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GUEST EDITORIAL

An obsession with numbers: quantifying quality

One of the things that we learn in our early childhood is numbers: 1, 2, 3,… in our mother tongue. Subsequently, we learn the difference between zero and nonzero, about smaller and larger numbers, and about integers and non-integers. Much later we learn about negative numbers, and rational and irrational numbers. As Indians, we are proud of our Bhaskaracharya of ancient times and Srinivasa Ramanujan of recent times. Kanigel declared the latter to be the man who knew infinity.

Numbers are unavoidable in a society. For its smooth functioning, a society maintains the birth and death records of its citizens and a variety of other things. As children, my generation used to memorize multiplication tables and we were good at mental arithmetic. As time went by, calculators made me lose my ability to do mental arithmetic. When cell phones were introduced, I started storing telephone numbers of contacts and stopped remembering them. With smart phones, I have started storing more information and I remember much less now.

Richard Feynman, an outstanding physicist, declared long ago that he did not have to remember numbers because he could always look them up. However, he admitted that he did remember the velocity of light, Planck's constant and a few other important numbers. The society as a whole has changed a lot in the last few decades: people remember numbers less, but deal with numbers more.

This is ironic. The digital era has brought about sweeping changes. All information (and images) is stored digitally – be it in binary or some other system of numbers. The information explosion in the form of 'big data' indicates that individuals can no longer deal with a multitude numbers. However, the computer can retrieve them all, process them and store them for subsequent retrievals. Progress is measured in terms of the increase in the capacity of the storage devices (from kilobytes to megabytes to gigabytes and terabytes), and an increase in the speed of processing (from megaflops to gigaflops to teraflops).

Students of science tend to report their results to several digits that come out of their calculators/computers, without realizing the importance of significant numbers. Over the years, scientists have measured fundamental quantities such as the velocity of light, gravitational constant, etc. to increased accuracy (increased number of digits) to test the existing theories and our understanding of Nature. When experimental results agree with theoretical predictions, we believe that our understanding of the phenomenon concerned is complete. Herzberg's measurement of the bond dissociation energy (D_0) of hydrogen molecule is a case in point. He found it to lie between 36,116.3 and 36,118.3 cm^{-1}, thus confirming the molecular orbital theoretic prediction of 36,117.9 cm^{-1} by Kolos and Wolniewicz. Any discrepancy between the predicted and measured numbers is invariably an indication of the inadequacy of the theory and/or uncertainty in the experimental result. This often leads to an improvement in theory and/or refinement in measurement. Sometimes, it leads to a paradigm shift as it happened in the early part of the 20th century, with the discovery of quantum mechanics, and in the formulation of special theory of relativity. Heisenberg's uncertainty principle took the cake, putting a limit on the accuracy of measurements at the atomic level.

Numbers are important in our description (understanding) of space and time. The size of the universe is reflected in large numbers (10^{26} m). In contrast, the inner structure of the atomic nucleus is measured in terms of numbers as small as 10^{-18} m. If the age of the universe (~13.9 billion years) is at one end of the timescale, the electronic motion in atoms occurring in sub-attosecond (10^{-18} s) scale is at the other end. We understand everything around us in motion or otherwise, in terms of the length and breadth of space and time mentioned above.

Ranking requires numbers. For instance, countries are ranked on the basis of their GDP and other indicators, and Institutions are ranked on the basis of the number of students, the number of faculty and their output in terms of the number of research publications, patents, etc. Moreover, any Government's strategies to improve the quality of education in a country are decided on the basis of the number of students enrolled in higher education and the required number of teachers based on the faculty : student ratio. The health of the economy is measured by the annual percentage growth. The United Nations has come up with Human Development Index. I am sure somebody will come up with a Happiness Index before too long.

The scientific community is obsessed with numbers for yet another reason. Practising scientists are expected to publish (in large numbers) or perish. Their output is often measured in terms of the number of publications, number of citations they have received, impact factor of the journals in which the papers were published, cumulative number of the citations, *h*-index and a variety of other metrics. In the early years of Science Citation Index, we were keen to know how many people cited our work. Nowadays, journals tell you how many times your paper has been 'downloaded'. We will never know if the readers ever read beyond the title and the abstract.

In view of the exponential increase in the number of research publications, judging quality by quantitative measures has become a formidable task, in particular, for expert committees which appoint/promote/reward colleagues. Quantification has become necessary to ensure both fairness and transparency in evaluation. But science and society cannot escape from quality judgement. Year after year, when the Nobel Prizes are announced, the impact of the discovery by the Nobel laureates is emphasized in terms of how fundamental or path-breaking the discovery was – not necessarily in terms of the number of publications and the number of citations that followed.

Looking back, one could trace the phase transition in the number of research publications globally to the discovery of high-T_c superconductors three decades ago. When the discovery was announced, the whole world was excited about it because only metals were supposed to be conductors and superconductors until then. Ceramic materials becoming superconductors was an unexpected finding. The result was the rush by a large number of chemists and physicists to synthesize a large number of superconducting materials. The periodic table contains a finite number (<92) of naturally occurring elements, but they can be combined to give an infinite number of superconducting materials. Thanks to the improvement in technology, the discovery of fullerenes, carbon nanotubes and other nano materials, and their potential use in myriad applications have led to yet another exponential growth in the number of research publications.

I learned recently how hotness of a chilli could be measured in Scoville units. But how do I judge the quality of a spicy food that is served? By its appearance, flavour or taste? Each one of us invariably knows how to judge our favourite food in terms of the 'gastronomical delight'. While numbers may help in assessing incremental contributions to science, an assessment of disruptive progress calls for measures that go beyond numbers.

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