# Face to Face

**This section features conversations with personalities related to science, highlighting the factors and circumstances that guided them in making the career choice to be a scientist.**

# Wise Decisions Under Uncertainty

***C R Rao talks to B V Rajarama Bhat***

Calyampudi Radhakrishna Rao is a living legend known for Cramer–Rao Inequality, Rao–Blackwell Theorem, Rao Distance, Rao's Score Test, Rao's Generalized-Inverse, and Rao's Quadratic Entropy and Orthogonal Arrays, and so on. Along with P C Mahalanobis he played a major role in developing the Indian Statistical Institute as a premier educational institute. Rao is the author of 14 books and 475 research papers, several of which are recognized as classics. He guided the research work of 50 students for PhD, who in turn produced about 450 PhDs. The long list of awards he received includes:

- Padma Vibhushan 2001– the second highest civilian award, from the Government of India. (*Figure* 1);
- National Medal of Science 2003 – the highest award given to a scientist in USA (*Figure* 2);
- India Science Award 2009 – the highest recognition given to a scientist in India (*Figure* 3).

In honour of C R Rao, the Ministry of Statistics and Programme Implementation, Government of India has instituted the 'Prof. C R Rao National Award for Young Statisticians' to recognize significant work in the field of statistics by a young statistician.

**Figure 1.**

**Figure 2.**

**Figure 3.**

**The following interview with C R Rao was conducted through email by B V Rajarama Bhat with some input from Siva Athreya and Mohan Delampady.**

**RB:** To begin with please tell us a little bit about your childhood and early education.

**CRR:** I was born on 10 September 1920 in Huvanna Hadagali, in Madras Presidency during the British period, and now in Karnataka State, and had all of my education in towns in present-day Andhra Pradesh. I joined class 2 in school when I was five years old. In class 3, when I was six years old, I could memorise multiplication tables up to 16 by 16, necessary for monetary transactions in those days, with 16 annas per rupee, 4 pice for an anna and 3 pies for a pice. The class teacher used to line up the students in my class, ask me to stand in front of them and recite the multiplication tables line by line, which the other boys would then repeat. I completed my education from third form up to Intermediate at a local college in Visakhapatnam, 'getting first rank in all classes and receiving all coveted prizes'. I then joined Andhra University for graduate studies. I obtained BA (Hons) degree, equivalent to MA, in mathematics with a first class and first rank in 1940.

**RB:** How did you come to do statistics? Please tell us about your student days at ISI and your teachers of those days.

**CRR:** My father, who recognised my interest in mathematics, encouraged me to have a role model, pursue higher studies, do research, and get a PhD degree. I chose Ramanujan, an autodidact and a mathematical genius who made remarkable contributions to mathematics and laid the foundations to several new areas of mathematics. Unfortunately, my father died before I completed my education at Andhra University. After getting my degree, I wanted to get a job and earn money to support the family as my mother was not eligible to get my father's pension. I tried sending applications for various jobs without success. I applied for a research scholarship to do research in mathematics at Andhra University. The scholarship application was denied as I was late in sending the paperwork by a week. As a last resort, I applied for a job in the military, which was recruiting mathematicians to serve in the survey team during wartime. I was called for an interview in Kolkata, but the military officers rejected me, saying that I was too young at the age of 20. During my visit to Kolkata, I stayed in a hotel where I met a South Indian by the name of Subramaniam who had come from Mumbai to receive training at the Indian Statistical Institute (ISI) in Kolkata. At that time, there were no courses in statistics leading to a degree in any university in India. He said that I would have a good chance of getting a job if I received some training in statistics at ISI. He took me to ISI, showed me computing machines, and introduced me to some research staff. He asked me to apply for admission. I went back to

Visakhapatnam and told my mother that the only alternative for me was to get admitted to ISI for training in statistics, and it would cost me Rs.30 a month to stay in Kolkata. She said that she would raise the money somehow and that I should go to Kolkata to join ISI. I travelled to Kolkata with Rs.30 in my pocket and joined ISI on 1st January 1941. I worked for about 40 years at ISI and took compulsory retirement at the age of 60. I was denied any opportunity to work in India and continue my research after retirement, but attractive offers came from universities in the USA. I worked in the US for 20 years as University Professor at the University of Pittsburgh and as the first Eberly Professor of Statistics at Pennsylvania State University in State College. I retired from teaching in 2001at the age of 81 but continued as Director of the Center for Multivariate Analysis at Pennsylvania State University. In 2009, I moved to Buffalo at the age of 90, where I have the position of a Research Professor at the University at Buffalo. I spend some time in Hyderabad developing the Institute named after me, C R Rao Advanced Institute of Mathematics, Statistics and Computer Science. So it was chance that led me to study statistics and a series of chance events that led me to spend 70 years of my life, 40 years at ISI and 30 years in USA, pursuing statistics. I am now 93 years old.

**RB:** Tell us how Mahalanobis succeeded in bringing a large number of top scientists together in his project of building an institute of national importance, and how you got involved in it.

**CRR:** The Professor, as P C Mahalanobis was known in India, was a remarkable person. He was a physicist by training, a statistician by instinct, and an economist by conviction. He was convinced that the problems of the country could be solved by taking optimal decisions based on information from available data and collecting necessary fresh data, and founded the Indian Statistical Institute to achieve these objectives. It was not easy to develop an institute without financial support and talented people to develop his ideas. The Professor was successful in achieving both. He was a talent scout and went out of the way in locating bright people, going to their houses and offering them jobs in ISI. By the time I joined ISI, there were R C Bose, S N Roy, K R Nair and Bhattacharya, all of whom made valuable contributions to statistics. He convinced Pandit Nehru about the need for statistics to develop the country. The Professor also believed that involving foreign scientists would be of great help in his endeavour. He used to make frequent trips abroad to meet well-known statisticians and economists and lure them to visit the Institute by offering them travel costs and local hospitality. Some of the pioneers who visited ISI are R A Fisher in statistics, Ragnar Fish in econometrics, Norbert Wiener in mathematics, and Walter Shewhart in statistical quality control (SQC). Most of the outstation branches of ISI were initially established after Shewhart's visit in order to provide SQC technology to local industries using techniques developed by him.

**RB:** Which result of yours are you most happy about?

**CRR:** I joined ISI in 1941 and started doing research on combinatorial problems in design of experiments, which was the main topic of research at ISI at that time. On the advice of the Professor, I took admission to the newly started MA program in statistics at Calcutta University in 1941 and passed the examination with a first class and first rank with record marks, which is not broken till today. I accepted a part-time position to teach MA, MSc students at Calcutta University while doing my research at ISI. While teaching the course on estimation, a student, V M Dandekar asked me whether *I can give a finite sample version on the upper limit to the variance of an unbiased estimator*. I worked on the problem overnight and discussed the solution in the class the next day, which is named by J Neyman as Cramer–Rao inequality and which is quoted in textbooks on statistics and engineering. This result, along with the introduction of a distance measure based on a differential metric, was published in a mathematics journal in 1945. This paper gave rise to other technical terms like Rao–Blackwellization, Fisher–Rao Metric, and Rao Distance and promoted research by others in various directions. During the forties I made other contributions such as Rao's Score test, Orthogonal Arrays, and Analysis of Dispersion (AD) renamed by American statisticians as MANOVA. Another important contribution is the use of generalised inverse of a matrix which enabled a unified treatment of multivariate methods irrespective of linear relationships among the variables**.**

Terry Speed, a senior professor at the University of Berkeley, wrote in the *Bulletin of the Institute of Mathematical Statistics*, USA, Jan– Feb, 2010 issue:

The 1940s were ungrudgingly C.R.Rao's. His 1945 paper, which contains the Cramer–Rao Inequality, Rao–Blackwell Theorem, and the beginning of differential geometry of parameter spaces, will guarantee that, even had he done nothing else – but there was much *else*.

That is something to be happy. But what makes me most happy and proud is that I have guided 50 students for a PhD degree who in turn have produced about 400 PhDs (website: math. genealogy of C R Rao), and many of them have made valuable contributions to theory and applications of statistics and probability.

I was deputed by ISI to work for 2 years in Cambridge University as a research scholar at the invitation of a Professor of Anthropology to do statistical analysis of multivariate measurements made on skeletons brought from Africa. I had the necessary expertise on the use of Mahalanobis distance in such analyses. Thus I had the opportunity to meet R A Fisher and choose him as my thesis advisor. I received the PhD degree of Cambridge University in 1948 based on multivariate methods of analysis I developed to analyse the skeletal data and the senior doctorate ScD in 1965 by peer review of my published research papers.

**RB:** You are very prolific in publishing. What is the secret?

**CRR:** There is no secret. In ISI, where I worked for about 40 years in various capacities as a Research Scholar, Head of the Division of Research and Training School (RTS), Director of RTS, and Director of ISI until retirement, there was a proper environment with a sizable group of research workers who tried to compete with each other in producing good research. I published 201 papers in the 40 years at ISI, of which 156 were as the sole author and 45 in collaboration with others. During the 20 years at universities in USA, I have 272 published papers of which 90 papers are as a sole author and 182 are jointly with others. In USA, the number of faculty members in any department is quite large, and often two or three individuals join together to work on a problem.

India has a very low rank in publication of papers in high impact journals, even below that of some third world countries. There is an urgent need for encouraging students and faculty to pursue quality research and reward them in a suitable way. This is a challenge and does not seem to be possible in a system where promotions are made by seniority and not by merit. Indians doing good research have to go abroad to get recognition for their research and win international awards.

**RB:** What are your views on the current debate on 'big data analytics' versus statistical methods?

**CRR:** The unprecedented advances in digital technology during the second half of the 20th century have produced a measurement revolution that is transforming the world. Many areas of science are now being driven by new measurement technologies and many insights are being made by discovery-driven, as opposed to hypothesis-driven, experiments. Empiricism is back with a vengeance. The current scientific era is defined by its dependence on large amounts of available data termed as Big Data (BD) and Data Mining (DM) for information. These are new challenges that require the development of appropriate statistical methods advantage of the enormous increase in computing that take power. Big Data needs statistical methods for analysis which may be somewhat different from the traditional ones of experimentation, estimation, and testing of hypotheses. BD is a natural evolution of statistics. With BD, it should be possible to predict future observations more accurately and at the same time gain insight into the relationship between the features and response for scientific purposes. This is a challenge for current researchers in statistics.

**RB:** What is your definition of Statistics?

**CRR:** Statistics is the science of developing human knowledge through the use of empirical

data and of taking wise decisions under uncertainty.

**RB:** What should a student focus on when learning elementary statistics?

**CRR:** A physicist learns physics to solve problems in physics. A chemist learns chemistry to solve problems in chemistry, and a biologist learns biology to solve problems in biology. There is nothing like a statistical problem that we solve by using statistics. We learn statistics to solve problems in other areas of knowledge. By elementary statistics we mean some simple methods of analysing data to provide some information. Students can look for the kind of problems they can investigate with the knowledge they have.

**RB:** What are some of the interesting careers in statistics?

**CRR:** Governments need statisticians to help in taking short-term policy decisions and making long-term economic plans, to catch terrorists, to detect forged currency, to forecast catastrophic events, and so on. The judge needs statistical evidence in cases of disputed paternity and disputed authorship. The industrialist is looking for operations research (OR) for efficient management and quality control of industrial products. The pharmaceutical company wants to know whether the new drug it produced is better than the existing one in curing a disease and so on. There is no area of human endeavour where decisions can be taken without statistical help, and careers in all areas should be equally challenging and interesting. The demand for qualified statisticians will grow as Hal Varian, chief economist at Google said, the "sexy jobs in the next ten years will be statisticians."

**RB:** Is there anything else that you wish to convey to students and future mathematicians and statisticians?

**CRR:** Data is merely the raw material of knowledge. We are rapidly entering a world where everything can be monitored and measured. But the big problem is going to be the ability of humans to use, analyse, and make sense of the data. We need a new breed of statisticians to hunt for meaningful patterns and insights in vast troves of data with the use of powerful computers and sophisticated mathematical models. The statisticians have a challenging role to play. The year 2013 was declared an International Year of Statistics to promote the following three objectives:

1. Increasing public awareness of statistics
2. Encouraging students to study statistics
3. Promoting creativity and development in statistical science

I wish the younger generation good luck in achieving these objectives.