NUSAP – philosophical background
Jerome R. Ravetz
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The NUSAP system was motivated by practical concerns, but it could be devised only because of its philosophical background. The practical concern was my perception of widespread incompetence in the expression of quantitative information. This is most clearly seen in the use of long strings of insignificant digits in common arithmetical expressions. I eventually traced this phenomenon back to a lack of understanding of uncertainty and its expression; but I was not able to move forward in resolving the problem, without the philosophical insights provided by Silvio.

There are three sources of the philosophical insights that formed the NUSAP system. The first, and oldest, is the tradition of foundations of mathematics, partly realised in formal logic and also in intuitionist philosophy of mathematics. This latter was developed in the early twentieth century, in reaction against programmes for the foundations of mathematics that conceived it in exclusively logical terms. One of the criticisms made by the intuitionists is that a formal system (one consisting solely of symbols to be manipulated) must be translated into ordinary language if it is to be of any use. In particular, when there is a hierarchy of 'meta-systems' that elucidate a mathematical language, eventually there must be an informal system; the sequence cannot go on forever. Silvio Funtowicz had been trained in the foundations of mathematics, and was able to deploy the insights he learned there.

The other source within the philosophy of mathematics was the work of the Hungarian scholar Imre Lakatos. In his classic book *Conjectures and Refutations* he showed how an apparently simple idea, 'polyhedron' (thus cube, octahedron, etc.) is actually shaped through an historical process, one of 'conjectures and refutations', as a succession of concepts of the key object is shaped through refutations of conjectures about the argument. Lakatos sketched an extension of his argument to the creation of rigour in nineteenth-century mathematics, a subjcct that I had already studied historically. Through my friendship with Lakatos, and appreciation of his work, I gained confidence in my own approach to the historical development of mathematics, including its concepts and even its ideas of proof. Since almost all the philosophy and pedagogy of mathematics was based on the assumption of mathematics being a rigid, timeless logical system, this support was crucial for me.

In my own work, I first came across the criticisms of 'the calculus' by the philosopher George Berkeley, Bishop of Cloyne. In *The* Analyst he examined the confused justifications of the the apparent division of zero by zero that are necessary in the differential calculus, and in *A Defence of Freethinking in Mathematics* he exposed the lame defence of these confusions, even by the greatest of mathematics like Sir Isaac Newton. All this confirmed and justified my own private concerns about the meaning and rigour of mathematics as taught, and doubts about the universally acknowledged truth that mathematics is a purely logical subject. The critical insight was generalised to science in a chapter in my book *Scientific Knowledge and its Social Problems*, where I discussed 'Obscurities at the foundations of theoretical science'.

Thus emboldened, I was quite ready to admit confusions and obscurities in the ordinary practice of quantitative science. Recently there have been devastating critiques of statistical significance-testing and of the misuse and abuse of computer models; but there were few who appreciated these points when I first developed them. My first foray was into the suppression of uncertainty in economics; and around the same time I was exploring the widespread use of meaningless precision in numerical statements. But this did not seem to be getting anywhere; I had no theory to help explain and remedy the situation. Then, in the early 1980's, I met Silvio Funtowicz. Silvio had received a classic education in mathematics and its foundations in Buenos Aires. There he also studied and taught the philosophy of science, with a focus on the uses of science in the policy domain. We quickly established a partnership, and got funding for a project on the management of uncertainty in technological risks. Silvio brought two key insights from his studies. The first was a critique of attempts, already underway, to create new formal systems to encompass uncertainties that could not be reduced to mathematical probabilities. He saw that formalisms could be iterated without end, but eventually there would need to be an informal, ordinary-language system for practical use; and so why not start at the bottom? We are both very practical people, and our goal was to improve the skills of practitioners, not to replace them.

Silvio's second key insight was about the structure of whatever notational system we might develop. At the highest level is a scheme, of categories or we might call them 'boxes'. These are the entries: Numeral, Unit, Spread, Assessment, Pedigree, whose initials make up the acronym NUSAP. Below that we have the notation, with the characteristic entries like kilometer, kilometer/hour, ±%, … . The point is that there might be another set of notations, depending on the situation being described. Then for each notation, there will be 'instances', the particular numbers or codes. With that structure, NUSAP is flexible and coherent.

It was easy to create a system with the first three categories; the last two required some imagination. We needed some way to characterise the more qualitative aspects of quantitative information, designing notations that enabled variety and nuance without becoming prolix or obscure. The invention of 'Pedigree' is worth recounting, as it indicates our approach. I had given a lecture on uncertainties at a seminar for staff of the Health and Safety Executive. Another lecture was on a probabilistic analysis of explosions in storage tanks for Chlorine, a common industrial feedstock. Afterwards, on the train station platform, I was approached by someone from the audience. He made it plain that he disapproved of the abstract mathematical approach. He told me that when he inspects a tank, he considers its documentation, its general condition, the history of its maintenance and repairs – in short, as he said, its 'pedigree'. I reflected that this is an odd concept for a Chlorine tank; but then, why not for numbers? Then we got the idea of a matrix, with phases for columns and normatively ranged modes within them. The NUSAP system was born.

We had the great good fortune to get a contract for a book on 'Numbers with Fringes', which gave us the opportunity to expand on our philosophy of quantities. It is called *Uncertainty and Quality in Science for Policy*. It is something of a collector's item, though the forthcoming Chinese translation should be cheaper. The NUSAP approach got its great chance when there was a scandal over the management of uncertainty at the Dutch environmental assessment agency. The management brought in some scholars, who advocated a 'Guidance' whose core is the Pedigree idea. This is being implemented at the agency, and the leader of the development, Jeroen van der Sluijs, promotes NUSAP and also PNS vigorously and effectively. He hosts the nusap.net website, on which an introductory essay on NUSAP has had some fifteen thousand reads.