental protocol, data and language of explanation in a simple experiment with polarization of light of different intensities, ranging from wave-like to particle-like conditions. It also illustrates the interplay between reasoning and the object of reasoning. To that point, Robert Rosen (e.g., Casti & Karlqvist (1991, Ch. 1)) argues that what we can know about a research program (e.g., the polarization of light) pertains to one or another of its specific quantization models; *other things pertain to the relations between such models; still others to the properties of the category of all such models.* This is the notion of *entailment*, proposed by Rosen. Therefore, as the notion suggests, statisticians and investigators alike should benefit from discussing the conditions

[1]Plenary address to the 4th Valencia International Meeting on Bayesian Statistics, Peñiscola, Spain, 1991.

on the relationships among the collective of protocols $\mathcal{M}_1, \mathcal{M}_2, \mathcal{M}_3, \ldots$, outside of which the body of obtained evidence becomes sensitive to extensions or restrictions on those protocols. Charles Rhula's example points to the consequences of considering the same research program (related to the polarization of light) under a set of different experimental protocols (e.g., normal light intensity, single-photon emission). It shows that different protocols require different languages to reason with common notions such as probability and statistical independence.

Quantification. In contrast to the common material of early hypothetic-deductive reasoning, modern-day experimental protocols include the arts (novels, plays, music, visual arts), the social sciences (politics, sociology, economics) and health (biomedical, behavioral, clinical) sciences. Immersed in the corresponding languages of scientific inquiry is the general and common notion of quantification. The collective of quantification mechanisms, too, is worth the appreciation of every statistician. Quantification mechanisms may include the common notion of Gaussian measurement error and, in other cases, a complex interface of many intertwining random mechanisms, e.g., a response of the human visual system to a light stimulus. A beautiful account of the early presence of quantification in the Western society is found in Alfred Crosby (1997).

Historical and social context. Also part of the experimental discourse is the historical and social context of scientific decision-making. In fact, it is argued that scientists can decide nothing of significance by reference to the rigid scientific method of hypothesis verification alone. This is not to say, points Barry Gower (1997, p.16),

> that scientists are illogical or unmethodical; it is to say that logic and method are totally inadequate when what we seek is an understanding of the construction of scientific knowledge. We are persuaded to accept scientific claims in the same way that we are persuaded to accept non-scientific claims, namely by means of interests and rhetoric rather than reason or experiment... Science is a social activity, and the means by which it is pursued are matter for negotiation between scientists, and between them and those other members of their society who have some control over what they do. Accordingly, the methods of science are grounded in the needs and interests of particular and different societies within which scientists work.

Here, it is the awareness of the collective of those different needs that should contribute to our broader understanding of reasoning and explanation with statistics and probability.

Summary. We have proposed that it is the cultural segregation of today's science that explains the ongoing presence of routine and extensive statistical quantification in experimental programs that may lack the intrinsically probabilistic, predictive and risk-taking nature of statistical reasoning. Segregation leads to isolated markets where scientific results are traded according to the local language and rhetoric of scientific explanation. Reward system includes publications, promotions, funding grants and a sense of security. Mathematicians learned from Gödel's Theorem that mathematics itself, is not just syntax - number theory is about numbers. Statistics and probability are about the collection of ways of experimenting with and representing the phenomenon and the reality of uncertainty, and about ways of consistently resolving uncertainty into actions and decisions. The simultaneous consideration of the many different experimental protocols $\mathcal{M}_1, \mathcal{M}_2, \ldots$, however, is a necessary component of the formulation and adequacy of those decisions.

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The University of Illinois at Chicago, College of Medicine, m/c 648
1855 West Taylor Street, Chicago, IL 60612.
viana@uic.edu, http://www.uic.edu/~viana/homepage.html

Northwestern University Medical School, Department of Preventive Medicine
680 North Lake Shore Drive, Chicago, IL 60611, borko@nwu.edu