Rs 50

CURRENT SCIENCE

Volume 118 Number 8 25 April 2020

Vikram Sarabhai birth centenary

Micro-irrigation development in India

Nitrous oxide emissions from turfgrass lawns

Current Science Association ■ Indian Academy of Sciences

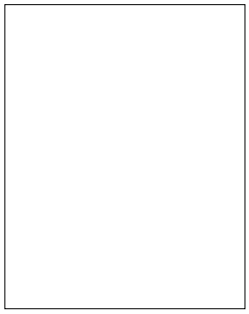
Founded: 1932 ISSN: 0011–3891

CURRENT SCIENCE

Volume 118 Number 8 25 April 2020

RESEARCH ARTICLES

RESEARCH COMMUNICATIONS



◀ COVER. Vikram Sarabhai: A visionary scientist. See special section.

Indexed in CURRENT CONTENTS/GEOBASE/CHEMICAL ABSTRACTS/IndMED/SCOPUS/
WEB OF SCIENCE

Foreword

I am delighted to see that *Current Science* is bringing out a special section on Dr Vikram Sarabhai on the eve of his birth centenary year. I find no better way to describe the personality of this great Indian than to reproduce what Prof. C. N. R. Rao says about him in his concluding paragraph as a part of his tribute in this issue: 'Vikram Sarabhai was one of the most cultured persons that I have known. He was educated in the true sense. His wife Mrinalini was a great classical dancer and ran a dance academy. I consider myself lucky to have known a person as sophisticated, as *suave*, as human and as charming, as Vikram Sarabhai. I have not met anyone like Vikram Sarabhai in my dealings with the scientific community. There was only one Vikram Sarabhai.'

Vikram Ambalal Sarabhai was born on 12 August 1919 in an illustrious family, well known for its social prominence and wealth, in business and in philanthropy. His parents were professionally prominent with his father Ambalal Sarabhai being a pioneer in textile industry and his mother Sarla Devi being a social activist. Sarabhai's early schooling was patterned on the model of a Montessori education, with the idea of imparting knowledge towards stimulating in the pupil its love and pursuit. The early childhood environment of Sarabhai was one where he came in contact with such dignitaries as Mahatma Gandhi, Annie Besant, Rabindranath Tagore, Maulana Azad, Sarojini Naidu, J. C. Bose, C. V. Raman, Pandit Madan Mohan Malaviya, Sardar Vallabhai Patel and Pandit Nehru among many others. This in turn had a unique and positive impact on young Sarabhai. After the completion of formal school education from R. C. High School of Ahmedabad, he continued his interests to pursue Science and Mathematics in higher education at Gujarat College. Following this, in 1940, he got an opportunity to study and complete his Tripos in Physics and Mathematics at St Johns College of Cambridge. He continued his post-graduate studies in Cambridge when the World War II broke out. In view of this, Sarabhai returned to India to work with Sir C. V. Raman at Indian Institute of Science for which Raman got a special permission from Cambridge to ensure continuity of his research work. He could thus, return back to Cambridge and complete his Ph D in Cosmic Rays working on the Doctoral thesis 'Cosmic ray investigation – experiments with gamma rays' under Prof. Robert Millikan. The thesis itself was evaluated by Prof. P. M. S. Blackett. Working with three Nobel laureates in his early phase of academic career could have had a remarkable influence in Sarabhai's later professional life with its multiple dimensions. During a visit to India just before completing his Ph D, Sarabhai met Mrinalini at Bangalore through contacts developed during meetings where arts and culture were the focus of discussion and in which he had deep interest. Upon the completion of his Ph D they finally got married in Chennai. Soon the family became four, with the birth of Karthikeya and Mallika, both of whom in the later years repeated the qualities of their parents with their brilliance both academically and professionally. The country honoured the entire family with *Padma* Awards.

Coming from a family of industrialists, Sarabhai was a part of the family management team to oversee the functioning of the different business establishments. He gave up his business responsibilities when he took over the major task of creating and managing India's space programme.

In the period after Sarabhai returned to India with a Ph D from Cambridge, in order to pursue his interest in Cosmic rays and interplanetary medium, he set up Physical Research Laboratory, Ahmedabad in 1948. This laboratory had two major areas of research, one relating to the study of cosmic ray time variations under the direct supervision of Sarabhai and the other relating to atmospheric and ionospheric studies under the overall guidance of Prof. K. R. Ramanathan. Sarabhai and his students made seminal contributions to the understanding of the interplanetary medium using cosmic rays as a sounding probe. He and his team set up such major observational facilities as Giger Muller Counter telescopes, plastic scintillator telescopes and neutron monitors. In the process of analysing the data from these instruments he and his students established that cosmic ray anisotropy is something that originates beyond the atmosphere and the geomagnetic field, discovery of the 22-year-old variation of solar magnetic field as well as detection of 27-day modulation of cosmic ray intensity on Earth due to solar rotation.

By 1960s, the world having seen satellites of Soviet Union and USA being orbited around Earth was getting ready for a new era of space exploration. The Indian National Committee for Space Research (INCoSPAR) was set up by the Government with its headquarters at Physical Research Laboratory and Sarabhai being its first Chairman. The first contours of India's space endeavour were drawn up at this time through the meetings of INCoSPAR under the visionary leadership of Sarabhai. One of the first tasks was to setup a rocket launching station at Thumba close to the geomagnetic equator (TERLS). The first rocket from TERLS was launched on 21 November 1963. Many aspects of atmospheric and ionospheric scientific investigations above geomagnetic equator were facilitated in the subsequent years through a number of rocket launchings including the French, American and Soviet rockets and also instruments from these countries among others. Around this time, Sarabhai also initiated establishing Space Science and Technology Centre (SSTC), in the outskirts of Thiruvananthapuram, now known as Vikram Sarabhai Space Centre (VSSC),

charged with the responsibility of developments of rockets and satellite technologies.

As a part of the first steps towards establishing India's space programme, Sarabhai undertook several initiatives with the policy of indigenization, licensed production and also technology transfer arrangements. Among the many initiatives that the initial part of the space programme witnessed under Sarabhai, some of the more prominent ones include licensed production of the French Sounding Rockets Centaur, finalization and initiation of the work on India's first launch vehicle SLV-3, preparation for undertaking satellite communications at experimental level by an agreement with NASA to loan their ATS-F satellite for the conduct of Satellite Instructional Television Experiment (SITE) – one of the largest sociological experiment ever planned and executed with high technology, and establishment of a unique Developmental Educational Communication Unit (DECU) at Ahmedabad to produce appropriate software for a variety of developmental themes like health, agriculture, family planning, environment and such other areas. As a part of a long term strategy, Sarabhai also initiated studies on a satellite system INSAT for national television, broadcasting and telephony applications. Recognizing the importance of satellite-based remote sensing from space for timely and precise resource management, an agreement was signed with US to receive the imagery data from the first American remote sensing satellite Landsat. The necessary ground systems for the reception, analysis and interpretation of data as well as its utilization by the various user agencies like those related to agriculture, environment, water resources, land use and land cover planning, wasteland mapping, etc. were also initiated. One of the other major steps that Sarabhai took before passing away in 1971 was to discuss with the then Soviet Union about the possibility of launching an Indian satellite with the help of a Soviet Rocket. The first thoughts in this direction were shared between Vikram Sarabhai and the then Soviet Ambassador, which subsequently gave birth to the Aryabhata project.

Sarabhai took over the leadership of Atomic Energy Commission (AEC) as its Chairman, after the untimely demise of Dr Homi J. Bhabha in 1966. In continuing the vision of Homi Bhabha, Sarabhai provided exceptional leadership in spite of his disposition of possessing peaceful frame of mind and therefore very much against coercion in signing the non-proliferation treaty. As Chairman AEC, Vikram Sarabhai took the bold step of starting the fast breeder reactor at Kalpakkam, a far-sighted decision. He also established the variable energy cyclotron project at Kolkata and the heavy water plant at Baroda. Further, as a part of giving vital inputs to the agricultural field, Sarabhai planned a joint venture between Department of Atomic Energy (DAE) and Indian Council of Agriculture Research (ICAR) to set up a nuclear centre for agriculture, to bring together the resources and support of nuclear scientists and agricultural scientists. Under Sarabhai's supervision, the first school run by the Atomic Energy Education Society started functioning in 1969.

At the time Sarabhai took over DAE, there were several management issues arising from running a large diversified programme. Among the notable initiatives that he set in motion includes setting up of a programme analysis group in the department to help in the process of policy formulation. This was a very active group which with time went through several transformations. The present nuclear control and planning wing is in a sense carrying out similar functions to the earlier Sarabhai's set up.

During the time when Sarabhai was Chairman AEC between 1966 and 1971 and at the same time Chairman of Indian Space Research Organisation (ISRO), a profile for decade 1970–1980 was drafted for both atomic energy and space research. Atomic energy went ahead with its plan by starting the implementation, whereas ISRO decided to hold a seminar to consult the stakeholders. A committee was constituted in November 1971. Some of the key people included Prof. P. D. Bhavasar, Prof. P. R. Pisharoty, Prof. E. V. Chitnis and Prof. U. R. Rao. Later on, six study groups were set up in areas of communications, meteorology, Earth resources survey, geodesey, navigation and space sciences; the study groups worked over a period of six months culminating in the August 1972 seminar attended by 201 participants and 78 different organizations. The seminar was presided over by Prof. Satish Dhawan, inaugurated by Shri K. C. Pant, Minister and the keynote address was delivered by Prof. M. G. K. Menon. The outcome of this seminar along with the vision of Sarabhai is the mainstay of ISRO's programmes until recently.

ISRO is currently in the process of executing a mission to place human/humans in space. It is interesting to note the observations of Sarabhai in this context which he made five decades ago as a part of the National Programme of Talk, Series – Exploration of Space 1966 and quote 'There is active debate in the world today on the value of space exploration in the context of the many immediate problems of human existence. Why does man wish to go to the moon when he has sophisticated instruments including television cameras, which can be sent in spacecraft under command and can communicate information from millions of miles. It is because nothing that has been developed with the most sophisticated technology so far approaches anywhere near the capability of man who possesses the facility of receiving information simultaneously from a number of channels to synthesize it to create an image of the environment as a whole. Let us note here that our present-day computers and systems for analysis operate only serially, i.e., taking one bit of information after another. It is unlikely that man will restrain his image to see, to feel and to listen, himself if he can possibly accomplish all these. I do not expect that the debate on the merit or otherwise of putting man into

space would ever be settled. If we are to rely on historical experience, man will surely push ahead with adventures of this type backed by motives which will inevitably be mixed. In India the immediate goals of our space research are modest. We do not expect to send a man to the moon or put elephants, white, pink or black, into orbit round the Earth.'

I cannot close a narration on Sarabhai without highlighting some of his management style. Coming from a family of businessmen and directing complex programmes in science and technologies whose outcomes cannot be predicted with regard to timeframe, finance and other resources, he uniquely brought to bear this duality in him to manage different systems and institutions successfully. I cannot do better justice in this context than to quote from two of his close colleagues who knew him intimately, his methodologies and approaches, i.e. Mr J. R. D. Tata and Dr Kamla Chowdhry and I quote

> 'Like Homi Bhabha, he sought to rid science and technology of the incubus of past practices, static thinking, purposeless controls, and restraints that hamstring development.'
>
> – JRD Tata

> 'Vikram, like Bhabha, built institutions around the competence of people. There was no master plan of an organization structure that guided him. The structure evolved depending on how the people grew and developed, the underlying approach being a deep concern for the potentialities of people and their development. An organization based on caring for people gives assurance to individuals to innovate and to respond to situations with creative problem solving – a situation as likely to occur in government settings as in scientific organizations. As long as people know that there is an attitude of caring for them in the leadership of the institution, they can be committed and creative.'
>
> – Dr Kamla Chowdhry

While drawing up an overall framework for this special section on Sarabhai, we had to carefully select the names of authors who could understand and therefore contribute to the rich legacy of Vikram Sarabhai spread over many dimensions of national and international endeavours. Mr Aravamudan, Former Director of Satish Dhawan Space Centre and subsequently of U. R. Rao Satellite centre in his article 'Vikram Sarabhai – His vision of India as a space power and its fulfilment' has highlighted his eventful association with Sarabhai from the inception of ISRO to the last moments before Sarabhai's passing away. Aravamudan has worked with Sarabhai closely on many ISRO programmes, particularly on launch vehicles and satellite missions, besides the related applications. Mr Pramod Kale, Former Director of Space Applications Centre and later Director VSSC had also a long association with Sarabhai, especially in defining ISRO's early versions of INSAT systems and also contributing several ideas related to configurational studies of the multipurpose INSAT systems and dealing with major satellite manufacturers in USA. In his article 'Vikram Sarabhai – Visionary motivator' Kale recalls Sarabhai's deep commitment to get the best out of his colleagues. In a sense, he treats Sarabhai as his teacher and mentor. Dr Abhijit Sen, one of the pioneers in plasma fusion research has provided an insightful article 'Sowing the seeds of an Indian fusion programme – an untold legacy of Vikram Sarabhai'. He traces the development of Sarabhai's role in giving an early start to the fusion programme in India through facts and incidents which are not well-known. Dr M. S. Swaminathan has had a wide-ranging role in working with Sarabhai on a variety of programmes that encompassed translating the brainchild of Sarabhai – the use of remote-sensing for agriculture, initiation of Krishi Darshan programme in Doordarshan and use of space for forecasting crop yields. In the field of Atomic Energy, Dr Swaminathan worked with Sarabhai in establishing Nuclear Research Laboratory at Indian Agricultural Research Institute. In his contribution 'Vikram Sarabhai – A scientist's scientist' Dr Swaminathan explains many of these developments where he and Sarabhai worked together. In an article by Dr Karthikeya V. Sarabhai and Mr Padmanabh Joshi 'Vikram Sarabhai – Science in developing countries', the authors have highlighted the several facets of Sarabhai's thinking and unique strategies. They have tried to relate this to the extraordinary ecosystem that Sarabhai experienced in different phases of his life. Prof. Joseph Francombe of University of Cambridge, UK in his article 'Propagating and practising "horizontal control": Vikram Sarabhai, management and American social science' has described Sarabhai as a pioneer of management education in India. He points out that there has been little attempt to examine critically the nature of Sarabhai's thought in this area. In this context, he has argued that Sarabhai's thinking on management converged around one particular set of ideas about the types of organizations (and leadership) required for effective management at the centre of which sat the horizontal control. Further, the author has explored the parallels between Sarabhai's thinking on this and the forms of management education adopted by post-war American social sciences. In a comprehensive article 'Vikram Sarabhai: His vision for the development of atomic energy in India', Dr R. B. Grover and Dr M. R. Srinivasan have highlighted some of the unique contributions of Vikram Sarabhai to the development of Atomic Energy that includes the management strategy to translate Bhabha's visionary ideas into concrete outcomes. Further, they have dealt with some of the special contributions from Sarabhai in areas of heavy water, fast reactors, nuclear fuel, radioisotopes, reprocessing and thermal reactors.

The challenges of technology denials and the way Sarabhai crafted innovative approaches to deal with the same is a matter that has been discussed by the authors authoritatively. In his article 'Vikram A. Sarabhai Community Science Centre', Dr Dilip Surkar outlines the genesis, vision and evolution of this innovative institution, established by Vikram Sarabhai with the purpose to encourage scientific thinking and innovative teaching. The author has identified several areas of implementation and its futuristic directions consistent with the dreams of Sarabhai, who was always concerned about quality of science education in India. Prof. E. V. Chitnis was one of the closest associates of Sarabhai in the formative years of ISRO. In his contribution 'Scientist, businessman, visionary, institution builder', Chitnis has traced his own educational trajectory and how he was inspired with the vision and ideas of Sarabhai. Going beyond his scientific pursuits, Chitnis worked closely with Sarabhai in evolving the technical, managerial and governance elements of the overall supervision of India's space programme. Ms Amrita Shah in her article in *Times of India* 'The man with big ears, and big dreams that took India to the moon', reproduced here, vividly describes Sarabhai's personality, his life, academic interests, professional inclinations and very many personal interest in the areas like arts and crafts, besides, of course, management styles and running of successful businesses. His handling of two major S&T establishments of India and the extraordinary knowledge that he brought to bear from his other areas of activities certainly makes a very enriching reading. I find that the tributes and reminiscences of three eminent authors, Prof. C. N. R. Rao, Prof. Govind Swarup and Prof. Praful D. Bhavasar, stem out of their very personal associations and intimate knowledge of his thinking and working methods. The common thread that runs across their write-ups is the one of highest regard and esteem with which they hold Vikram Sarabhai as a total personality or in other words a true 'Purushotthama'.

K. Kasturirangan

Former Chairman, Indian Space Research Organisation,
Emeritus Professor,
National Institute of Advanced Studies,
Bengaluru 560 012, India
e-mail: krangank@gmail.com

Sowing the seeds of an Indian fusion programme – an untold legacy of Vikram Sarabhai

Abhijit Sen*

Institute for Plasma Research, Bhat, Gandhinagar 382 428, India

THE year was 1970 and a faculty meeting was in progress in the committee room of the Physical Research Laboratory (PRL) in Ahmedabad. Among those present in the meeting was A. C. Das, then a young scientist who had joined the laboratory as a Research Associate just about a year ago. He was not yet a full faculty member but had nevertheless been asked by Vikram Sarabhai to attend all faculty meetings. He has a vivid recollection of how in the middle of that particular meeting Sarabhai had suddenly risen and gone to the blackboard to announce his plans for starting an experimental plasma physics programme in PRL that would act as a seed programme for a future fusion research programme in the country. He then briefly explained why it was important to do so not only for the present needs of the PRL but also for the future energy needs of the country. The announcement took everybody by surprise as PRL at that time was primarily engaged in space research, e.g. study of cosmic rays, ionospheric phenomena and some areas of basic theoretical physics. Das, who had done his doctoral work under the guidance of J. W. Dungey – the man whose seminal ideas had revolutionized our understanding of the earth's magnetosphere – had been hired for his expertise in magnetospheric physics and was expected to lend theoretical support to the experimental space programme at PRL. But Sarabhai saw beyond his usefulness to the space programme and recognized the value of his knowledge of plasma physics – so essential for the success of any fusion programme. As he sketched the outline of his plans on the blackboard, for which he also allocated a modest budget, it became clear that he had a clear strategy in mind for moving forward.

As always, finding the correct people was his first priority – something that he strongly believed in and had implemented for the space programme. So for some time now he had been systematically hunting for talent and hiring them. One of the first places he had looked for was the Tata Institute for Fundamental Research (TIFR), Bombay, where an earlier fusion-related experimental programme on a theta pinch had been unfortunately shut down and the group disbanded. The principal experimental scientists of that group had left and joined other areas of research. For example, Seetharam George, the leading scientist of that group had migrated towards development of the microwave industry in the country that eventually led to the establishment of SAMEER (Society for Applied Microwave Electronics Engineering and Research). However, some of the eminent theorists were still around and Sarabhai was able to reach two of them. R. K. Varma, who had worked with Marshall Rosenbluth – one of the world leaders of fusion research and popularly acknowledged as the `Pope' of plasma physics – had a strong background not only in fusion physics but also in fundamental plasma physics. He was one of the first persons to be recruited by Sarabhai. R. Pratap traced his lineage to the Brussels School of Ilya Prigogine and was an expert in formal statistical approaches to plasma kinetics and transport. He was also persuaded to join the fledgling PRL programme and was happy to do so.

The next catch was Bimla Buti – a former student of S. Chandrasekhar and at that time a faculty member at the Indian Institute of Technology Delhi (IITD) after her return from a two-year stint at the Goddard Space Flight Center (NASA), USA. Sarabhai had known about her and met her in Delhi at a dinner hosted for Chandrasekhar. They were seated on the same table and next to each other. As Buti recalls she was startled by the very first question that Sarabhai asked her – 'So Bimla, when are you joining PRL?' She did not know what to say and mumbled something about her willingness to come and give a talk but Sarabhai had other things in mind. He told her briefly about his plans for the plasma programme at PRL and invited her to join. Buti felt a bit cheeky at that point and asked him half-jokingly – 'How can you start such a programme without having a core group in place?'. To which apparently, Sarabhai had given his characteristic disarming smile and told her – 'Bimla, you say this because you do not know me!' Soon thereafter Buti received an invitation to visit PRL and give a talk followed by an offer to join the PRL faculty. It was when she had finally arrived in Ahmedabad did she realize how Sarabhai had been quietly busy creating a core group.

A. K. Sundaram – then a young scientist working at a NASA Centre in Hampton, Virginia – had sent a letter to Sarabhai enquiring about the possibility of employment in India. One fine morning he received an envelope from the Chairman, Dept of Atomic Energy, India. Inside was a letter from the personal secretary of the Chairman informing him that Sarabhai was in Washington, DC, for a meeting and would like to see him the following day during the lunch hour. Reaching the venue at the appointed time, Sundaram was ushered into an ante-room where he found Sarabhai having a quiet lunch. Sarabhai instantly got up and warmly welcomed him and asked him if he

*e-mail: abhijit@ipr.res.in

would like to join him in eating a 'khakhra' (a thin cracker snack) – which was what he was lunching on. This being his first meeting with the great man, Sundaram in his own words 'was totally awestruck and disarmed by the utter simplicity of the person in front of him'. Somewhat tongue-tied he tried to organize in his mind what he wanted to say. But before he could say anything, Sarabhai told him that he had gone through his application fully and was very impressed with his background and accomplishments. In particular he appreciated the fact that Sundaram was well versed in both fusion physics and space plasma-related research. He then briefly outlined the plans he had for the fusion cum plasma programme at PRL and why he felt it was important to launch such a programme. According to Sundaram, Sarabhai appeared to be well informed about the current status of fusion research in the world and particularly in the US – thanks perhaps to his strong academic connections with MIT. By the end of the meeting in addition to a 'khakhra', Sundaram also received a job offer to join the programme at PRL.

The next pick for the core group was a prize catch. Predhiman Kishen Kaw – the boy genius who had earned his Ph D from IITD at the age of eighteen and was currently dazzling his peers and seniors with his brilliance at the Princeton Plasma Physics Laboratory (PPPL) – the US flagship laboratory for fusion research. Predhiman's fame had obviously spread far and wide and Sarabhai was well aware of his prowess. He personally travelled to Princeton and sought him out and convinced him to return to India and join the nascent group at PRL. For him he spelt out his plans in greater detail and in the process struck a strong resonance with the young man's own desires and ambitions. Thereby he not only floated a dream in his mind but also lit a fire in his heart that had important consequences for the future.

Finally, the last member of the group! Soon after completing my Ph D in June 1970 I had come home and had gone to meet Sarabhai for his counsel and suggestions on my future plans. This was a natural thing for me to do as in a sense he had been my mentor from my undergraduate days. I had been fortunate to have been a member of a small pilot group that he had formed in the mid sixties to try out new science education methods based on the Physical Science Study Committee report that had come out in the US. The pilot study was the precursor to the establishment of the Community Science Centre – Sarabhai's unique contribution to science education for young children and society at large. The pilot group had continued to meet in PRL till our final undergraduate year with one of the PRL faculty members – K. B. Shah – exposing us to the Feynman lectures. Sarabhai would often stop by during our discussions and personally interact with us and question us on various topics. That early exposure to the research environment at PRL and the personal interest that Sarabhai took in us had inspired most of us towards a research career. When I went up to meet Sarabhai he seemed to know all about my graduate education and after congratulating me told me that he was very happy that I had done my dissertation in plasma physics. He then made me privy to his future plans for PRL and how he was building up a core team. At the end he told me – 'I do not want you to go anywhere else but join us in this new venture'. To me this was a manna from heaven – to be able to work in my own special field in my home town and in the laboratory that I was so familiar with. Of course I instantly agreed but he made a condition. I was to go back to the US for a year and work in the fusion group at the Oak Ridge National Laboratory (close to my erstwhile graduate school) and pick up as much as possible about their experimental programme. He called S. R. Thakore to his office and instructed him to make all arrangements for my appointment in PRL and permission for me to spend a year away.

When after a year I came back and started work at PRL in mid-1971 the entire team was in place. The atmosphere was scintillating and it was an exciting time for all of us. While pursuing our own individual research problems we also spent a lot of time as a group planning for the future that Sarabhai had sketched out for us. One of the first items on the agenda was to initiate an experimental plasma programme that would set the ball rolling towards developing basic skills in plasma experimental techniques and also build up trained manpower. For the programme to have meaningful physics goals it was decided to align it with some of the major space plasma investigations of PRL. One of the first planned experiments was thus to create plasma conditions in a laboratory device that would permit exploration of instabilities associated with the F region and compare them to the *in-situ* measurements obtained from rocket borne instruments. Senior scientists from PRL like Satya Prakash who were engaged in such space experiments readily lent their support towards the planning of the laboratory experiments. To develop human resources for the future, large scale programme plans were drawn up to suitably augment the PRL graduate programme to train a large body of young talented students in theoretical and experimental plasma physics. For this the core group had sufficient expertise and experience to design a high level curriculum and to teach it. An active effort was also afoot to quickly acquire trained manpower to implement the planned experiments – partly by inducting fresh Ph Ds from within PRL and partly by recruitment of eminent faculty from Universities and other Institutions in India. The mood within the core group was very upbeat and for somebody like Kaw whose sights were set on the ultimate goal of setting up a fusion programme and who had the assurance of full support from Sarabhai, the level of excitement was quite palpable and visible to all around. His boundless energy and enthusiasm were also infectious and created quite a stir in the erstwhile sedate atmosphere of PRL. Above all, the vision of a clear path ahead forged a wonderful bond within the core group and provided a strong motivation to move forward.

Then we were all thunder struck on 30 December 1971 as the shattering news of Sarabhai's sudden demise in

Kovalam reached us in PRL. For many of us who had known him personally it was a day of deep sorrow. His death was also a momentous loss for the scientific community in India as a whole and the fledging plasma group at PRL in particular. I remember Kaw recalling all the discussions he had had with Sarabhai in the recent past and the dreams they had shared. Fate seemed to have dealt a cruel blow. However the strength of his vision and the inspiration that he had provided helped us endure this catastrophic loss and move forward. Over the next few years the plans that had been put in place during Sarabhai's presence started unfolding under the energetic leadership of Kaw and with strong support from the new management at PRL. The enlarged graduate programme attracted a lot of young talent and the experimental programme took off well under the stewardship of P. I. John who had been a faculty member at Aligarh Muslim University and had been recruited to join the plasma core group at PRL. The effort was further strengthened by the contributions of scientists like Y. C. Saxena – who had just then obtained his Ph D at PRL working on cosmic ray research in the Kolar Gold Fields – and S. K. Mattoo – who had done his Ph D dissertation in the area of solar physics. Over the next few years the group saw tremendous progress in terms of both theoretical research and development of experimental expertise. Although the stated orientation was towards the simulation of space plasma phenomena, there was an unstated purpose of eventually acquiring the skills necessary for building fusion experiments. High vacuum, pulsed power, magnet design and fabrication were some of the skills acquired in this phase. Thus the foundation for a future fusion programme was rapidly being put in place.

However, the prospect of initiating such a programme seemed to be receding further and further. Times had changed and it was not easy to get government approval for such an ambitious programme amidst competing demands from other scientific projects and the overall budgetary constraints. Sarabhai's absence was keenly felt – he had departed far too early and without having had an opportunity to put the project on an official footing. The fast receding goal post led to considerable disappointment and disillusion among some in the group. Kaw decided to quit and to go back to PPPL in 1975. Some others went on sabbaticals to other institutions in the US and Europe. Many of the bright young graduates migrated abroad on postdoctoral or other long-term appointments. The fusion dream appeared to die.

But this is not the end of the story. The dream that Sarabhai had floated and the fires that he had lit in some of us did not die that quickly. The late 70s saw a strong upsurge in fusion activities abroad particularly in the US. Tokamak machines world over were having a phenomenal success and the prospect of achieving controlled fusion suddenly appeared to be very bright. The enthusiasm within the fusion community was very contagious and inspired fresh hopes in many of us. It was felt that this was a right time to attempt a resurrection of the old dream and try initiating an appropriate programme in India. Plans were hatched during numerous discussions among Indian plasma physicists present in the US at that time and a proposal was finally sent to the authorities in India. It is a long story thereafter and needs a separate telling but the end result – thanks to strong support from people like Devendra Lal, S. P. Pandya and M. G. K. Menon – an independent programme supported by the Dept of Science and Technology, named Plasma Physics Programme (PPP), was launched in PRL in 1982. The programme centred around a Tokamak device – ADITYA – drew on the existing experimental expertise at PRL and was expected to attract many of the Indian plasma physicists who had migrated abroad. Kaw returned to India and assumed directorship of the programme in the same year.

The rest is history, as they say. That initial 'nucleation' at PRL – a favourite ploy of Sarabhai who had launched many an ISRO programme in that manner – has today given rise to the Institute for Plasma Research with a thriving programme in fusion research and many allied areas of plasma physics and plasma technology. India is an equal partner in the largest international fusion programme – the International Tokamak Experimental Reactor (ITER) – and is contributing actively to the world fusion research effort. The dream has now materialized and put us on the path to exploiting this future source of abundant energy. It has taken a long time to realize this dream since it was first spelt out in the committee room in PRL and many players have contributed to bring this about. The early history – the beginnings of the journey – is now buried in the past and mostly forgotten. However, it embodies another important legacy of Sarabhai that has remained overshadowed by his other well-known achievements and is worth recalling in this year of celebrating his hundredth birth anniversary. It is a legacy that highlights once more the breadth of his scientific awareness and his remarkable vision for the future of the country. That he conceived of a fusion programme way back in 1970 and did the initial spade work for it also makes one wonder about what course we would have taken had he lived longer. Could we have leap frogged much further with such an early start? Recalling the long period it took after his death to revive the programme and maintain the enthusiasm and stamina for doing so, one must perforce acknowledge and be grateful for the valuable legacy he had bequeathed us and the head start he had given us. One hopes that this legacy will continue to inspire the present and future generations of fusion researchers in India and lead to the fulfilment of that grand vision and the realization of the ultimate goal of achieving fusion power for the country.

ACKNOWLEDGEMENT. I am grateful to many members of the original core group for sharing their memories of that early period with me and to P. I. John for a critical reading of the manuscript and very helpful suggestions.

doi: 10.18520/cs/v118/i8/1196-1198

Tribute to Vikram Sarabhai

C. N. R. Rao*

Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru 560 064, India

When I was very young, I remember people doing balloon experiments in the Indian Institute of Science campus, Bangalore. It was young Sarabhai with Homi Bhabha carrying out cosmic ray experiments. Vikram Sarabhai officially had registered for the Ph D degree of Cambridge University under the supervision of C. V. Raman, but his immediate guide was Homi Bhabha. Though I could not have known him at that time, I got in touch with him in 1961 when he was the President of the Physics Section of the Indian Science Congress. He had invited me to give a talk on Spectroscopy in Chemistry. After that meeting, we became good friends and met each other on different occasions.

Vikram Sarabhai arranged the meeting of the Indian Academy of Sciences to celebrate the 80th birthday of Prof. Raman in 1968 in Ahmadabad. It was a fantastic occasion where everybody worth the name in science was present. Vikram was a great organizer. On that occasion, I had been invited to talk on some of my research work. About a year later in 1970, we had the last meeting of the Indian Academy of Sciences presided over by Prof. Raman in Bangalore. Prof. Raman had asked me to give a lecture in that meeting. A few weeks after that occasion, Raman passed away. Vikram Sarabhai held Raman in great respect and I equally respected and loved Raman. This was one of the binding forces probably between us.

Vikram Sarabhai became the Chairman of the Atomic Energy Commission after the sad demise of Homi Bhabha in 1966. He was also running the space programme. As chairman of the Atomic Energy Commission, he asked me to be the chairman of the chemistry and metallurgy committee of AEC and some other activities. He had tremendous trust in people. He showed much confidence in my abilities, as he did in many others who worked with him in the space organization and elsewhere.

He visited IIT Kanpur in 1971 when I was the Dean of Research there. He wanted to have a link between IIT Kanpur and BARC to carry out joint educational and research progammes in a mutually beneficial fashion. He asked me to come to Bombay along with the Director to discuss details. When we went to Bombay, we stayed in the Guest Rooms of the BARC. To my great sadness, the next morning, we found that Vikram Sarabhai had just passed away in Trivandrum. I went to the airport to be there when his body was brought to Bombay on a plane from Trivandrum. The date was 31 December 1971 when Vikram was hardly 52 years old.

Vikram Sarabhai used to work very hard. Whatever he took on, got his complete attention and that was so with respect to the space programme as well. He used to go back and forth between Bombay and Trivandrum, and day or night did not matter to him. I still remember Prof. Raman advising him to be careful, not to travel too much, and take care of his health. I used to see him travelling on planes going through innumerable files during the trip.

Vikram Sarabhai was one of the most cultured persons that I have known. He was educated in the true sense. His wife Mrinalini, was a great classical dancer and ran a dance academy. I consider myself lucky to have known a person as sophisticated, as *suave*, as human and as charming, as Vikram Sarabhai. I have not met anyone like Vikram Sarabhai in my dealings with the scientific community.

There was only one Vikram Sarabhai. This is my tribute to this great soul on his centenary.

*e-mail: cnrrao@jncasr.ac.in

doi: 10.18520/cs/v118/i8/1182

Scientist, businessman, visionary institution builder

E. V. Chitnis*

Varsha Vasant Vihar, Lane-2, Plot 71, Anand Park, Aundh, Pune 411 007, India

The first time I saw Vikram Sarabhai was in Pune, in 1950. He and Homi Bhabha were giving lectures at the Indian Science Congress, and I was quite impressed by their presentations. I was a student of Physics then. In my Masters, I specialized in Electronics. Since the syllabus for M Sc Wireless was oriented primarily to theory, to make up, we were encouraged to do a Diploma in Electronics. In the Diploma course, we were exposed to the most recent laboratory instruments and procedures. So after my Masters from Pune University, when I went for an interview at ATIRA, the Ahmedabad Textile Industry's Research Association, for a post related to electronics, I had the advantage of hands-on experience. I was selected by the committee and finally interviewed by Vikram Sarabhai, Director of ATIRA. I asked him if I could work at the Physical Research Laboratory (PRL) while I was employed by ATIRA. My real desire was to work at PRL. He said, if that was the case, I had to meet K. R. Ramanathan, the Director of PRL, and he organized a meeting for me.

Ramanathan, when he met me, asked me why I was there. I told him that I was there because he was there. We were expecting him to take over the post of Head of the Department of Physics at Pune University after retiring from the India Meteorological Department and I was hoping to do research under him. But, unfortunately for us, in the meanwhile, Vikram Sarabahai had offered him the post of Director at PRL.

Ramanathan did not agree to my joining ATIRA and doing part time work at PRL. He told me that he could not offer me any scholarship for the moment, but that, within a few months, he might be able to arrange some finances. So I taught Physics at a college for a semester and then joined PRL for research with a scholarship of 100 rupees per month. Meanwhile, I had an offer from UPSC to join All India Radio. Though that had a much higher salary, I joined PRL instead. That was 1953. Vikram Sarabhai remembered that and mentioned it a few years later, to explain my ignoring the offer of a post at MIT.

PRL was then a small set-up at the M.G. Science Institute. Ramanathan occupied one small room. Then there were three college classrooms and a connecting corridor. One had a small library and a row of benches for lectures. In another, three of us researchers were given a table and two chairs – which meant that at least one of us should be working at the lab, while two of us sat.

Vikram Sarabhai had a table and chair at the end of the corridor. So whenever Sarabahai was not there, we would occupy his table. Sarabhai would come in the morning at about 8, and work at PRL till about 10.30 and then go to ATIRA. He would go home for lunch and then till about five in the evening, he would attend to his other businesses. At about 5 pm, he would come back and work in PRL till about 8.30. This gave us a role model, to work without thinking about office hours.

PRL was poor those days in terms of funding. But because of Sarabhai, we had many visitors. Krishnan from NPL would come for lectures. P. M. S. Blackett from Cambridge would come often. Once, four people came and Vikram Sarabhai told me: 'Chitnis, explain to them what we are doing here'. Three of them were Nobel Prize winners. And the fourth was Chandrasekhar, who got the Nobel later. So, though we were poor, we had the richest of inputs at PRL because of Sarabhai, Linus Pauling, Hannes Alfvén...

We had a lot of freedom to dream big and the motivation to work hard to achieve those dreams. I developed the Geiger counter, Cherenkov counter, scintillation counters, etc. And we got a project, along with Bruno Rossi in MIT, to set up instrumentation at Kodaikanal, to detect particle showers and to provide clues about the direction from where they were coming.

Kodaikanal had the most interesting weather pattern. It would be clear in the morning. Then it would cloud over on most days and, by afternoon, it would rain. It would clear up quickly and the nights were always very clear. I have never seen the moon so bright anywhere else. With such clear skies, we accumulated a lot of data. Rossi was happy and offered me a position at MIT. I did not reply. After a few weeks, Rossi told Sarabahai. And when Sarabhai met me, he asked me. I told him that the project would take two more years and that I would think about the position at MIT later.

But we had accumulated a lot of data and it was impossible to make sense of it without adequate computation power, which we did not have in India at that time.

*As told to K. P. Madhu, Science Writing Consultant
scienceandmediaworkshops@gmail.com

So ultimately, I went and joined MIT to work with Rossi in 1957.

This was a time when the US was overhauling its science education. Textbooks were being revised; new experiments were being included in the curriculum. One of the main people involved used to sit one floor below where I worked. When Sarabhai came to visit MIT, he collected some of the experiments, took them to PRL and started the Community Science Centre. Later, it was shifted to a museum, before the Centre got its own land and building. As an institution builder, this was his consistent strategy: dream big and not hesitate to start, however small.

Meanwhile, the intellectual freedom and the work culture at MIT influenced me greatly. I adapted quickly and enjoyed my work. So time passed quickly. And then Vikram Sarabhai contacted me and asked me to join the Space Application Centre.

People at MIT found it amusing for a country like India in the early 1960s to get into space research. Our aim was not to conquer space, but to overcome underdevelopment and poverty on the ground, using space technologies. Vikram Sarabhai argued that the experimental earth station for satellite communication set up in Ahmedabad would help not only India, but would work as a training ground for the other countries in the region. Thus he could secure funding from UNDP.

I left MIT to join the Space Applications Centre (SAC). My wife also had to leave her job. So we were back at PRL. PRL had a new two-storey building by then and SAC started operations there – the usual two-fold strategy of Sarabhai: 'thin end of the wedge' and 'sudden expansion', as he used to say. Thus PRL became the cradle of space science in India.

By this time, quite a few had gone from PRL to not only MIT, but also to Cambridge, Stanford and other places – Canada, France…. Most of them came back. There were people from different parts of India, with exposure to research and contacts in different parts of the world – factors that played a role in the success stories that followed.

People came back leaving their well-paid jobs abroad because of Sarabhai. He was kind and compassionate. Even a peon could walk into his room with grievances and grumbles. And people who came out of his room were always smiling.

He was egalitarian. He would introduce his colleagues to the foreign visitors as if they were equal. While Dr Ramanathan followed C. V. Raman's attitude to women and scientists less brilliant, Sarabhai was humane. Though he was not really an artist like Bhabha was, he appreciated art forms and respected Mrinalini, his wife – enough to help set up the Darpana Academy of Performing Arts.

He could judge others' capabilities, delegate responsibilities and give full freedom and trust people to perform to the best of their abilities. So, the first earth station in India was soon set up in Ahmedabad. And it became the training ground for engineers in not only India, but also for those in the African and other Asian countries.

Meanwhile, Sarabhai's 'thin edge strategy' was working in another direction. Between the regions where satellites are and the regions of atmosphere that can be explored with balloons, there is a big gap. That was to be explored using sounding rockets. Most of the sounding rockets those days were in the polar and temperate zones. And we felt that one near the magnetic equator would be useful to explore the equatorial electrojet. So I was asked to look into it.

Though the magnetic equator passed south of what is now Kollam, Thumba was identified as the best location, with minimum disturbance to local population. To finalize the decisions, we were to meet the Governor, V. V. Giri. We, including Bhabha, reached early and were accommodated at his residence. But Sarabhai arrived late. When he reached, the introductions to Giri's friend, Raghu and Raghu's wife, a Swedish citizen, were already over. So Bhabha played the gentleman and tried to introduce Raghu and his wife. Before he could start, Sarabhai said, 'Oh, Raghu, how nice to meet you again', shook his hand and kissed his wife's cheek, European fashion.

I still have to see anybody who needs to be introduced to Vikram Sarabhai. He knew people. And he knew how to deal with them.

He got what he wanted from other countries also. He convinced decision makers in other countries that India could deliver. We got a helicopter from Russia to monitor the sea and to ensure the safety of fishermen when the sounding rockets were launched along with a computer and the vibration table for testing the components. Though we used American-made rockets initially, we had to buy the rockets and the technology from the French and we soon started making rockets indigenously. Hideo Itokawa, the Japanese contact that I had, helped in improving the rocket design. This is how the 'sudden expansion' strategy of Sarabhai worked.

Meanwhile, many people complained about the location. Thumba, and even Trivandrum of those days, were considered too backward to attract scientists to come and stay. That was one time that I saw Sarabhai putting his foot down. He put an end to the discussion. The location, though it was not too convenient, was important from the point of view of international collaboration in scientific research. He even got Indira Gandhi to dedicate Thumba to the UN. Sounding rockets of the US, Germany, France, Russia and Japan were launched from there.

We had access to the skies of the southern hemisphere from Thumba. And, since we carried X-ray detectors in some of the rockets, we found a large number of X-ray sources. Though the experiment was to check possible X-ray emissions from the moon, which we did not find,

these findings kicked off the discipline of X-ray astronomy. The International Union of Geodesy and Geophysics and the Space Shuttle Mission of the US took India seriously because of this commitment to space science.

I remember a meeting with H. G. S. Murthy, the Director of Thumba who was enlarging his team, coming to Sarabhai with a problem. He had one post, but two very good candidates. He would have liked to offer jobs to both. We were sitting in a hotel in Boston. Sarabhai pushed the biodata of the second candidate over to me and asked my opinion. It was Kalam's. Given the way he managed to grow from his poor circumstances, I also recommended that he be taken in. Later, Sarabhai would smilingly refer to Kalam as busy bee. Whenever Sarabhai would go for a meeting in Thumba, Kalam would come up with many new projects for approval.

It is not only people. Sarabhai had the ability to anticipate and to make use of what he had. So we had received this computer, IBM…. And he got people trained to operate it. The computer was on 23 hours a day, leaving one hour for maintenance. It would work on SAC projects for eight hours and, the rest of the time, other things could be done. So we were soon making money by handling the payrolls of large corporations like ONGC. Meanwhile, another computer which was delivered to the Department of Atomic Energy was still lying in its crate.

Bhabha who was spearheading the Atomic Energy Commission was frustrated by the bureaucratic processes and promised Sarabhai a more convenient constitution for ISRO. But unfortunately, before that could materialize, the plane carrying Bhabha was shot down. So ultimately Atomic Energy and ISRO had a similar constitution: the Finance Secretary is the Member Finance and the budget that is approved in the Commission is binding.

Sarabhai knew how to anticipate and overcome obstacles. He convinced Morarji Desai to induct a renowned economist as the Secretary Finance to get his way around the bureaucratic impedance and to get the projects going – a trick that Bhabha could not envisage.

Sarabhai was a businessman. He knew how to negotiate, how to leverage on existing contacts, how to overcome bureaucratic barriers. By close observations, we, the engineers and scientists, also imbibed his ways and benefited from them, later.

I was asked to find a site for a launching station. Sarabhai asked me to take along Abid Hussain from Madras, as Chennai was called those days. He had the right contacts and commanded respect among the bureaucracy. But I could not get time from him. So I had to go on my own and explain the requirements to the bureaucrats – a place near the sea, unoccupied acreage, safety for local population…

I had surveyed the coasts in Tamil Nadu. But Tamil Nadu was too near Sri Lanka and we did not want any trouble with neighbours. Sriharikota in Andhra Pradesh seemed to be the best location. Abid Ali, the bureaucrat that I had to deal with, was from the Nizam's rule. He did not understand our purpose nor cared. So to clinch the deal, Abid Hussain from Madras came with me to convince him. And Bhrahmananda Reddy, of the Andhra Pradesh Government, gave us an island of 40,000 acres, free of cost.

The way Vikram Sarabahai conceptualized the SITE project is the most telling example of his negotiation skills. The telecommunication people those days did not feel the need for a satellite. But to achieve all India coverage for television using the technologies of those days would have taken about half a century or more. Satellites could achieve it, in a much shorter time and with one-tenth the costs.

That was a time when we did not have much foreign exchange. Sarabhai knew he could not buy things from abroad for the project with foreign currency. So he organized the project such that there was no transfer of money. We would spend money on behalf of the Americans and the Americans would spend money on our behalf. And all parties kept detailed accounts to cancel each other's expenses. His business and financial acumen kept the project on track.

We should not forget that he came from a business community that could envisage a port in Ahmedabad for easing their shipping problems. But he was also a scientist and a humanist. So his vision went further than taking commercial products to the Arabian Sea: he envisioned an ISRO that could put satellites in space.

Sarabhai, of course, could not see the SITE project take shape and become an internationally acclaimed communication project. He passed away peacefully in his sleep, a few years before the SITE experiment. But because of his vision, space science in India has firm roots in Indian soil, and plays a central role in communication, meteorology, agriculture, land-use planning, disaster detection, monitoring....

doi: 10.18520/cs/v118/i8/1177-1179

My reminisces of interaction with Vikram Sarabhai

Govind Swarup*

National Centre for Radio Astrophysics, Pune 411 007, India

After working in the field of radio astronomy for two years in Australia and seven years in USA, I joined the Tata Institute of Fundamental Research (TIFR) at Mumbai in April 1963. I met Vikram Sarabhai in 1964 during his visit to TIFR. He invited me to visit the Physical Research Laboratory (PRL) in Ahmedabad to interact with its faculty and students. I went to PRL several times during the next three years. There I also gave talks on radio astronomy, the Kalyan Radio Interferometer and the Ooty Radio Telescope (ORT). I had many discussions with the faculty and students at PRL regarding research being carried out in several fields, such as cosmic rays, atmospheric sciences. I also recall discussions with U. R. Rao about his work on cosmic rays and solar wind. During one of my visits to PRL, Sarabhai described to me his plans for building capabilities for space research and communication in India. He had a clear vision about it. He also took me to visit the Indian Institute of Management in Ahmedabad that was founded by him. It was a great experience. I also visited two sites that were selected by him for establishment of the proposed Space Applications Centre (SAC) at Ahmedabad. I was also told then that it was planned to import a 45 ft parabolic dish from Japan for microwave communication at the SAC. I told Sarabhai that it could be designed and built in India in a couple of years instead of being imported.

Sarabhai became the Chairman of the Atomic Energy Commission after the untimely death of Homi Bhabha in January 1966 in a plane crash at the Mont Blanc in the Swiss Alps. In 1965, Bhabha had approved the construction of the ORT that was proposed by me. During a visit to TIFR, Sarabhai asked me the details of the construction being done for the ORT that consisted of a 530 m long and 30 m wide parabolic cylindrical reflector being placed on a hill at Ooty. Sarabhai made several valuable comments that we considered.

In 1967, Sarabhai invited M. G. K. Menon, Yash Pal, I and Sitaram from TIFR to visit the Thumba Equatorial Rocket Launching Station (TERLS) where a rocket was being designed for launching in space. After we reached TERLS, Sarabhai introduced to us the teams that were designing various sub-systems of the rocket. Menon and Yash Pal visited the group that was designing the solid state propellant for the rocket under the guidance of Vasant Gowrikar and others. They were very impressed by the work being done by the group. I interacted with Kalam who was designing the Nose Cone of the rocket. As I recall he had placed several posters on a wall in a hall describing the design of the Nose Cone being done by him and likely problems. I told him that he would certainly find solutions since he had already posed questions. He was also concerned about the effect of air turbulence on the Nose Cone. I described to him its role on large parabolic dishes used in radio astronomy. Sitaram who was an expert in the field of microwaves at TIFR offered help to the team designing communication equipment for the rocket at TERLS.

In early April 1968, Sarabhai planned to spend two weeks at Ooty for a vacation along with Mrinalini Sarabhai and his daughter Mallika Sarabhai. Sarabhai could not find a suitable accommodation at Ooty because of the summer rush. I was also not able to find it for them. Thereafter, Sardar Ujjal Singh, the Governor of Tamil Nadu, invited Sarabhai to stay at the Raj Bhawan at Ooty that he accepted after some hesitation because he generally avoided availing facilities by the Government for himself as he told me. After a few days he, Mrinalini Sarabhai and Mallika Sarabhai visited the site where the ORT was under construction. Sarabhai wanted to know its details that I described to him. The ORT was being constructed as a parabolic cylindrical reflector antenna of 530 m length and 30 m width that was being placed on a hill at Ooty with its north-south slope of 11°23′ same as its latitude, thus becoming parallel to the axis of rotation of the earth allowing its rotation for about 10 hours every day. I told Sarabhai that ORT was planned for lunar occultation observations for measuring angular sizes of radio galaxies with arc second resolution for the first time in radio astronomy and for other investigations. Stainless steel wires of 0.38 mm formed reflecting surface of the ORT. The parabolic cylindrical antenna consisted of 24 parabolic frames each of 30 m width that were mounted on 24 steel towers. Near the top of the hill three towers that mounted parabolic frames had been erected when Sarabhai visited the site. Few more were under erection by M/s Bridge of Roof of Kolkata. Considering its complexity Sarabhai asked me whether I had seen the movie *Zorba the Greek*. Zorba was always dreaming big

*e-mail: gswarup29@gmail.com

projects but his schemes always failed because he had not considered details! Sarabhai told me to ensure that no accidents should take place during the construction of the ORT and gave few hints. I asked Mrinalini Sarabhai which colour should be painted for the ORT. She looked around, saw many eucalyptus trees at the site, and suggested to me the same as back of the eucalyptus leaves. We did that and ORT looked magnificent.

Sarabhai phoned me at ~10 PM on the night of 31 December 1968 and said 'Govind you have put me in a difficulty'. I asked him why. He told me that he had attended a meeting of the Scientific Advisory Committee of the Cabinet chaired by Mrs Indira Gandhi, the Prime Minister of India, earlier on that day. She asked the members as to what equipment are being imported that could be made in India. Sarabhai informed her that the Overseas Commission of India (OCS) was planning to import a 29.6 m (97 feet) antenna for the ARVI Satellite Communication Project that perhaps could be made in India. She told him to get it made by the DAE and asked him to submit a report in a month. Therefore in the night of 31 December 1968 Sarabhai asked me to attend a meeting in his office on 1 January 1969 at 9 AM. I told him that a New Year's party was taking place at our residence that would last till 3 AM. Sarabhai told me that the party would be over by 2 AM and the meeting would take place at 10 AM!

After some discussions in the meeting held on 1 January 1969, Sarabhai asked me to submit a feasibility report in two weeks examining the possibility of manufacturing the 29.6 m antenna in India. I then obtained the tender document for the ARVI Satellite Communication Project including the 29.6 m antenna from the OCS. I had access to several drawings of the structural and mechanical parts of a large parabolic dish antenna. Using these, I and S. S. Bhave from TIFR, Colonel Pant from PRL and a senior engineer of the Tata Consulting Engineers visited several firms in Mumbai: Richardson and Cruddas, Larsen & Toubro, New Standard Engineering Company and a few others. We concluded that 29.6 m antenna could be manufactured in Mumbai, installed at ARVI and made operational within 15 months. Sarabhai got approval of Mrs Gandhi for the antenna to be made in India by the DAE. Sarabhai negotiated the purchase of drawings of the 29.6 m antenna from the RCA Canada who had quoted to OCS for its supply and installation at ARVI in India. Several electronic parts required for the project were imported from Canada. Sometime later Sarabhai phoned me that he would be meeting Sumant Moolgaonkar, Chairman of TISCO at Jamshedpur, at a lunch and asked me to submit a note regarding essential qualifications of the Project Engineer for the 29.6 m antenna. In the note I wrote that the Project Engineer for the 29.6 m antenna should have worked on the floor of a workshop for several years before reaching a senior position. After discussions with Sarabhai, Moolgaonkar released N. K. Ghosh who was the Head of the General Engineering Division at TISCO. He was then appointed by the DAE as the Project Engineer for the 29.6 m antenna project. He ensured fabrication of the 29.6 m antenna to the required accuracy and its installation at ARVI within 15 months by the New Standard Engineering Company. I made contributions to the manufacturing of antenna panels to sub-mm accuracy as required for the antenna to operate at microwave frequencies. Sarabhai appointed Wg. Cdr. K. R. Rao as the Chairman of the team for the management and installation of the ARVI Satellite and Communication Earth Station at ARVI. The Earth Station for satellite communication to other countries at ARVI was completed in January 1971. At that time India became the fifth nation in the world who had installed Earth Stations for broadband satellite communications to far away countries. Before that only narrowband communication was done at several MHz that was reflected by the ionosphere and therefore had very limited range.

Seldom is a person born that makes unique contributions to his country. Sarabhai was such a person. He established many institutions in India of considerable importance. Soon after the launching of *Sputnik* by USSR in 1957, USA and USSR launched many satellites for space communications. Thereafter Sarabhai conceived manufacturing the required equipment for space communications and research in India. Step by step he organized teams that have resulted in the great capabilities of ISRO today. Sarabhai was not only a great scientist but also a very kind and gentle human being.

doi: 10.18520/cs/v118/i8/1188-1189

Vikram Sarabhai: his vision for the development of atomic energy in India

R. B. Grover[1,*] and M. R. Srinivasan[2]

[1]Member, Atomic Energy Commission, and Homi Bhabha National Institute, Mumbai 400 094
[2]Former Chairman, and Member, Atomic Energy Commission, Ootacamund 643 002

Vikram Sarabhai formulated an ambitious profile for the development of atomic energy in India. Despite challenges arising from denial of international cooperation for several decades, technologies envisioned in the profile have been developed and the Department of Atomic Energy is now working to implement the technologies with the objective of accelerating the growth of installed nuclear capacity in the country.

Keywords: Heavy water, fast reactors, nuclear fuel, radio-isotopes, reprocessing, thermal reactors.

'There are three unique families of 20th century India – the Tagores, the Sarabhais and the Tyabjis', opines Ramachandra Guha[1]. Indians generally know about the Tagores; not many know about the contributions of others. Coming to the Sarabhais, they lived in Ahmedabad, which was a thriving business city even before Mumbai and Kolkata. Ambalal Sarabhai generated great wealth through banking and money lending, textiles and other industries. He sent his children abroad for studies and amongst them was Vikram, who went to Cambridge. While Vikram and his siblings imbibed western culture, they were encouraged to respect Indian roots and culture. They returned to India and set up various institutions, and these included Physical Research Laboratory (PRL) and Indian Institute of Management (IIM), both at Ahmedabad, set up by Vikram Sarabhai. Both these institutions became trend setters. PRL led to setting up of India's Space programme, and IIM to a series of similar institutions.

From PRL, Vikram Sarabhai moved to Mumbai in May 1966 to steer India's atomic energy and space programmes after the untimely demise of Homi Bhabha. It fell upon Sarabhai to implement the vision of Bhabha by formalizing the organization structure of the Department of Atomic Energy (DAE). Uranium Corporation of India Limited (UCIL) as well as Electronics Corporation of India Limited (ECIL) were incorporated as Public-Sector Enterprises in 1967. Power Projects Engineering Division, the forerunner of Nuclear Corporation of India Limited (NPCIL), was established in 1967. Nuclear Fuel Complex (NFC) was set up in 1968 with Sarabhai as the first Chairman of its Board. An organization dedicated to build heavy water plants, named Heavy Water Projects, was established in 1969. It was later renamed as Heavy Water Board. Activity at Kolkata to set up a Variable Energy Cyclotron was started in 1969 by BARC. Reactor Research Centre, later renamed as Indira Gandhi Centre for Atomic Research (IGCAR), was set up at Kalpakkam, 80 km south of Madras (now Chennai) in 1971 with the objective of conducting broad-based academic and post-academic research directed towards the development of sodium-cooled Fast Breeder Reactor (FBR) technology. The first school run by the Atomic Energy Education Society started functioning in Anushakti Nagar, Mumbai in 1969.

Activities of DAE were expanding and Sarabhai was aware of the management issues involved in running a large diversified programme. Scientists and engineers including the second author, who interacted with him, recall his mature decision making and practical approach toward management. He set up a Programme Analysis Group in the Department to help in the process of policy formulation. This group was very active during his time, but subsequently had a turbulent history, and went through several mutations. The present Nuclear Control and Planning Wing is doing somewhat similar function.

A landmark initiative by Sarabhai was to organize a seminar in January 1970. The seminar attracted large participation (the second author was one of the participants), about 800, from diverse organizations in India and about a dozen scientists from foreign countries. Subsequent to the seminar, in July 1970, DAE released 'Atomic energy and space research: a profile for the decade 1970–80'[2]. A press release issued by Sarabhai on 25 May 1970 provides a glimpse of his thinking about the programmes in both atomic energy and space[3]. Contours of the programme listed in the profile and the press release are more or less the same. Taking the list of programmes included in the press release as well as the profile as the starting point, this article analyses how far the country has been successful in achieving the vision of Vikram Sarabhai in the area of atomic energy. The programmes listed include expanding nuclear installed capacity based on thermal reactors, designing and constructing 500 MWe Pressurized Heavy Water Reactors (PHWRs), completing Fast Breeder Test Reactor (FBTR), designing and

*For correspondence. (e-mail: rbgrover@hbni.ac.in)

constructing a 500 MWe Prototype Fast Breeder Reactor (PFBR), augmenting heavy water production capacity, augmenting uranium mining, completing Nuclear Fuel Complex, developing uranium enrichment technology based on gas centrifuge process and promoting widespread application of radio-isotopes in food preservation, sterilization of medical products, medicine and research.

Development of nuclear technologies by India

When looked from the point of view of development of technologies, DAE has done a very good job. While details can be seen in numerous publications from units of DAE, in particular two recent special issues of journals *Sadhana* and *Progress in Nuclear Energy*[4,5], a brief summary follows.

Thermal reactors

Pressurized heavy water reactors (PHWRs) were chosen by India as the mainstay for the thermal reactor programme and units of DAE together with the Indian industry have mastered the PHWR technology. PHWRs are operating at Rawatbhata (Rajasthan), Kalpakkam (Tamil Nadu), Narora (UP), Kaiga (Karnataka), Kakrapar (Gujarat) and Tarapur (Maharashtra). After setting up TAPS-3 and -4 at Tarapur, there was slowdown in building PHWRs as there was a significant mismatch between demand and domestic supply of uranium. Even the operating PHWRs were running at very low capacity factors in the first decade of this century and capacity factors reached as low as 50% in 2008. It was not possible to import uranium due to the then prevailing guidelines of the Nuclear Suppliers Group (NSG). A two-pronged strategy was developed by the Government of India: to intensify exploration in the country and open more uranium mines, and to launch a diplomatic initiative to resume international civil nuclear trade. Both initiatives have been successful. Domestic uranium production has increased and India is able to import uranium from the international market due to NSG adjusting its guidelines to facilitate international civil nuclear trade with India. Capacity factor of operating reactors started looking up from 2008 onwards (Table 1). Natural uranium is now available for setting up PHWRs and as a result, the Government first sanctioned construction of PHWRs at Rawatbhata (Rajasthan), Kakrapar (Gujarat) and Gorakhpur (Haryana) and subsequently ten units in fleet mode. Table 2 lists PHWRs under construction and already sanctioned. Additional sites have also been identified for construction of reactors. While Sarabhai had envisioned setting up of PHWRs of 500 MWe rating, units now being set up are of 700 MWe rating.

India started its nuclear power programme by setting up two Light Water Reactor (LWR) units at Tarapur on turn-key basis, and is now again setting up LWRs in addition to ongoing PHWR programme. Since modern LWRs have large rating, this will help India to quickly ramp up nuclear installed capacity, which is a necessity for deep decarbonization of the energy sector. Two VVER units, each 1000 MWe, set up in technical collaboration with Russia are already operating at Kudankulam (Tamil Nadu) and four more are under construction at the same site. It is envisaged to set up six more VVERs, of 1200 MWe rating at a new site in technical collaboration with Russia.

Dialogue is ongoing with EDF, France to set up six EPRs, each 1650 MWe, at Jaitapur (Maharashtra), and with Westinghouse, USA to set up six APWRs, at Kovvada (Andhra Pradesh).

Fast reactors

India has been steadfast in pursuing a closed fuel cycle right from the inception of the atomic energy programme. A beginning toward pursuing a closed fuel cycle was made with the setting up of the first spent fuel reprocessing plant at Trombay and setting up of FBTR at Kalpakkam. India embarked on the construction of FBTR in collaboration with France, but had to go alone when

Table 1. Improvement in capacity factors of all Indian reactors over the past few years

Year	Capacity factor (%)	Generation in million kW-hours
2008–09	50	14,927
2009–10	61	18,831
2010–11	71	26,473
2011–12	79	32,455
2012–13	80	32,863
2013–14	83	35,333
2014–15	82	37,835
2015–16	75	37,456
2016–17	80	37,674
2017–18	70	38,336
2018–19	70	37,813

Total installed capacity: 6780 MWe. 2008–09 means the year from 1 April 2008 to 31 March 2009. Low capacity factors for 2017–18 and 2018–19 are due to initial problems with power plant components at Kudankulam.

Table 2. PHWRs under construction, and approved for construction

Location	No. of units	Status
Rawatbhata, Rajasthan	2	Under construction
Kakrapar, Gujarat	2	Under construction
Gorakhpur, Haryana	4	Approved
Mahi-Banswara, Rajasthan	4	Approved
Kaiga, Karnataka	2	Approved
Chutka, Madhya Pradesh	2	Approved

Unit size: 700 MWe.

collaboration came to an end after India went in for a Peaceful Nuclear Explosion (PNE) in 1974. Original intent was to use MOX fuel with 30% PuO_2 and 70% UO_2 (with uranium enriched to 85%) as the driver fuel. In view of non-availability of highly enriched uranium, a unique carbide fuel was developed and used in FBTR. This delayed first criticality of FBTR much beyond the original schedule, but made India confident of standing on its own.

Simultaneously, India embarked on design and development of a 500 MWe PFBR which was included in the profile. The work involved challenges which have been met by DAE and Indian industry. Construction at Kalpakkam has now been completed. PFBR is a pool type reactor with two primary loops, and two secondary loops with four steam generators per loop. The reactor is now under commissioning and being the first such reactor, the commissioning process is going on longer than normal. After PFBR has been commissioned and has run successfully for a while, commercial sodium-cooled fast breeder reactors will be launched and two such reactors will come close to the site of PFBR. A roadmap for further development of sodium-cooled fast reactors, including reactors having metallic fuel, has been prepared and is being pursued.

The profile acknowledges that production of plutonium for use in fast reactors was one of the considerations for launching of PHWR programme. The profile recognizes that development of technology for reprocessing of spent fuel to recover plutonium is a must to proceed further with the fast breeder reactor programme. India has indeed made rapid strides in developing and deploying reprocessing technology. Trombay facility reprocesses aluminium-clad spent fuel from research reactors. Plants at Tarapur and Kalpakkam process zircaloy-clad oxide fuels from PHWRs. To significantly increase reprocessing capability, an industrial scale Integrated Nuclear Recycle Plant (INRP) to reprocess PHWR fuel is under construction at Tarapur. Waste management facility has been integrated with this plant.

India has also set up an industrial scale demonstration plant at Tarapur for separation of minor actinides from spent fuel from thermal reactors.

Technology for reprocessing spent fuel from fast reactors, which is characterized by high burn-up, has also been developed and a facility for reprocessing, having capacity to reprocess spent fuel from PFBR and two more such reactors, is under construction at Kalpakkam close to the site of PFBR.

Uranium mining and nuclear fuel fabrication

Atomic Minerals Directorate for Exploration and Research, with its headquarters at Hyderabad and regional centres located in different parts of the country, is engaged in uranium exploration. For exploration of uranium, it employs latest technologies such as time domain electro-magnetic system along with gamma-ray spectrometer and magnetometer for airborne geophysical surveys, and multi-disciplinary field operations namely geological, geophysical, geo-chemical surveys, and drilling for obtaining rock samples.

India's uranium resources are not significant, and are of low grade. Despite low grade, India is exploiting whatever uranium resource is available and continuing exploration to locate further resources. As a result of its efforts, identified conventional uranium resources (Reasonably assured resources and inferred) are approaching 300,000 tonnes of U_3O_8. Two decades back this number was less than 100,000 tonnes. Apart from mines in Jaduguda region, mines have been opened up by UCIL at Tummalapalle in Andhra Pradesh. It is also planned to open mines in Meghalaya and Telangana.

Fuel is fabricated by NFC and it is meeting demands of continuously expanding nuclear power programme. Its products include fuel bundles for PHWRs and boiling water reactors (BWRs), sub-assemblies and hexagonal channels for FBR, core components for PHWR, square channels, cruciform rods and poison tubes for BWRs, zircaloy tubes and rods, stainless steel and special alloy grade tubes and pipes, steam generator and heat exchanger tubes for PHWR, high purity materials, etc. Apart from Hyderabad, it has facilities at Pazhayakayal (Tuticorin, Tamil Nadu) and is constructing a new facility at Rawatbhata (Rajasthan).

In addition, India has set up a facility for enrichment of uranium based on gas centrifuge process, the necessity for which was identified in the Profile.

Heavy water production

Research for developing technologies for producing heavy water was started in early nineteen-sixties. The first plant using electrolysis of water and liquid hydrogen distillation process was set up in Nangal in 1962. At present, six heavy water production plants are operating: two plants are based on H_2S–H_2O exchange process and the remaining use NH_3–H_2 exchange process. Since heavy water production process is energy intensive, special attention has been paid to reducing specific energy consumption. India is now the largest producer of heavy water and has sufficient heavy water in stock to feed upcoming PHWRs. Heavy water is also being exported.

Applications of radio-isotopes

Recognizing the contribution to economy and well-being of citizens of the applications of radiation and radioisotopes, the Profile calls for developing a plan for such applications. This in fact has been done by the Department

and a separate organization, Board of Radiation and Isotope Technology (BRIT) was set up in 1989 and has been marketing radioisotopes, radiopharmaceuticals, radiation technology equipment, etc. BRIT works in close cooperation with BARC where radioisotopes are produced in research reactors. To meet growing need of radioisotopes and radiopharmaceuticals, additional research reactors are also planned.

Based on research done at BARC, several high-yielding varieties of oilseeds and pulses have been produced and this is a continuing activity.

Manpower training

Recognizing the need for trained manpower, DAE has taken several initiatives, including setting up of Homi Bhabha National Institute (HBNI), an institute having the status of a deemed to be university, and getting Tata Institute of Fundamental Research recognized as a deemed to be university. Academic programmes being run at BARC Training School have now been accredited by HBNI. While the name Training School has been retained, it now runs as a Graduate School of a university. HBNI brings together academic programmes running at 11 institutions of DAE and programmes have seen significant expansion since the setting up of HBNI[6]. Nature index has ranked HBNI at 291st position amongst all academic institutions globally based on research output in science, gleaned from publications in 82 select science journals, during August 2018–July 2019.

In addition, NPCIL has set up training centers at its sites. The training centers are equipped to train engineers, supervisors, plant operators and maintenance technicians. Training includes facilitating licensing and qualification of the operation and maintenance personnel of the power stations. NPCIL has also developed and deployed full scope replica simulators for training control room personnel.

Programme implementation and directions for the future

Carrying forward the vision of Bhabha, Sarabhai formulated the Profile for the decade 1970–80 at a time when India was cooperating globally in nuclear science and engineering, and technology control regime applicable to nuclear arena had not yet evolved. This started changing with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) coming into force in March 1970, setting up of Zangger committee for implementation of export controls in accordance with Article III of NPT in 1971, and PNE by India in 1974. All international cooperation came to an abrupt halt, and slowed down India's progress in deployment of nuclear technology. NSG, an informal group of 'supplier' countries, also came into being after 1974 and gradual evolution of its guidelines made India's participation in international civil nuclear trade and cooperation even more difficult. Implementation of the programmes formulated by leaders of DAE had to factor in the changed international regime. DAE did continue with all programmes, but after 1974, it had to follow an autarchic path. Despite this adverse development, India has been able to develop technologies for building PHWRs including fuel fabrication, heavy water production, spent fuel reprocessing, waste management and other nuclear technologies on a broad front.

During initial years, besides design and development, construction of nuclear power plants was also a challenge as industry in India was going through a process of maturation. Many special materials, semi-finished items, rotating machinery, valves and instruments had to be imported for the reactors set up in the beginning of the programme. Engineers from the establishments of DAE worked in close cooperation with industry to realize manufacturing of complex equipment and components meeting stringent quality control requirements. Cooperation with DAE helped industry to expand expertise in detailed engineering, complex manufacturing processes and non-destructive testing techniques. Spillover of expertise to other industrial sectors has been of significant benefit to the growth of Indian economy. Expanded expertise and growth in size of the Indian industry (including public sector units) as well as establishments within DAE has given NPCIL confidence to envision and take up simultaneous construction of several reactors.

After having mastered PHWR technology, a two-pronged approach indicated earlier with regard to getting access to more uranium was launched and is now showing results. Working together with Indian industry, NPCIL has to look at innovative ways to complete projects on time and within budget. Recent high-profile cases of project delays and cost overruns in nuclear industry in the West should be used to learn lessons to avoid their repeat in India. NPCIL did construct TAPS-3 and -4 on schedule and within the original budget. With regards to building PHWRs, India should set an ambitious target and collaborate with other public sector power companies to achieve the target.

India has also embarked upon building LWRs in technical collaboration with vendors in other countries. This will help ramping up nuclear installed capacity faster as LWRs have higher plant size. While doing so, NPCIL should absorb technology so that in due course of time, it can set up LWRs on its own as has been done by South Korea and China. Expertise acquired while building compact reactors for transport application should be leveraged to build large LWRs.

Economy of scale in nuclear power sector can be achieved either by increasing the unit size, or by building several units of small size. So far, nuclear industry has tried to achieve economy of scale by increasing the unit

size. A section of leadership in nuclear industry in the West opines that economy of scale can also be achieved by building small and modular reactors (SMR), and building them in such a manner that fraction of work done in factories is maximized and that at site is minimized. Reduction in site work brings down gestation period and reduces cost as site work is expensive. For adopting this concept in India, detailed study is needed as relative cost of site work and factory work in India is not the same as in the West. Design of SMRs has to be so optimized that capital cost per MWe as well as land footprint per MWe is competitive when compared to large LWRs. Claims made about competitiveness of SMRs are based on feasibility studies and predicated on the assumption of large volumes. This would need confirmation by implementing projects.

PFBR is being commissioned and will provide valuable experience in building more such reactors. While negotiating for resumption of civil nuclear trade, it has been ensured that India has rights to reprocess imported fuel. As India sets up more reactors using imported uranium, it will be possible to use plutonium recovered from spent fuel to build more fast reactors.

In short, DAE has realized the objective of developing technologies as envisaged by the early leadership and now has to accelerate the ongoing implementation phase with a focus on cost optimization along with safety.

1. Guha, R., In conversation with Aparna Basu, IIC Quarterly, Summer 2019, pp. 66–76.
2. DAE, Atomic Energy and Space Research: A Profile for the Decade 1970–80, Bombay, 1970.
3. Sarabhai, V., Proposals for India's nuclear energy programme. *Strategic Analysis*, 2010, **34**(2), 340–341.
4. Special issue on Nuclear Power Programme in India – Past, Present and Future. *Sadhana*, 2013, **38**(5).
5. Special Issue on Development of Advanced Nuclear Technologies. *Prog. Nucl. Energy*, 2017, **101**(A).
6. Grover, R. B., Integrating the function of a university to a work place to promote post-academic research. *Curr. Sci.*, 2019, **117**(7).

doi: 10.18520/cs/v118/i8/1191-1195

Propagating and practising 'horizontal control': Vikram Sarabhai, management and American social science

Joseph Francombe*

Faculty of History, University of Cambridge, UK

Vikram Sarabhai has long been recognized as a pioneer of 'management education' in India. Thus far, however, there has been little attempt to examine more deeply the nature of Sarabhai's thought in this area. In this article, I argue that Sarabhai's thinking on management converged around one particular set of ideas about the types of organization (and leadership) required for effective development, at the centre of which sat the concept of 'horizontal control'. The article goes on to explore parallels between Sarabhai's thinking on horizontal control and the forms of management education forwarded by post-war American social science.

Keywords: American social science, horizontal control, management, Vikram Sarabhai.

AS an industrialist, institution-builder and key player in the creation of the Indian Institute of Management Ahmedabad (IIMA), Vikram Sarabhai has long been recognized as a pioneer of 'management' and 'management education' in India during the post-independence decades. Thus far, however, there has been little attempt to examine more deeply the nature of Sarabhai's thinking on management, still less to consider the implications of his ideas for the forms of management education he promoted. In this article, I argue that Sarabhai's thinking on management converged around one particular set of ideas about the types of organization – and in turn the types of leadership – required for effective development, at the centre of which sat the concept of 'horizontal control'.

The concept of horizontal control held that the key to effective organizational functioning was a rejection of hierarchical authority and its replacement by systems based on autonomy, mutuality, respect and trust. Sarabhai's belief in the merits of horizontal management was reflected in his own institution-building pursuits, from scientific research institutes to corporate enterprises. It also became a core feature of the organizational ethos of the IIMA.

In tracing these efforts to propagate horizontal principles, this article will also suggest that Sarabhai's thinking found parallels in the forms of knowledge espoused by post-war American management theory. As Sarabhai worked to build the IIMA as a temple to horizontal control, the Americanized management education that the IIMA then embraced also brought its own attempts to promote horizontality, in this case in the form of social-psychological science.

*e-mail: jpf31@cam.ac.uk

Vikram Sarabhai and 'horizontal control'

The concept of horizontal control had its origins in Sarabhai's observations concerning the organization of scientific research. As a young scientist, Sarabhai would later recall, he had been greatly impressed by the organizational ethos of the Indian Atomic Energy Commission (AEC) under its first Director, Homi Bhabha. Rather than building the AEC around a formal hierarchical structure extrapolated through an 'organizational chart', Sarabhai explained, Babha had established a loose system of oversight in which control was 'largely inherent and contained in professional commitments'[1]. The AEC's decision making was therefore conducted 'through discussion and the judgement of peers, with administration performing largely the role of service'[2]. According to Sarabhai, this emphasis on flexibility and autonomy had proved conducive not just to the performance of the organization as a whole, but also to the self-development of individual AEC researchers.

From this example, Sarabhai developed a firm conviction that effective scientific research required the creation of organizational structures that allowed practitioners freedom to innovate and self-direct, rather than structures that controlled them from above. The best research results, he argued, came when individuals or groups were given space and autonomy to pursue their own interests and needs and when management systems fostered 'direct interaction' between individuals 'at the same level', rather than elaborate vertical procedures for 'reporting and feedback'. He called this approach 'horizontal control'[3].

The concept of horizontal control was fluid and multifaceted. At its core, however, was an eschewal of all forms of top-down, hierarchical authority. This meant a commitment to organizational structures that allowed for

delegation, freedom and 'trust'. It also meant a commitment to decision-making based on deliberation, discussion and consensus[4]. Horizontal control thus called not just for certain forms of organizational structuring, but also for certain types of leadership. In horizontal control systems, Sarabhai explained:

> '…a leader, if one chooses to identify one, has to be a cultivator rather than a manufacturer. He has to provide the soil and the overall climate and environment in which the seed can grow. One wants permissive individuals who do not have a compelling need to reassure themselves that they are leaders through issuing instructions to others rather they set an example through their own creativity, love of nature and identification to what one may call the 'scientific method[5].'

For Sarabhai, horizontal approaches offered more than just greater efficiency over hierarchical ones; they also offered a model of management more suited to democracy. '[I]f we are to base the growth of this country on the application of science and technology within the democratic framework', he argued, 'we shall have to increasingly rely on horizontal controls'[6]. As a form of organizational management suited to both development and democracy, horizontal control was the mirror-image of the logic pervading 'colonial' institutions[7].

Upon his return to India from Cambridge, in 1948, Sarabhai would soon find himself presented with his own institution-building opportunities. In each case, he would use these opportunities to create institutions which, in their own way, embraced the concept of horizontal control. The first of these was the Physical Research Laboratory (PRL), established in Ahmedabad in 1947, an institution born directly out of Sarabhai's interests as a physicist. Funded jointly by the Bombay Provincial Government, the Centre for Scientific and Industrial Research and the Ahmedabad Educational Society, the PRL was established to conduct research in cosmic ray and astrophysics, building in part on Sarabhai's own doctoral research at the University of Cambridge[8]. In establishing the Laboratory, Sarabhai took great pains to create a system built around horizontal control. Like their AEC counterparts, PRL researchers were given considerable autonomy over their own areas of research. The most important feature of the Laboratory's administration, however, was its 'committee system' of management. Under this system, all major decisions related to scientific research and administration were taken by committees comprising of employees from different levels of the organization, with committee chairmanship shared between members by rotation. The system ensured that control over institutional decision making remained diffused amongst members, rather than concentrated within any one individual. At its root, writes Padmanabh Joshi, 'was an attempt to avoid a hierarchical control system'[9].

Sarabhai's second major institution building pursuit of the 1950s, the Ahmedabad Textile Industry's Research Association (ATIRA), was a similar story. At ATIRA, an institute established to conduct 'operational, applied and fundamental research to improve understanding of men, materials and processes in industry', Sarabhai set about building an organizational structure built around three interlinking 'clusters' of control[10]. The first comprised the Association's Board members, including Sarabhai himself. The second consisted of ATIRA's researchers. The third cluster comprised the targets and ultimately the beneficiaries of ATIRA's scientific research: the city's textile mills. Decision making concerning research priorities, methods and processes was taken across these three clusters with participative and discussion-based decision making being encouraged at all levels. ATIRA's researchers, meanwhile, enjoyed 'freedom of work and trust' and a license to plan, budget and implement tasks with autonomy[11]. At ATIRA, noted one contemporary, Sarabhai viewed his role, in relation to researchers as being 'to nourish their developing capacities, to permit them to move in directions that made sense to each'[12].

According to Sarabhai, principles of horizontal control were of particular relevance to 'scientific organizations' like the AEC, the PRL and ATIRA. This was because 'scientists', together with other select 'professional groups', possessed a particular set of motives and values, at the centre of which sat 'the need for autonomy of working conditions and opportunities'[13]. During the 1950s, however, Sarabhai would also seek to propagate the concept of horizontal control within a broader range of organizations, most notably within the corporate sphere.

Here, Sarabhai made use of his privileged position within the industrial community of Ahmedabad. By the mid-1950s, in addition to his scientific pursuits, he had also taken up positions in a number of enterprises within the Sarabhai group, including Sarabhai Chemicals, Sarabhai Glass, Sarabhai Engineering Group, Swastik Oil Mills, and Standard Pharmaceuticals Limited[14]. Sarabhai used these positions to promote a norm of corporate leadership that, once again, eschewed notions of vertical control. 'Vikram's approach', recalled one former Swastik Oil Mills employee:

> '…was democratic. He believed in the delegation of powers and group discussions to arrive at sound management decisions. The working of the company was discussed in detail at monthly meetings. Each person whatever his position was encouraged to express his thought freely and to criticise constructively without any inhibition…He believed in the delegation of duties. At staff meetings, even when he was present, he would insist that the Chief Executive should take the chair and he would sit as an ordinary member even though he was the Chairman of the Company[15].'

Propagating horizontality at the IIMA

During the early 1960s, Sarabhai played a key role in the establishment of IIMA. Together with its sister institution, the Indian Institute of Management Calcutta (IIMC), the IIMA responded to a widely felt need among policymakers, planners and industrialists for new 'all-India' institutes of professionalized management education. Following a Government of India decision to establish IIMs, Sarabhai quickly embarked on a campaign to convince Nehruvian policymakers that Ahmedabad represented a suitable site for a new Institute. Mobilizing his contacts within the Government of India, including M. S. Thacker, Secretary in the Ministry of Scientific Research and Cultural Affairs, Sarabhai also successfully persuaded key figures in the provincial Government of Gujarat and the Ahmedabad industrial community to support the proposal for an Ahmedabad Institute. In 1962, following the decision to establish the IIMA, Sarabhai was appointed Honorary Director, thereby giving him a direct role in the planning of the Institute[16].

Much like Sarabhai's earlier institution-building pursuits, the IIMA was an institution built to reify the principles of horizontal control. This began at the top, in the relationship between the IIMA and the Government. The IIMA was founded as a 'semi-autonomous' Institute under the auspices of a triumvirate comprising the Government of India, the Government of Gujarat and Ahmedabad industrialists. Unlike other similar institutions, however, which in practice found themselves subject to a significant degree of top-down interference in internal affairs, Sarabhai insisted on the preservation of the IIMA's genuine autonomy and self-determination. Together with other IIMA leaders, including the influential millowner Kasturbhai Lalbhai, he successfully convinced the participating government departments to limit their representation on the IIMA Board, thereby giving the IIMA's own leadership more control over policies and decision making[17].

An aversion to vertical authority was also instilled in the day-to-day organizational structure of the IIMA. When it came to the teaching and research undertaken by the Institute, tasks and activities were accomplished through 'management by committees'. The committees, recalled one IIMA publication:

> '…consisted of not those who held academic positions or had senior rank but of faculty members who were responsible for performing a group of activities to fulfil a need. These committees implemented policy decisions with the advice and approval of the total faculty and the Director. In such a system of management, the initiative and responsibility for accomplishing tasks was spread widely among the faculty and other task groups. Thus the need for a hierarchical structure for academic decision making was avoided[18].'

The philosophy of horizontal control pervaded Sarabhai's choice for IIMA leadership too. In seeking out a permanent Director for the Institute, Sarabhai took great care to identify an individual who possessed the unique characteristics he deemed necessary for effective leadership. 'Sarabhai', T. T. Ram Mohan argues, 'judged that it was better to have somebody with the qualities of a good manager and a value system that fitted in with IIMA's own, than somebody with great credentials'[19]. Bypassing a number of senior figures, the man Sarabhai nominated for the job was the then largely unknown figure of Ravi J. Matthai. An English literature graduate with only ten years industrial experience (plus one year at the IIMC), Matthai was not only inexperienced; at 38, he was also extremely young to assume such an esteemed position. For Sarabhai, however, what mattered was Matthai's commitment to leadership based on 'freedom', 'autonomy' and 'trust' and his faith in non-hierarchical institutional structures[20]. Following his appointment in 1965, Matthai went onto 'strengthen the foundations laid by Sarabhai': 'Not only did he give freedom to the faculty, he also gave it autonomy…[he] ensured that the academic management was insulated against ingress and interference from the [Board]'[21].

Even the IIMA's physical architecture was intended to provide, among other things, an expression of the virtues of non-hierarchical authority. Designed by the American architect, Louis Kahn, with close input from Sarabhai, Matthai and Lalbhai, the IIMA campus buildings prioritized the creation of spaces that facilitated the 'open and easy interaction between teachers and learners, between teachers and teachers, and between learners and learners'[22]. Open arches, rather than restrictive doorways, demarcated the space between students and faculty, thereby encouraging individuals to move freely between them. Classrooms, meanwhile, took the form of 'amphitheatres with large wells and wide aisles' in which the professor could roam and ruminate, reinforcing the idea that their job was to integrate with students and be one among them, not to direct and dispense wisdom from the 'safety of the lectern'[23]. Physically as well as administratively, the IIMA was built to model a form of human relations that was, at its core, horizontal in nature.

Creating horizontal leaders: American social science, group dynamics, and management education

As much as a pioneering management education institute geared towards the provision of technical training in areas such as accountancy, procurement and sales, then, the IIMA was also an institution built to reify the principles of horizontal control. Moreover, as Sarabhai and other IIMA leaders looked to build organizational ethos centred around the rejection of hierarchical authority, the

management courses that their new institute now promoted were also opening the door to new forms of knowledge and practice which, in their own way, emphasized the merits of non-hierarchical authority.

The most important element of this field was an ostensibly bland sounding set of practices known as 'T-group training'. Known also as 'sensitivity training', T-groups comprised experimental group 'laboratories' designed to help individuals explore the effects of different forms of leadership behaviour on themselves and others. In the experimental environment of the T-group, proponents argued, participants would learn through experience, the merits of leadership-based 'participative', 'sensitive', and 'democratic' principles. During the 1960s, T-group training became a key feature of the management courses provided to both graduates and existing corporate leaders at the IIMA[24].

The T-group traced its origins to a series of experiments conducted by psychologists at the University of Iowa during the late 1930s. Led by the German-Jewish émigré Kurt Lewin, the Iowa experiments set out to observe the impact of three different forms of leadership – 'autocratic', 'laissez-faire' and 'democratic' – on groups of young children. Comparing the results, the psychologists had argued that 'democratic' leadership, wherein leaders encouraged discussion, consensus-building and participated as 'a regular group member in spirit', had produced multifaceted benefits when compared to other leadership styles. In democratic groups, children had cooperated constructively towards the group goal, and demonstrated a capacity to 'give and take… objective criticism without personal involvement'. They also proved consistently more productive when it came to completing tasks[25].

From this experiment, Lewin and his colleagues had drawn a firm conviction that meaningful and effective democracy hinged on the proliferation of the democratic leader-group relations witnessed at Iowa. In the years that followed, they had worked tirelessly to promote this model of 'democratic group relations' within American society. The 'Basic Skills Training Group' – soon shortened to T-group – was one outcome of this. At its centre sat one basic concept. By putting individuals within informal group situations and encouraging free and open 'feedback' on the functioning of the group itself, the psychologists argued that participants would learn through experience the merits of 'democratic group relations'[26].

The T-group had soon found an institutional home in the form of the National Training Laboratories, a training institute established in Bethel, Maine. By the mid-1950s, the T-group had found footing within one place more than any other: the corporate sphere. The key here was a wave of interest, shared by American social scientists and corporate leaders alike, in the merits of participative, democratic management styles for both workplace relations and workforce productivity. From its origins as a tool for promoting democratic citizenship, by the mid-1950s the T-group had morphed into a core feature of the management training programmes offered by many American business schools[27].

The inclusion of T-groups within the curriculum of the IIMA spoke of the transnational connections surrounding the Institute's formation. Like its counterpart in Calcutta, the IIMA drew liberally on the support of American consultants and advisors during its early years. In the case of the IIMA, Institute leaders, including Sarabhai, embraced a five-year collaborative partnership with the faculty of the Harvard Business School (HBS), funded and facilitated by the Ford Foundation. Arriving in Ahmedabad from 1962 onwards, HBS personnel would promote an

Planning the IIMA: Those pictured include Kasturbhai Lalbhai (third from left), Prakash Tandon (fourth from right), Vikram Sarabhai (third from right) and Kamla Chowdhry (second from right). (Source: IIMA: India's Management Athenaeum (1961–2011), Indian Institute of Management, 2010.)

Vikram Sarabhai and Kamla Chowdhry: (Source: Merriam, D., Marshall, K. and Chen, L. (eds), In *Service to Humanity: Kamla Chowdhry: A Loving Tribute to Her Life and Spirit*, Ruder Finn, New York, 2008.)

approach to management education centred around the prevailing practices of the American business school – one aspect of which would be T-group training[28].

At the same time, however, there were also clear correlations between the T-group concept and Sarabhai's own ideas about horizontal control. Like Sarabhai's calls for management based on non-hierarchical principles, the T-group promised to produce individuals marked by new, non-authoritarian attitudes and behaviours. This 'systematic' form of behavioural training, explained one IIMA trainer, would assist with the 'development of those horizontal relationships that are necessary for modern technology and administration'[29].

The alignments between Sarabhai, horizontal control and the experimental format of the T-group found concrete expression in the form of one individual: Kamla Chowdhry. A social psychologist by training, Chowdhry had studied for a Ph D at the University of Michigan during the late 1940s, at that time an emerging centre of Lewinian group dynamics research. In 1949, following her return to India, she had taken up a position as head of Psychological Research at ATIRA, therein leading studies on a wide range of topics concerning workforce productivity and industrial labour relations. At ATIRA, Chowdhry embraced wholesale. Sarabhai's thinking on horizontality[30]. In doing so, she also sought to connect these ideas to the latest 'human relations' concepts. At the centre of these efforts sat the enterprise of T-group training.

During the 1950s, in her capacity as an ATIRA researcher, Chowdhry led numerous T-group laboratories for the managers of Ahmedabad's textile mills. Here, she collaborated with social scientists from the London-based Tavistock Institute for Human Relations, a UK partner of the American NTL. From 1962 onwards, Chowdhry assumed the new position of 'Director of IIMA programmes', thereby giving her the key role in the development of the IIMA's curriculum. At the IIMA, Chowdhry would further advocate the use of T-group training as a technique for promoting new leadership behaviours. The 'use of sensitivity training as a method of teaching human relations', she reported to HBS colleagues, had made her and other IIMA staff 'very excited about the possibilities'[31].

Conclusion

For Vikram Sarabhai, the success or failure of post-colonial nation-building and 'development' hinged on the effective 'management' of institutions. In examining Sarabhai's thought on management more deeply, this article has drawn attention to one organizing principle running through it: the concept of 'horizontal control'. As an ardent advocate of the need for horizontal forms of management, I have suggested, Sarabhai used both his own institution-building pursuits and his own leadership behaviour in an attempt to elucidate the merits of a horizontal approach.

The concept of horizontal control was one that responded to the particular challenges and opportunities faced by India in the immediate post-independence decades – from development to democratization. At the same time, however, it also found compelling parallels in the forms of thinking espoused by post-war American management education. At the IIMA, Sarabhai's thinking on horizontality dovetailed neatly with prevailing American approaches to 'democratizing' corporate leadership, foremost among which was the enterprise of T-group training. As these two agenda came into contact, American behavioural techniques like the T-group became key mechanisms through which Sarabhai and other IIMA leaders sought to propagate ideas about horizontal control.

1. Sarabhai, V. A., Science and National Goals. In *Science Policy and National Development* (ed. Kamla Chowdhry), Macmillan and Co, New Delhi, 1974, p. 5; Sarabhai, V. A., Organisation for Developmental Tasks: Atomic Energy Commission of India. In *Management for Development, Vikram Sarabhai, A Collection of Papers* (ed. Kamla Chowdhry), Vikas Publishing, Delhi, 1975, pp. 1–31; Bhabha, for his part, had modelled the AEC's approach from the Kaiser Wilhelm Society (later renamed the Max Plank Institute), a scientific research institute in Berlin, citing that organization's motto that 'the Kaiser Wilhelm Society shall not first built an institute for research and then seek out a suitable man, but shall first pick up an outstanding man and then build an institute for him'. Sreekantan, B. V., Singh, V. and Udgaonkar, B. M. (eds), *Homi Jehangir Bhabha: Collected Scientific Papers*, Tata Institute of Fundamental Research, 1985, p. 57.
2. Ibid., p. 5.
3. Sarabhai, V. A., *Science and National Goals*, pp. 4–5.
4. For discussions on the concept of horizontal control see Sarabhai, V. A., Approaches to the administration of scientific organisations; and Sarabhai, V. A., Development through pace setting: horizontal and vertical control systems. In *Science Policy and National Development.*
5. Cited in Parikh, K., The 'Permissive' Leader. In *Vikram Sarabhai: The Man and the Vision* (ed. Joshi, P. K.), Mapin Publishing, Ahmedabad, 1992, p. 109.
6. Sarabhai, Development through pace setting: horizontal and vertical control systems, p. 41.
7. For Sarabhai, the overarching logic of most colonial institutions had been verticality, not horizontality. In large part this was because the focus of those institutions had been 'preservation' and 'control', rather than innovation, creativity and progress. See Sarabhai, *Preservation and Innovation: The Tasks of Government*, pp. 32–38.
8. In establishing the PRL, notes Robert S. Anderson, Sarabhai was building 'the home of his professional life as a physicist'. Anderson, R. S., *Nucleus and Nation: Scientists, International Networks, and Power in India*, University of Chicago Press, Chicago, 2010, p. 283.
9. Joshi, P. K., Dr. Vikram Sarabhai: A Study of Innovative Leadership and Institution Building, Unpublished Ph D dissertation, University of Gujarat, 1985, p. 136.
10. 'ATIRA – The Ahmedabad Textile Industry's Research Association, pamphlet issued on the occasion of the foundation stone laying ceremony of the ATIRA laboratories by the Hon'ble Sardar

Vallbhbhai Patel, 1 November 1950', File Number 4(8).46, Vol. IV, Records of the Ministry of Education, Government of India, National Archives of India. See also Sarabhai, V. A., Ahmedabad textile industry's research association. *Nature*, 1954, **174**, 578–580.
11. Joshi, P. K., Dr. Vikram Sarabhai: A Study of Innovative Leadership and Institution Building, Unpublished Ph D dissertation, University of Gujarat, 1985, p. 116.
12. The researcher in question was Kamla Chowdhry, about which more will be said in the third section of this article. Chowdhry, K., Institution building and social change: The Ahmedabad Textile Industry's Research Association. *Indian J. Public Admin.*, 1968, **XIV**(4), 956.
13. Sarabhai, V. A., Approaches to the Administration of Scientific Organisations, p. 23.
14. Nadkarni, N. R., Dr. Sarabhai – the Industrialist. *Electronics Today*, 1972, pp. 95–98.
15. Badami, J. S., Dr. Vikram Sarabhai: My Student, Employer and Friend. *Electronics Today*, 1972, p. 48.
16. On the founding of the IIMA and Sarabhai's leading role see Anubhai, P., *The IIMA Story: The DNA of an Institution*, Random House, New Delhi, 2011; Ram Mohan, T. T., *Brick by Red Brick: Ravi Matthai and the Making of IIM Ahmedabad*, Rupa and Co, Kolkata, 2011.
17. Paul, S., Building on a solid foundation. In *Institution Building: The IIMA Experience – Vol. I: The Early Years* (eds Matthai, R. J. *et al*.), Indian Institute of Management Ahmedabad, Ahmedabad, 1993, p. 93. As one former faculty member has noted, the ability of the IIMA to secure such concessions from the government owed no small debt to the esteem and influence of its leading figures, including Sarabhai. Bhattacharya, S. K., The early years of institutional development. In *Institution Building: The IIMA Experience* (eds Matthai, R. J. *et al*.), p. 17.
18. *IIMA: The First Decade, 1962–1972*, Indian Institute of Management, Ahmedabad, 1973, pp. 19–20.
19. Mohan, *Brick by Red Brick*, p. 76.
20. Ibid., pp. 65–80.
21. Ibid., p. 117.
22. *IIMA: India's Management Athenaeum (1961–2011)*, Indian Institute of Management Ahmedabad, Ahmedabad, 2010, p. 32.
23. Ibid., p. 69.
24. T-group training formed the core feature of a branch of the IIMA's early management education referred to as 'Organisational Behaviour'.
25. For more on the original Iowa experiments see White, R. K. and Lippitt, R., *Autocracy and Democracy: An Experimental Inquiry*, Harper, New York, 1976; Lewin, K., Lippitt, R. and White, R. K., Patterns of aggressive behaviour in experimentally created social climates. *J. Social Psychol.*, 1939, **10**(2), 269–299; Lippitt, R. and White, R. K., An experimental study of authoritarian and group atmospheres. In *Studies in Topological and Vector Psychology*, University of Iowa Studies in Child Welfare, 1940, vol. 16, no. 3, pp. 45–193; Lewin, K. *et al*., Patterns of aggressive behavior in experimentally created social climates, pp. 269–299.
26. For a historical account of the emergence of the T-group see Alden, J. F., Bottom-up management: participative philosophy and humanistic psychology in American organizational culture, 1930–1970, unpublished Ph D Dissertation, Columbia University, 2012, chapters 1, 4 and 7.
27. On this transition see Ibid., ch. 7.
28. As the T-group concept found a foothold amongst the horizontalist leadership of the IIMA, it also took root elsewhere. In Calcutta, for instance, leaders at the IIMC would also espouse the virtues of T-group training. Here, in fact, social scientists would go one step further, creating a new exportable model of T-group training geared not just towards individuals attending management training courses, but for organisations as well. On the enterprise of T-group training at the IIMC see Sinha, D. P., *T-Group Team Building and Organisational Development*, Indian Society of Applied Behavioural Science, New Delhi, 1986; Sinha, D. P., *Learning from Life*, Excel Books, New Delhi, 2007, pp. 107–116.
29. The trainer was Rolf P. Lynton, a prominent exponent of T-group training in India. Based at the Small Industries Extension Training Institute in Hyderabad, Lynton would also lead T-groups at IIMA during the early years. Lynton, R. P., Laboratory training for organizational development, Report 009233, Catalogued Reports 6262-9268 (FA739C) Box 383, Ford Foundation Archives, Tarrytown, NY, p. 2.
30. For examples of this thinking see Chowdhry, K., Institution building: Two approaches in contrast. In *Institution-building in Education and Research* (eds Matthai, R., Pareek, U. and Rao, T. V.), All India Management Association, New Delhi, 1977, pp. 12–18; Chowdhry, K., Organization and administration of scientific institutions: A case study of Atira. *Manage. Int. Rev.*, 1969, **9**(6), 97–104; Chowdhry, K., Organizational innovation in universities: Relevance of industrial Eexperience. *Econ. Polit. Wkly*, IV, 35, M97–M100; Chowdhry, K., Developing administrators for tomorrow. *Indian J. Public Admin.*, 1969, **15**(2), 221–227.
31. Kamla Chowdhry to Harry Hansen, 7 October 1964, File: Chowdhry, Dr Kamla, 1964-5, Box 2, Indian Institute of Management Records, Special Collections, Baker Library, Harvard Business School, Cambridge, MA.

doi: 10.18520/cs/v118/i8/1207-1212

Vikram Sarabhai: science in developing countries

Kartikeya V. Sarabhai[1,*] and Padmanabh Joshi[2,*]

[1]Centre for Environment Education, Ahmedabad 380 054, India
[2]Vikram Sarabhai Archives, Nehru Foundation for Development, Ahmedabad 380 054, India

Vikram Sarabhai's parents, Sarladevi and Ambalal Sarabhai wanted more for their children from education than what was available at the time in schools in Ahmedabad. In the 1920s they had travelled to London and were going to spend the next year or so in England. Young Ambalal had taken charge of the Ahmedabad Manufacturing and Calico Printing Company. He wanted to modernize the Calico Mills and learn from those in England. It was at that time that Sarladevi had learnt of the Montessori method with its child-centric approach. On their return, they established a school at their residential compound, the Retreat. 'The Retreat School was modelled on Montessorian principles, where the highest function of a teacher was considered not so much the imparting of knowledge as stimulating in the pupil its love and pursuit[1].' This was the school in which young Vikram studied and had the opportunity to not only do his academic work but to work with engineers with whom he built a small train that went around the campus. The Sarabhai family was close to Ravindranath Tagore and Mahatma Gandhi and their influences were very clearly seen in the way the Retreat School was run. Tagore's influence brought in the arts and Indian culture while Gandhiji's influence taught the dignity of labour and self-reliance. In his diary, J. S. Badami, the Physics and Chemistry teacher at the school writes that 'Vikram has a very inquisitive mind, often asks questions for explaining which I have to go far and wide out of the prescribed course. This is very good and he should be encouraged to discuss details.'[2] His mother, Sarladevi's remarked to the teacher, 'I am glad you are encouraging him even within the limited time at your disposal.' On his childhood Vikram Sarabhai once observed, 'All through my childhood, I was brought up on doing what one felt was right rather than what necessarily what society thought was appropriate.'

Vikram Sarabhai saw quality education and especially science education, as not only critical for the individual but for the nation as a whole. In a talk he expressed it thus: 'The development of a nation is intimately linked with the understanding and application of science and technology by its people. It has sometime been argued that the application of technology by itself can contribute to growth. This is certainly true as an abstract proposition, but fails in practice…… History has demonstrated that the real social and economic fruits of technology go to those who apply them through understanding. Therefore, a significant number of citizens of every developing country must understand the ways of modern science and the technology that flows from it[3].'

As his son, there were several instances where I (Kartikeya) experienced this thinking. In 1965, I was a student of Theoretical Physics and Mathematics studying for a Tripos in Natural Sciences at Cambridge University. When I had left India I was sure that this was what I would like to do. While at Cambridge, I was exposed to many development issues of India. In 1966 there was a major drought in Bihar and I spent my summer there, and was greatly impressed by the voluntary work which was being done and the tremendous scope for working in the developmental sector. I told Papa that I would like to work in development rather than continue to study Physics. His strong advice was that Science provides a very solid base to understand not only the phenomenon of science but other processes including development and it would really be advisable to complete my degree in science and then move to development. This was the advice I took and completed my degree before going on to do Development Communication at MIT. He advised me that many students at MIT came from engineering and science background and I would be 'more at home' with the type of approach to problem solving that was being taken at MIT. The application of education to critical thinking and problem solving was something that Vikram Sarabhai had experienced in his own education and had strongly felt that this was what was required in our educational system as well.

He said 'An ability to question basic assumptions in any situation is fostered by probing the frontiers of science, whatever field one may be engaged in …. countries have to provide facilities for its nationals to do front rank research within the resources available. It is equally necessary, having produced the men and women who can do research, to organize task-oriented projects for the nation's practical problems[4].'

Today there is wide recognition that this approach of organizing task oriented projects to deal with India's problem is very much required. Sarabhai felt atomic

*For correspondence. (e-mail: ceedo@ceeindia.org; pkjoshi8945@gmail.com)

energy could play an important role in Indian agriculture. A major problem with India is the ability to store vegetables and increase their life before they reach the market place. He formed a group which then came up with a proposal for irradiation of vegetables and this also lead to the creation of the Nuclear Centre for Agriculture. Similarly he wanted space research in India to help with the issues of agriculture. He spoke extensively on the 'national benefits from an application of operational Remote Sensing techniques to agriculture' which he felt could be large and appealing[5].

Sarabhai was aware that there would be tremendous pressure for developing India's space programme imitating the programmes in the West. He spoke about this pressure at a talk in 1966 where he said, 'In appreciating the value of space activities to a developing nation, one should recognize some inherent problems. They arise from the glamour that is associated with space activities. There is a real danger that developing nations may adopt a space programme largely for the glamour, devoting resources not through a recognition of the value of which we are talking about here, but from a desire to create a sham image nationally and internationally[5].'

There were many challenges of putting a new programme together. Aravamudan writes about these early days 'Dr Vikram Sarabhai floated the idea of a space program when rocketry and space technology was unknown in India'. 'I was in a comfortable and prestigious central government scientific position in the Department of Atomic Energy[6],' informs Aravamudan. Despite the friendly warnings from friends about leaving a prestigious job for something still in its nascent stage, Aravamudan accepted. Identifying young talent and giving them an exposure was critical to Sarabhai's way of managing any operations. He sent both Aravamudan and A. P. J. Abdul Kalam to NASA along with several others for initial training. Besides science there were many other aspects of Sarabhai's method of interacting with society and with other disciplines and societies.

In the 1960s, Thumba was a small fishing village on the outskirts of Thiruvananthapuram city. But for the country's space scientists, the location was exceptional as it was very close to the earth's magnetic equator. The site selected at Thumba lay between the railway line and the sea coast, covering a distance of about two and a half km and measuring about 600 acres. Within this area, stood a large church, whose site had to be acquired. 'INCOSPAR decided to build a sounding rocket range on the geomagnetic equator at Thumba, near Thiruvanathapuram to study of problems in aeronomy up to 200 km. The planned program would be conducted with sounding rockets and the scientific results were expected to have a direct bearing on a better understanding of meteorology.'

Kalam recalls the way this was achieved. 'Both Dr Homi Bhabha and Prof. Vikram Sarabhai were looking for a site to establish space research station in the equatorial region. These two great scientists visited a number of places. Thumba in Kerala was selected by the scientific community for space research as it was near the equatorial region and was ideally suited for ionospheric research in upper atmosphere apart from study of atmospheric structure. When Prof. Vikram Sarabhai visited Thumba, the locality had series of villages and thousands of fishermen folk were living in that area. It also had a beautiful ancient church, St Mary Magdalene Church, Pallithura and a Bishop's House. Prof. Vikram Sarabhai met many politicians and bureaucrats to get the place for the work of space science research. It did not move further because of the nature of the place. He was asked to see the Bishop of Trivandrum, at that time in 1962, His Excellency Rct Rev Dr Peter Bernard Pereira. It was a Saturday when Prof Vikram Sarabhai met the Bishop. The Bishop smiled and asked him to meet him the next day, i.e. Sunday. In the morning Service, the Bishop told the congregation, 'My children, I have a famous scientist with me who wants our church and the place I live for the work of space science research. Dear children, science seeks truth by reasoning. In one way, science and spiritualism seek the same divine blessings for doing good for the people. My children, can we give the God's abode for a scientific mission?' There was a chorus of 'Amen' from the congregation and the whole church reverberated. Subsequently, the big event took place in 1962. His Excellency Rct Rev Dr Peter Bernard Pereira, the Bishop of Trivandrum, took the noble decision to dedicate the church in recognition of the national goal for the establishment of the Indian Space Research Organization at Pallithura, Thumba. That was the church where we had our design centre, started rocket assembly, design of filament winding machine for FRP product and the Bishop's house was our scientists' place. Later, the Thumba Equatorial Rocket Launching Station (TERLS) led to the establishment of Vikram Sarabhai Space Centre (VSSC) and multiple space centres throughout the country[7].'

I remember as a student in India doing a summer break attending a meeting where Sarabhai was trying to convince the audience of people from other different departments in the government why space had a role to play in telecommunications and television. He said 'In India, at the moment, we are deeply interested in an evaluation of the benefits that a synchronous satellite can provide for national needs of point to point communications, for mass communications through direct broadcast television to promote national integration as well as the economic development of isolated communities.'

'Just for one application, namely, the provision of broadband communication for reaching half a million villages of India through television, it can be shown that the investment for using satellites would be only a third of what would be required with conventional technologies[8].'

K. G. McCracken, an Australian space scientist talks of his interactions with Sarabhai.

'Vikram injected an element of realism into the fairy-tale world in which I was living, Thus, in 1961 he began speaking of the Indian view of Space research; a view that was clearly different from that of the developed countries which were active in space at that time. He spoke of using satellites to provide television for the half million villages of India; TV in which there would be a single video channel, and 14 different sound channels to bridge the linguistic gaps that divide the Indian nation. He spoke of agricultural, family planning and health education being given to the non-urban population by satellite. He argued that it would be faster to use a satellite to provide a high quality, nationwide telephone system than to use a conventional ground based microwave system. That is, he spoke of careful tailoring of space science to the national goals of his country. He spoke of space scientists applying their intellectual capabilities to practical problems, and set the example by doing so himself.'

As a scientist, Dr Sarabhai felt the need to prove by actual experiment that TV could actually be used as a tool for development in the rural areas. He, therefore, took the initiative in organising the Krishi-Darshan Project around Delhi, with the collaboration of AIR, the Delhi Administration and the Indian Agricultural Research Institute. This project was inaugurated in 1967 and initially two agricultural programs a week were broadcast to TV sets located in 80 villages around Delhi. Independent evaluations of this project effectively proved that TV was particularly successful in spreading new techniques and methods.

The possibilities of using high-power synchronous satellites for direct broadcast to the whole country made it possible to think of using a nation-wide TV system in India.

He did not merely suggest satellite television as a possible solution to the problems of mass-communication, education and information transfer, but he went a stage further and concluded an agreement with the United States, following the recommendations of the various studies he had initiated, to conduct a joint Satellite Instructional Television Experiment (SITE). This agreement would allow India the use of a NASA satellite for a period of one year during which the experiment would be conducted[8].'

Vikram Sarabhai established many collaborations and he was all for getting the best technologies in the world. But he was also equally clear that when we have capabilities in our own country, these need to be used first before searching for them abroad. He said, 'There is a seduction by their (advanced nations) political and commercial salesmen who dangle new gimmicks which they suggest should be imported rather than indigenous capability be developed and supported. There are those who preach, as guardians of the economic wellbeing of the developing nations, that we must proceed step by step following the same process by which nations themselves progressed. One is often told that such and such a thing is too sophisticated to be applied. The approach disregards what should be obvious, that when a problem is great, one requires the most effective means available to deal with it[3].'

He further said, 'One should ensure that nationals of the country at the operative level of the programme are sufficiently committed and are willing to stretch themselves to the fullest before asking for help outside[3].'

P. N. Haksar, the then Deputy Chairman Planning Commission and someone who had worked closely with Sarabhai as a member of the Atomic Energy Commission recounts the way the first Earth Station came to be built in Arvi near Pune. 'I remember once in pursuit of this deed of partnership which we solemnly executed and signed, he (Vikram Sarabhai) said to me, soon after I became a member (AEC) in an agitated mind, "What is happening to this country? Are we selling it down the drain?" I said: "Well, possibly we might be. But what is the matter?" He said: "The Ministry of Communications has signed a contract or about to sign a contract with RCA giving them a turnkey job for India's first earth station to be built up at Arvi." He felt that we could do it, that he could do it, that our scientists and our engineers could do it. It was a shame that this was being handed over to a foreign firm on turnkey basis. I naturally scratched my[3] head. It was too big. I rang up the then secretary of the Ministry of Communications and asked him. He told me the usual story that they had made detailed enquiry, that it could not be done, that we had no competence, that we had a time-bound programme. Even if it could be done it would be late by six months, so on, and so forth. Since I could not let down my partner, Vikram, I had to think quickly as to what can one do about these things in our country? One goes to the final court of appeal. One goes to the Prime Minister. It so happened that the Prime Minister understood the message, and we had a meeting with the Ministry of Communications in their full regalia. Vikram was diffident, nervous, angry, red in his face, and trembling almost, but any rate he won, and though we had the psychological support of RCA in the electronics part of it, it was left to Indian engineers to design and build the Arvi Station[9].'

Bruno Rossi, Professor at the Massachusetts Institute of Technology and a colleague of Sarabhai wrote about him 'I believe that the stature of Vikram Sarabhai as a scientist depends not so much on any specific achievement as on the unique character of his scientific personality. For him scientific research was an act of love toward nature. He had an almost uncanny capability to absorb and store in his mind a vast amount of experimental and theoretical data. Having done that, and guided by what I am tempted to call an artistic intuition, he would then

proceed to arrange these data into a self-consistent picture bringing out hidden regularities and relationships; a picture which, through the years, would progressively evolve and become more precise. This is why his death dealt such a hard blow not only to the personal feelings of his fellow scientists, but to science itself[10].'

For Vikram Sarabhai, science education, research, institution building and working for development were a continuum. He said, 'The most effective development of education can take place only when the teacher, the student, the parents and the outside environment can interact with one another, in a series of feedback loops, free from regimentation and irrelevant theories and principles preached from the top.'

Once sitting in the United Nations Building, Vikram Sarabhai told Axel Horn, the American science educator who worked with him on developing the Community Science Centre, 'I have gone through three careers during my lifetime – scientist, industrialist and public servant. I want my final reincarnation as an educator[11].'

1. Badami, J. S., My student, employer and friend. In *Vikram Sarabhai: The Man and the Vision* (ed. Joshi, P.), MAPIN, 1992.
2. Ibid., Entry in his diary 20th December 1935 Vikram age 16.
3. Vikram Sarabhai, Space Activity for Developing Countries. In *Science Policy and National Development*, MacMillan, 1974.
4. Vikram Sarabhai, ibid.
5. Vikram Sarabhai, Remote sensing in the service of developing countries. In *Science Policy and National Development*, MacMillan, 1974, p. 77.
6. Aravamudan, R., *ISRO: A Personal History*, Harper Collins, 2017.
7. Abdul Kalam, A. P. J., *Wings of Fire*, Universities Press, 1999, p. 37.
8. Rao, B. S., Karnik, K. S. and Chitnis, E. V., In *Vikram Sarabhai: The Man and the Vision* (ed. Joshi, P.), MAPIN, 1992.
9. Haksar, P. N., The First Vikram Sarabhai Memorial Lecture, IIM-A, 11 February 1976.
10. Bruno Rossi, In *Vikram Sarabhai: The Man and the Vision* (ed. Joshi, P.), MAPIN, 1992.
11. Axel Horn (ed. Padmanabh Joshi). In *Vikram Sarabhai: The Man and the Vision*, MAPIN, 1992.

doi: 10.18520/cs/v118/i8/1203-1206

Vikram Sarabhai – A scientist's scientist

M. S. Swaminathan*

M.S. Swaminathan Research Foundation, Chennai 600 113, India

I first met Vikram Sarabhai in 1966 soon after he had taken over as Head of the Department of Atomic Energy following the premature and unfortunate demise of Homi Bhabha. I had known earlier his wife, the famous Bharanatyam dancer, Mrinalini. From 1966 onwards I have been in close touch with the Sarabhai family, although Vikram himself passed away suddenly at Thiruvananthapuram in December 1971. He had spoken at the dedication of the Nuclear Research Laboratory at IARI and he left for Thiruvananthapuram the following day. Thus we lost two of our eminent scientists – Homi Bhabha and Vikram Sarabhai soon after the other.

Vikram was a man of great vision and had dedication to national development. When asked why a poor country like India should go for high technology, he replied, 'But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society.' In addition to maintaining the momentum of progress in the area of atomic energy, Vikram started paving the way for one of the most effective Space Research Organizations. ISRO is now making us all proud by undertaking very challenging tasks like landing on the moon.

When Vikram became the Head of the Atomic Energy Department he told me that we should mobilize all new technologies for the benefit of small and marginal farmers. For this he felt there is need for more irrigation facilities. Extending the area under irrigation will need more power to pump the groundwater. Therefore he gave attention in an integrated way to agriculture, irrigation and power generation. He warned against complacency in his Lal Bahadur Sastri Memorial Lecture (April 1969, IARI, 'How green is our revolution'). In fact many new projects during the late 60s were developed at the insistence of Vikram. He wanted progress not only in agriculture, but in every economic field on the principle of inclusive growth, so that the benefits will be widespread.

Fortunately for me he was a close friend and guide. We shared many visions of the India of the future. He came to Delhi all the way in December 1971 for participating in the inauguration of the Nuclear Research Laboratory which he helped to develop with financial support from UNDP.

When Vikram and I were going round in 1967 the wheat fields of Delhi state he was fascinated by the new opportunities for wheat production in India. He mentioned to me that the news of this scientific breakthrough should be communicated to every farmer – whether large or small. He felt that the only way to achieve this is to mobilize the tools of television. He told me that we should go to the Prime Minister (Smt Indira Gandhi) and inform her about the exiting new opportunities in agriculture opened up by science and technology. He had good access to the Prime Minister and we went to her house to inform her about the possibility of launching an agricultural revolution starting with wheat and rice. She immediately mentioned to her Secretary that the Secretary Information and Broadcasting should be requested to launch a Krishi Darshan Programme on Doordarshan. She further said 'please inform him that it should be inaugurated on Republic Day'. This was done and Krishi Darshan became a powerful tool for the spread of knowledge concerning agricultural progress.

Vikram was very keen to develop a method of forecasting crop yields. Also he wanted to mobilize remote sensing for mapping the spread of diseases. We both decided that the first major application of remote sensing could be for studying the spread of the root wilt disease in coconut in Kerala. Later, we used it for making an advanced estimate of potential yield of the crops in Anantapur (dry farming) and Patiala (irrigated farming). The predicted and actual yields were very close to each other and this gave the push to the application of the Remote Sensing technology. The coconut root wilt disease became the first major plant disease to be studied in India in detail using remote sensing.

Among Vikram's unique qualities, I should mention that he desired to see progress not only in atomic energy, but in every field of agriculture, industry and medicine. He was not the one committed only to a narrow discipline in which he was interested. He encouraged his son (Kartikeya Sarabhai) to start an Institute for promoting harmony between human kind and nature. He laid the foundation at Sriharikota for starting a Centre for launching satellites.

When he suddenly passed away in Thiruvananthapuram in 1971, all scientists in this country felt that they had lost a friend, philosopher and guide. The best tribute we can pay to him is to follow his principle of harnessing science for public good.

*e-mail: swami@mssrf.res.in

doi: 10.18520/cs/v118/i8/1183

There is nobody to be ruled

Praful D. Bhavsar

Director (Retired), Space Applications Center, Indian Space Research Organisation, Ahmedabad 380 015, India

I *still* remember the day as if it was yesterday. It was Thursday 30 December 1971. I got up that morning, casually glanced at a magazine, and noticed a *sloka*.

न राज्यं न च राजासीत्, न दण्डयो न च दण्डिकः ।
धर्मेणैव प्रजास्सर्वा, रक्षन्ति स्म परस्परम् ॥

No state, no king, no judge and no criminal would exist if everybody lived by Dharma; for, then, people would protect each other.

I was in a great hurry that morning. I had reached Mumbai from Thiruvananthapuram the previous evening after a long day of meetings with Sarabhai. I was in the northern suburb of Khar, and in a hurry to reach the Department of Atomic Energy's office at the Old Yatch Club in south Mumbai, finish some work there, and then rush to the Santacruz airport to meet Sarabhai to continue the discussions from the previous day. But, alas, when I reached the DAE's office, I was informed of the sad news that Sarabhai had died the previous night. The gravity of the news was still sinking in.

In those sad moments, I realized the full significance of the *sloka* I had read that morning. What I was not able to understand that morning, nor had been able to fully grasp during the previous two decades working with Sarabhai, was suddenly and immediately clear to me. This is what Sarabhai was trying to achieve – establish a new organizational culture in the country. Some unknown power had driven me to that fact, that Thursday morning.

There is no ruler, there is nobody to be ruled;
There is no punisher, there is nobody to be punished.
All with righteous behavior, are protecting each other.

Sarabhai strongly believed in a collective responsibility.

In 1948, having finished my B Sc, I went to Pune in search of a college where I could pursue my studies towards M Sc in Physics. In Pune, I met L. A. Ramdas, Director of the Agricultural Meteorology section of the Indian Meteorology Department. He informed me of the newly started laboratory in Physics by Vikram Sarabhai in Ahmedabad and advised me to go and meet him.

Thus, I met Sarabhai for the first time in August 1948 in a small room at the M.G. Science Institute, where the Physical Research Laboratory had been given a couple of rooms by the Ahmedabad Education Society. He was wearing white Khadi trousers with a bright green shirt, working at the glass-blower's desk with a Geiger counter. He greeted me with a smile and asked me to wait a bit until he finished repairing the Geiger counter. I was at once impressed by this young, simple, unassuming person, who fit very well with my mental image of a young experimental physicist and was ready to accept him as my teacher. He briefly interviewed me, probed my interest and motives for studying Physics, and welcomed me to his laboratory. In those days, Sarabhai was quite fond of wearing bright coloured shirts, one day a deep green, another day a bright blue one, and the next day a shirt in scarlet. He changed his style of dress later to a simple *kurta-pajama* and *chappals*, but his ever-smiling face and the twinkle in his eyes remained unchanged through all those years since I met him in those early days of the Physical Research Laboratory in August 1948.

In those early years, Sarabhai would go to Vadodara by train, every Friday, to look after his work in Pharmaceuticals. He would take one of his students along with him in the train, so as not to waste the time while on the train. We would work on a manuscript for publication, or a chapter of a student's thesis, or work on some problem under study. During such trips to Vadodara I came to know Vikram Sarabhai as a person, his feelings, his deep concern for the country, and his strong desire to make a lasting change in the pattern of our society.

He believed that science and technology thrive only in a culture which relies on horizontal control systems rather than vertical control systems. This idea, when applied to an organization meant that an individual's position in that organization was defined by their job and/or responsibility, and not by their salary. He did not believe in the superiority of an 'officer' by virtue of their salary. He believed in free exchange of ideas within an organization, where everyone discussed and talked with each other without barriers, and worked together towards the common goal. Therefore, he would be deeply hurt, and would find it difficult to understand, when sometimes some important work would get delayed, just because someone did not share the right information at the right time with another person, because they perceived it was below their dignity to approach someone who 'ranked' lower than them in the organization.

*e-mail: professor.pdbhavsar@gmail.com

The humblest of persons, a peon or the car driver, was able to approach Sarabhai and discuss their needs without feeling inferior, and Sarabhai would always offer them a seat and have time to discuss their concerns without being conscious of his position at the top of the organization. To him all were equal. He believed in everyone's dignity and strived to preserve it, irrespective of their status in society, which tended to be defined by the level of wealth or poverty, educational background, or social status.

Sarabhai was always ready to help anybody who he found in a difficult position. I clearly remember the day when a labourer was bringing some heavy boxes to the laboratory in a handcart and was finding it difficult to push the cart up a slope. Sarabhai immediately joined the labourer to push the cart up the slope. In those early days at the Physical Research Laboratory, when there was work being done on electronic circuits for the construction of cosmic ray telescope, there was always a need to move heavy equipment such as an oscilloscope or a heavy power source. Sarabhai would never call for help and would lift the equipment himself and move it from one room to another.

Sarabhai was also never worried about the so-called brain drain from India during the late 1950s and early 1960s. On the contrary, he would always encourage young people to go abroad to learn new science, new technologies. He was very sure of those young minds returning to India; he had a vision, he knew what these young scientists wanted, and he was able to create situations and an atmosphere that encouraged these young minds to return home to India and contribute towards the growth of the country.

During his many trips abroad, no matter how busy, he never hesitated to meet with young Indian scientists who would request to meet him. And, that one meeting was usually enough to inspire that young mind to return to the homeland to do his, or her, bit towards building newer technologies in India.

India lost this great visionary at a very young age. I believe that the tribute we can continue to pay him is to remember his approach, to work incessantly with the zeal and vigour towards the one common goal, in the way he inspired each and every one of us who had a chance to work with him.

doi: 10.18520/cs/v118/i8/1180-1181

Vikram Sarabhai – Visionary motivator

Pramod Kale*

Director, Vikram Sarabhai Space Centre, Thiruvananthapuram 695 022, India

Vikram Sarabhai has been referred to as the 'Founder' or 'Architect' of the Indian Space Program. When such labels are used, people tend to forget or ignore many other significant contributions made by a multifaceted person like Sarabhai. More than forty-eight years ago Vikram Sarabhai passed away on 30 December 1971 at a young age of fifty-two. Last year in 2019 a large number of programmes were organized to mark the birth centenary of Vikram Sarabhai and these will be continued till August 2020. I was very fortunate to have met him in 1960, when I was very young, and had an opportunity to work with him during my association with him for eleven years.

He was not only a visionary scientist but was also an inspiring educator and motivator. He certainly had a vision for the self-reliant development of our country. He did not keep his ideas and vision to himself. He communicated the same to his colleagues and that motivated us. As a person he was warm and compassionate with an infectious smile. We used to track satellites at the Physical Research Laboratory. Many a times in the middle of the night, he would visit our tracking station to see what work was on going. His unannounced visits were very motivating for students, technical assistants and others. He remembered every person's name and enquired about their families as well. For many of us he was not just the head of the institution; he was our teacher and mentor.

Today when we remember or think about what Sarabhai had said or what he had written, we must try to understand the same in the context of the 'Socio Economic Situation' or 'Political Policy' prevalent at that time. Many people have questioned the relevance and expenses involved in the recent activities of ISRO concerning *Chandrayaan 1*, *Mangalyaan*, *Astrosat*, *Chandrayaan 2* and *Gaganyaan*. They consider these activities as a departure from the path charted by Sarabhai.

At the time of dedication of the Thumba Equatorial Rocket Launching Station to the United Nations on 2 February 1968, Sarabhai had said, 'There are some who question the relevance of space activities in a developing nation. To us there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in exploration of the moon or planets or manned spaceflight. But we are convinced that if we are to play a meaningful role nationally and in the community of nations, we must be second to none in the applications of advanced technologies to the real problems of man and society, which we find in our country.' These words and thoughts had defined the goals for the space programme of our country. Our space programme is driven by the space applications.

Sarabhai was convinced that no nation could afford to neglect scientific research while concentrating on economic, social and technological development. While establishing the rocket launching station at Thumba in 1963, the ionospheric research facilities were also simultaneously established there. It was clear that while rocket observations could give specific information, continuous ground-based observations were very much necessary. The work that was started then has resulted in an excellent Space Physics Laboratory as part of the Vikram Sarabhai Space Centre.

In the national programme of talks series – 'Exploration in space', Sarabhai had talked about 'Sources of man's knowledge' on 12 August 1966 and he had said, 'There is an active debate in the world today on the value of space exploration in the context of the many immediate problems of human existence. Why does man wish to go to the moon when he has sophisticated instruments including television cameras, which can be sent in spacecraft under command and can communicate information from millions of miles. It is because nothing that has been developed with the most sophisticated technology so far approaches anywhere near the capability of man who possesses the facility of receiving information simultaneously from a number of channels and to synthesise it to create an image of the environment as a whole. Let us note here that our present day computers and systems for analysis operate only serially, i.e. taking one bit of information after another. It is unlikely that man will restrain his urge to see, to feel and to listen, himself if he can possibly accomplish all these. I do not expect that the debate on the merit or otherwise of putting man into space would ever be settled. If we are to rely on historical experience, man will surely push ahead with adventures of this type backed by motives which will inevitably be mixed.'

We must also remember that Sarabhai had said the following at the United Nations Conference on 'Peaceful uses of outer space' in Vienna, August 1968, 'A third important scientific objective has been to view the universe, the galaxy and the solar system through a wide window. The blanket of the atmosphere under which we live eliminates all but a tiny fraction of the broad spectrum of electro-magnetic radiations and particles which impinge on the earth carrying with them information about the sources where they originated and the properties of the media through which they have traversed. Depending merely on observations made with earth bound instruments to picture the universe, and understand cosmology

*e-mail: kalepramod1941@gmail.com

is like the attempt of a blindfolded man to describe an elephant by touching the trunk and the legs of the animal.'

He not only discussed with us the future programmes for space research, space applications and space technology, but also simultaneously discussed about science and mathematics education for young students as well as the community. Based on his ideas, the first Community Science Centre was established in our country. This was the first place that I had seen where students at any age could carry out science experiments and learn through experimentation. He knew the value of encouraging the ability of asking questions and finding answers. He had always encouraged students in developing their own ideas.

His style of working, his way of communicating and the breadth of his thinking have been aptly summed up by the writer of his obituary that appeared in *Nature*, 1972, **236**; 'In his style of working, "hurry" had a charming leisurely quality about it, even though every minute of his time was claimed by one or the other of his self-created projects. Within the space of an hour he could go from cosmic-ray modulation, to rocket propellants at Thumba, to power reactors at Kalpakam, to the television satellite experiment, to community science education, to antenna systems for communication links, to infrared devices for surveillance of crop disease, to the administrative details of setting up a new public corporation and back perhaps to cosmic rays. And each of these transitions was deep, involving decision making, unwasteful of words, and outwardly done with a naturalness and charm which always overwhelmed his friends. Vikram Sarabhai will be missed on the Indian scene, as a scientist, as a scientific visionary, as a doer of things and as a remarkable human being.'

In 1963, the first geosynchronous satellite that was launched by NASA had generated large interest. The utilization of such a satellite for television broadcasting and telecommunications was envisaged by Arthur Clark as early as 1945. In our country, development of a national network for television was considered to be on a low priority due to the absence of a wideband microwave line of sight telecommunication network.

Internationally, discussions had already started regarding the formation of the International Telecommunication Satellite Organization – INTELSAT. India was one of the early signatories for the same. INCOSPAR had taken the required steps for the establishment of the Experimental Satellite Communication Earth Station at Ahmedabad. The station became operational in 1967 and is still fully operational. At that station, educational courses in space communications were started for people from our country as well as other developing countries. The facility continues to be used as a training facility for the United Nations sponsored programme CSSTEAP.

After the launch of INTELSAT III satellite, discussions had started on the subject of definitive arrangements for INTELSAT. Vikram Sarabhai had thought about developing communication satellites not just only for India but also for other developing nations. He was looking for an international agency acceptable to all the nations. Since a large number of countries were members of INTELSAT, Sarabhai had thought through the possibility of including the activity of getting domestic communication satellites developed by INTELSAT, in the definitive arrangements. As I was already deputed to work at Goddard Space Flight Centre, NASA, USA, I was asked by Sarabhai to assist our delegation in making certain that this was included in the definitive arrangements. I had asked for the supporting papers and after reading those, I realized how far sighted Sarabhai was. In his address at the United Nations conference on 'Peaceful uses of outer space' in Vienna, August 1968, he had said, 'One of the hardest questions to be faced in adopting a synchronous satellite for national needs, arises from the fact that many interested countries would not expect in the near future to have an independent capability for placing such a satellite in orbit. The nations advanced in space research have done much to extend the benefits of the peaceful uses of outer space to all countries, and one can reasonably count on their continued support. But the political implications of a national system dependent on foreign agencies for launching a satellite are complex. They are not negative in the present day world only in the context of the coming together of the national interest of the launcher and the user nations. As long as there is no effective mutuality or interdependence between the two, many nations left only with the ground segment would probably feel the need for some measure of redundant capability under complete national jurisdiction. There is great scope today to explore this structure of possible international systems which could provide credibility in increasing measure that the space segment could be relied upon even in the context of political and ideological differences amongst nations. Perhaps collaborative participation of nations in the construction and operation of a launching system for the peaceful uses of outer space would be realised in the long run.' I was able to use these thoughts during discussions and then after a long discussion we were able to get Sarabhai's idea incorporated in the definitive arrangements.

Sarabhai was convinced that television systems in our country could be developed by using space communications. Sarabhai always took a holistic view of any system that he studied and wanted to be developed and deployed in our country. He was convinced that education and instruction was the key to social and economic development. He was convinced that imparting education and instruction through use of television in our country was possible. In order to realize such a system, experimentation was necessary and for that purpose the Satellite Instructional Television Experiment was planned to be conducted using the NASA Applications Technology Satellite – *ATS F*. At that time, we had only one television station functioning in our country at New Delhi. To get the necessary experience, a programme named 'Krishi Darshan' was established. This involved development of the necessary 'software' or television programmes based on the information available with the Indian Agricultural Research Institute (IARI). These programmes were

transmitted using the New Delhi television station. In about 80 villages around Delhi, in the TV coverage area of the Delhi TV station, television sets were deployed by ISRO/DAE.

It is very important to remember that these television sets were regularly maintained by ISRO/DAE. Many people used to ask us about 'Why the Department of Atomic Energy was getting involved in deploying and maintaining TV sets around Delhi?' Sarabhai was convinced that this programme for farmers was the starting point for bringing television as a tool for development at the national level using space communications. In Sarabhai's view, the television programmes were to be utilized for education and instruction of the masses and at that time 80% of our population was residing in villages. To reach them, community reception sets were required to be established in each of 56,000 villages in our country.

In the headquarters of DAE, he had established the Program Analysis Group. This was a group that was responsible for bringing out interdisciplinary ideas about new projects and programmes. I was fortunate to be able to participate in this group. We had discussed many new ideas about the large system level projects. One of his important ideas was the development of 'Agro Industrial Complex' dealing with nuclear power production and linkages with agriculture and industry. It is unfortunate that this idea did not frutify.

We had concluded two system studies in 1969 on our national satellite for television and telecommunications and we were getting ready for the third definitive study to be jointly conducted with MIT, USA. The Memorandum of Understanding between the Department of Atomic Energy, Govt of India and NASA, USA, for conduct of the Satellite Instructional Television Experiment was signed in September 1969.

In his opening remarks at the National Conference on electronics on 24 March 1970, Sarabhai had said, 'We shall talk later in this Conference of the project proposed by the Indian Space Research Organisation of the Department of Atomic Energy for a national satellite for communication purposes. This is one major task which can provide, as the Apollo Project to the Moon did for the United States, a means for rallying engineers in a number of different directions to leap-frog from our state of technological and economic backwardness. It not only gives a most valuable input for national development through a powerful communication system reaching the remotest village or isolated community, but introduces us to the latest technology in space and electronics, offering employment to tens of thousands of engineers.'

These remarks by Sarabhai enlarged and transformed our own ideas regarding the task ahead. We were really motivated to realize the *INSAT* satellite system as an operational space communication system. Many of us had worked day and night to provide the material for Vikram Sarabhai for his paper 'INSAT-A National Satellite for Television and Telecommunications', which he had referred to in his opening remarks, however we had not seen the final paper. At that time; we were considering television broadcasting using *INSAT* satellite for community reception as a social service not generating any revenue but the telecommunication was expected to be revenue earner. Thus we had to project realistic numbers. We were surprised to see that he had included our names as authors when the paper was presented by him at the National Conference on Electronics held in March 1970 at the Tata Institute of Fundamental Research, Mumbai.

During 1968 and 1969, the earth oriented applications of space technology were defined properly. By that time the meteorological earth observations and space communications were already being operationally utilized. Monitoring the earth resources using imaging from space was the new discipline that was emerging. Use of satellites for imaging for reconnaissance and surveillance by USA and USSR was already known. Images of the land and ocean brought back by the astronauts were generating interest in identifying land use, water resources and agriculture. NASA of USA was in the process of building the first Earth Resources Technology Satellite – *ERTS 1* for civilian use.

Sarabhai had clearly understood the implications of the emerging remote sensing technology and had constituted a team of scientists, tasked to familiarize themselves with the new technology. Pisharoty had retired as Director of Indian Institute of Tropical Meteorology and joined PRL. Pisharoty, Dakshinamurthy from IARI, Krishnamurthy from Atomic Minerals Division and I were asked to visit various places in USA where work was on going in the field of remote sensing and study remote sensing as a technology and its applications. Sarabhai was not looking at the technology alone, but he was also looking for the utilization of the data, information and knowledge by all government agencies. From the very beginning of the work concerning remote sensing, he had thought through the utilization of the information. We were in the middle of discussions regarding establishing a ground station in India for receiving the data from *ERTS 1*, when Sarabhai had passed away.

The goals and outlines of our space programme were defined very clearly by Sarabhai in the 'Decade Profile of Space and Atomic Energy' issued in the period 1969/1970. It was clearly indicated in that profile, '*SLV-3* would be followed in the period 1975–79 by satellite launch vehicles using more powerful motors and it is the objective of the Space Science and Technology Centre to develop by the end of the 1970s a launch vehicle capable of putting a 1200 kg satellite into synchronous orbit at 40,000 km. This is the type of capability which is needed to fully exploit, on our own, the vast potential arising from the practical applications of space science and technology.' In these three short sentences, the tasks for the next ten years were described. In the decade profile he had also mentioned about the value of placing an imaging system in a geosynchronous satellite. While we knew that the primary goal for the *INSAT* satellite was provision of

communication capability for long distance telecommunication and television broadcasting, we had included the meteorological earth observation imaging system. This combination made the *INSAT* satellite a true 'multipurpose' satellite.

We did not achieve these goals as per the timeline projected by Sarabhai. There were international restrictions and 'embargos'. We have been able to overcome those difficulties in a self-reliant manner. We were delayed, but we did achieve the goals as set out then. Today we have a vibrant space program. We have assured 'access' to space. We have the ability to build our own satellites, our own launch vehicles and provide operational space systems and space services for our country. The necessary scientific disciplines and technological solutions are developed in our country. Sarabhai's vision was adopted and expanded by Satish Dhawan. The programmes started by Sarabhai were continued and grown by him. Under the leadership of A. P. J. Abdul Kalam and Satish Dhawan our launch vehicle programme was firmly established.

Kamla Chowdhry had written about him as follows: 'He created intellectual networks of natural and social scientists, of engineers, and architects and builders, of planners and management specialists and generated new ideas for innovative tasks in these interactive clusters. Wherever he went he created these overlapping clusters so that members of such clusters became "carriers" of new ideas and were able to perform leadership roles in their own professions.' She had further described him as, 'People can become bigger and stronger when they are wholly and totally accepted, and Vikram could make people feel bigger and stronger and wiser for he transferred to others a trust from his own trustworthiness.'

These words by Kamla Chowdhry clearly define how Sarabhai motivated people working with him by trusting their abilities. In a speech broadcast by the All India Radio in August 1965 on the topic, 'Leadership in Science', Sarabhai had expressed his thoughts about leadership as, 'Through experience we know that conditions of work in India within our own specialized scientific fields rarely match the facilities available in several other countries. Some of us get frustrated striving against heavy odds. Others leave the country. But those who can apply their insights to the problems of the community and of the nation discover an exciting area of activity where effort is rewarding even while the results come slowly. What should we do to provide opportunity for such leadership? I do not expect those attitudes which segregate scientists and intellectuals from the real world to change quickly. I do not believe that in the near future we are likely to provide to scientists and educationists job opportunities and service conditions which are on par with those enjoyed by administrators. But I have a dream; a fantasy maybe; that we can provide encouragement to those who will accept responsibilities for real tasks; big and small; even while they continue to do their own work.'

When we say that Sarabhai was a visionary 'institution builder' it does not mean that he built very large or grand institutional buildings. Apart from the Physical Research Laboratory, he was responsible for establishing the Ahmedabad Textile Industries Research Association, The Indian Institute of Management, Ahmedabad, The Indian Space Research Organization, The Vikram Ambalal Sarabhai Community Science Centre, The Ahmedabad Management Association, Darpana Academy and many others. He was heading his industries till he was appointed Chairman, Atomic Energy Commission. He was responsible for introducing modern management methods in his industries. Sarabhai always insisted that 'institutions' should be built around 'persons'.

He made certain that people working with him should grow. He relied on people to take up responsibilities and deliver the results. He had always delegated the authority commensurate with responsibility. He trusted the people working with him and all the people responded to that. This enabled people to grow and this in turn enabled the institutions to grow and thrive.

In 1962/1963 the work for the establishment of the Thumba Equatorial Rocket Launching Station was started under the direction of Vikram Sarabhai by a handful of people. That group of people continued to provide the necessary leadership for the space program. Vikram Sarabhai's vision was not restricted to his ideas about space research or atomic energy. He was a multifaceted person with multiple interests. He was very much interested in performing arts and culture.

Recently, I came across a pdf entitled 'Sarabhai_V_Speeches' published by the Physical Research Laboratory. It is fascinating to read the speeches given by Sarabhai on various occasions in person and on radio. These speeches provide an insight into his concerns about education, management and development. In this birth centenary year of Sarabhai, we remember him as a person, we remember his contributions in the field of National Science Policy, atomic energy, space research, applications of space technology, education, management and many more.

1. *Science Policy and National Development* a compilation of lectures by Dr Vikram Sarabhai; edited by Kamla Chowdhry, Macmilan, 1974.
2. *Vikram Sarabhai a Life* by Amrita Shah, Penguin, UK, 2007.
3. *Dr Vikram Sarabhai speaks Quotes (c) Dr Vikram Sarabhai Archives*, Nehru Foundation for Development, Ahmedabad edited by Padmanabh Joshi, 2008.
4. https://shodhganga.inflibnet.ac.in/bitstream/10603/46629/9/09_chapter%204.pdf
5. https://www.prl.res.in/~library/sarabhai_v_speeches.pdf
6. https://www.ias.ac.in/article/fulltext/reso/006/12/0010-0018

doi: 10.18520/cs/v118/i8/1184-1187

Vikram Sarabhai: his vision of India as a space power and its fulfilment

R. Aravamudan*

K5/3, 10th Cross, RMV Extension, Sadashivanagar, Bengaluru 560 080, India

Born a hundred years ago, Vikram Sarabhai was a man of many dimensions. He was a real visionary, an outstanding scientist, a great institution builder and a true patriot, who wanted to bring about the rapid development of India by making use of the most modern technological tools of the day.

Vikram was the scion of a family well known for industrial excellence. He was born with an aptitude for scientific enquiry, which he successfully coupled with his innate talent for enterprise and innovation. Many were the institutions which he envisioned and brought to successful realization. However, I would name making India a space power, as his first love. He was convinced that India can 'leap frog' over decades of scientific and industrial backwardness by using the tools of the latest advances in space science and technology, particularly in areas like communication, education, health, planning, disaster management and optimal resource utilization by remote sensing techniques. With his extensive contacts in the world scientific community and policy makers, he was able to convey and convince the decision makers of the urgency of taking active steps to achieve this and invest adequate resources for this purpose.

In a speech made by him at the Thumba Equatorial Rocket Launching Station in February 1968 Vikram Sarabhai said:

> 'There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in the explorations of the moon or the planets or manned space flight. But we are convinced that if we are to play a meaningful role nationally, and in the comity of nations, we must be second to none in the application of advanced technologies to the real problems of man and society, which we find in our country. And we should note that the application of sophisticated technologies and methods of analysis to our problems is not to be confused with embarking on grandiose schemes, whose primary impact is for show rather than progress measured in hard economic and social terms.'

*e-mail: aravamudan37@gmail.com

If a centenarian Sarabhai were alive today and he surveyed the state of space technology in India, this is what he would see.

From the tiny sounding rockets, which we were launching back then, the country has gone on to develop and produce SLV3, ASLV, PSLV and GSLV, launch vehicles capable of lofting a variety of payloads into different type of orbits. These have gone into Low Earth Orbits (LEO), Geosynchronous orbits, Lunar and Martian orbits.

Numerous spacecraft with varying missions to serve the nation are continuously providing information on resources, climate, geographical images, security-related inputs, agriculture and forestry.

Communication and television services are carried to every nook and corner of the country with our own satellites. They are part of the worldwide internet services and mobile telephony which connect continents seamlessly at virtually negligible cost.

India has risen to rank among the top half a dozen nations with mastery over all aspects of space technology and its applications. The various branches of the government make use of the services provided by ISRO, including the planning commission, the defence services, information and broadcasting services and others.

ISRO, apart from launching its own spacecraft has been regularly launching spacecraft for other countries on a commercial basis with a high degree of reliability.

ISRO has been hailed as a model government run technical organization which has delivered on its promises and has gained a reputation for cost effectiveness, dependability and quality.

Vikram Sarabhai was alive only for the first of the six decades of ISRO's existence, but undoubtedly, he himself would have been surprised to observe the spectacular progress achieved in his favourite initiative. Not only have the objectives set by him been achieved, but also exceeded in a large measure. Highly competent and professional expertise has been created, moulded from the human resources available across the country, mostly from average colleges and institutions. Their output has been as excellent as anywhere else in the world. For example, the PSLV rocket in its various configurations has until December 2019, successfully launched, according to the present Chairman, ISRO, '52.7 tonnes of a variety of satellites into different orbits, out of which 17% have

been for foreign customers'. The reliability of this vehicle rivals the best in the world, having achieved a reliability of more than 96% out of 50 launches!

Certainly, stalwarts like M. G. K. Menon, Satish Dhawan, U. R. Rao, Kasturirangan and others who carried the torch forward, guided the organization through its triumphs and achievements, but it was Sarabhai's bold vision and the initial managerial excellence which set the course ahead and continued to inspire the young scientists to carry on with determination.

In the digital world of today, we talk of 'start-ups' and their success, but the most spectacular story of a start-up which has been resoundingly successful is that of ISRO. I was fortunate to have been among the first, handful of young men to be personally recruited by Sarabhai to form the core team for starting space-related activities in the country. I have seen at first hand, the growth of the organization to the present day, having taken active part in almost all aspects of ISRO's work and have never ceased to be amazed by the successful crossing of milestone after milestone over the decades. I have described the story of this success elsewhere in my book, *ISRO, A Personal History*, Harper Collins, 2017.

The beginnings of space activity in India were rather modest. Although he came from a rich business family, Sarabhai had decided to pursue a career in physics. He was a student of the legendary C. V. Raman. After obtaining a degree from Cambridge he had set up the Physical Research Laboratory (PRL) in Ahmedabad in the late 1950s, already a hub of scientific activity.

Sarabhai was spearheading in the early sixties a project envisioned by a consortium of scientists from across the globe. They wanted to study the magnetic equator using sounding rockets. The magnetic equator is, like its cousin, the geographical equator, an imaginary line around the earth where its magnetic field becomes horizontal. It lies very close to the geographic equator. Scientists from all over the world wanted to launch rocket payloads from this region because they wanted to study a rather unique phenomenon: a strong belt of charged particles called the 'electrojet' which runs above the magnetic equator and has a great impact on worldwide radio communication. The study of this phenomenon could only be carried out *in situ* by instruments carried by sounding rockets.

Sites on the Kerala tip were found the best suited for locating such a rocket launching site. After inspecting several sites, Sarabhai and his advisors zeroed in on Thumba, a small fishing beach close to Thiruvananthapuram, the capital of Kerala. Thus, was born the nucleus of space research in India.

The initial activities of Thumba were under the umbrella of the Department of Atomic Energy and Homi Bhabha was an active participant in the enterprise. A core group of half a dozen young engineers and scientists were sent to NASA, USA for learning the ropes even before site acquisition was completed. A. P. J. Abdul Kalam, former President of India and I were amongst this first batch.

The rocket range had an area of around 600 acres and a sea front of about 2 km. Launch pads were built facing the Arabian Sea. Fishermen continued to ply their nets on the beach, but reluctantly cleared the area during launchings. Facilities for the assembly of rockets, launchpads, block houses, a control centre, telemetry and tracking stations were set up, initially with a lot of help from Space Agencies from countries like USA, France and the then USSR. The range, formally called Thumba Equatorial Rocket Launching Station (TERLS), was dedicated to the United Nations for cooperative programmes with any member country. A variety of rockets and payloads were launched from TERLS by Indian and foreign scientists gathering valuable data.

Meanwhile, Sarabhai initiated programmes to produce all elements of sounding rockets and payloads indigenously so that Indian scientists need not depend on foreign agencies for resources. A series of sounding rockets called the Rohini Sounding Rockets were produced to reach different altitudes up to 500 to 600 km.

While the focus was on sounding rocket activity, Sarabhai had envisioned the activation of long-term programmes for India's entry into satellite launching and its applications. The early 1960s saw the recruitment of the core group of engineers to commence development work on all subsystems of launch vehicles like propellants, materials, avionics, aerodynamics, propulsion, computation, miniaturization, fabrication techniques, systems reliability, ground support systems like telemetry, tracking, telecommand and so on. Pending commissioning of permanent laboratories and other facilities, available buildings like an old church with the bishop's house, an abandoned school building and abandoned dwellings of fishermen were used. The buildings of the fishing village had all been vacated as they were in the range of safety zones. Suitable new structures had been built on different beaches as a compensatory measure by the authorities. The newly formed groups started work on the design, development and testing of the various elements needed for an indigenous launch vehicle capability.

Satellite launching from Indian soil needed a much larger range, preferably east facing, to take advantage of the additional energy gained because of the earth's rotation. Sarabhai was able to convince the Andhra Pradesh government to make available a large area in the eastern coast of India, between Chennai city and Nellore. This island named Sriharikota was surrounded by the Pulicat Lake, the Bay of Bengal and the Buckingham Canal. It had an area of about 44,000 acres with a 50 km coastline. It was basically a scrub jungle with plantations of eucalyptus and casuarina trees developed by the government for fuel. Wild animals like jackals, wild boars and cattle roamed freely. Small groups of hunter-gatherer tribes

known as the Yenadis lived in dispersed villages over the island.

I still remember the very first visit made by Sarabhai and some of us in the original team to the proposed launch site, sometime in May 1969. The team numbering about 30 to 40 persons including some officials of the local government had to travel some 25 km in sturdy jeeps across dry lake beds and sandy surfaces to reach the coastal stretch of the Bay of Bengal where the launch facilities were proposed to be located. Sarabhai, in his late 40s was energetically leading the team across the beach looking for suitable locations to build launch pads and control buildings. As he covered miles of beach by foot, showing no signs of fatigue, we could see the gleam in his eyes as if he could already visualize the busy world class space port this would become.

While the launch vehicle development groups were busy with the design of subsystems at Thiruvananthapuram, the sounding rocket launches continued from there. Meanwhile, the preparations for the satellite launching facilities at Sriharikota were initiated. Key personnel were identified for the design of a modest solid fuel-based Satellite Launch Vehicle (SLV) to put a small (40 kg) satellite into a 600 km circular orbit around the earth. Project teams were designated for each of the important subsystems and the teams set to work in earnest.

Developments of space applications were also afoot in Ahmedabad. An experimental station for receiving data from geosynchronous spacecraft launched by other countries was set up to gain experience. Use of such satellites for centralized broadcast of television, intercontinental telephone communication, etc. was brought under a collaborative programme so as to sensitize the government and other user agencies of the efficacy of such technology for the rapid development of the country.

Towards the end of the 1960s, Sarabhai who had taken over the role of Chairmanship of the Department of Atomic Energy in addition to Space, proposed the plans for the development profile in the field of space research for the decade 1970 to 1980. Its conclusions in brief were as follows.

The programme envisages the establishment of the following for the decade 1970–80:

(1) Augmentation of the facilities for R&D at the Space Science and Technology Centre to be able to build scientific and communication satellites and to environmentally test them.
(2) Facilities at the Space Science and Technology Centre for the development of inertial guidance systems and onboard miniaturized computers.
(3) Development at (SSTC, TIFR and ECIL) and construction of high-performance missile tracking radars and PCM communication systems for installation in the range and downrange stations.
(4) Construction of a plant for the manufacture of large solid propellant blocks and facilities for testing these blocks on the ground under simulated high-altitude conditions.
(5) Completion of a rocket fabrication facility for the manufacture of large sized rocket casings and hardware for rocket motors including the development of special materials.
(6) Developing by 1974–75 a launcher of four stages, burning solid propellant, capable of putting into orbit a satellite of about 30 kg payload. This would be followed by development of more advanced rocket systems capable of putting 1200 kg of payloads into synchronous orbits.
(7) Fabrication of communication satellites by 1975 capable of providing high quality point to point telecommunication service between metropolitan areas and direct broadcast of television.
(8) Development of sensors and techniques for remote sensing.

Sarabhai also stated that the constraints of the development of space technology are related to the development of men and teams familiar with the new sophisticated technology. With a growth rate of 50% to 100% per year, we would still need about three years before reaching the minimum critical size for successfully implementing large scale projects of space technology.

Almost 50 years after these proposals were made and approved by the government, if I look back, I see that everyone of the tasks proposed has been completed and we have gone much beyond. Inspired leaders who followed Sarabhai after his premature death in December 1971 carried out elements of his vision with dedication and with the total involvement of the huge pool of manpower created over the decades. Some initial failures did not deter the organization from learning from them and going forward to successfully achieve the goals he set forth. More than the technology that has been generated, Sarabhai and his successors have created a vibrant organization, unfettered by red tape and hierarchical structures, able to make bold commitments and strive hard to deliver on them. No wonder that ISRO has often been cited as a model organization under government control which has succeeded.

An old saying goes, ‘those whom the gods love die young’. This was true in the case of Vikram Sarabhai. He passed away at the age of 52 in Thiruvananthapuram, his favourite place where he lovingly created an outstanding organization. I still remember the fateful day when he breathed his last at the lovely Halcyon Castle guest house in Kovalam.

It was the 29 December 1971, Sarabhai had visited Thumba and the Veli Hills laboratories for his monthly reviews of progress and proceeded to his place of stay at Kovalam where, as usual, the discussions and meetings

would continue long into the night. This time the plans for the development of SLV launch vehicle and its various subsystems as well as the details of the constructions at Sriharikota were the leading subject of discussions. I remember the scene at the makeshift conference hall at the Halcyon Castle where we jostled with each other to present our plans. My project, which was the establishment of the radar tracking and telemetry systems at SHAR, was presented to him. It was almost midnight and when I left for home, Sarabhai was still discussing with some of my colleagues. He was a very light sleeper and irrespective of the time he went to sleep, would rise at the crack of dawn and when at Kovalam, would have an early morning swim in the sea.

At around 6 a.m. in the morning as I was just about to get out of bed, the phone rang. It was the local PTI correspondent whom I knew. He was frantically asking me whether it was true that Sarabhai had suddenly passed away at Kovalam the previous night! I thought it was some cruel joke since I was personally with him well past midnight and he seemed perfectly fine. Soon I got another call from my PA confirming the sad news that Sarabhai had suffered a massive brain haemorrhage and was no more. I rushed to Kovalam which was about 12 km from where I stayed, and as I reached the gates of the hotel, I saw groups of my colleagues standing around in a daze. I hesitantly walked into the bed room and saw the much-loved kurta and pyjama clad figure of Sarabhai lying on the bed. He seemed to be asleep. He wore an expression of peace – almost as if he knew that he had completed his share of the tasks satisfactorily and handed them over to others to carry on.

And 'carry on', we did over the next almost half a century! I personally have grown along with ISRO since those days when it was a mere idea in a visionary's mind, through its phenomenal transformation into the veritable giant it is today. I have seen successive leaders steering it through the exciting phases almost seamlessly. Technical expertise and leadership have sprung from its workforce, as if by magic, to carry the torch forward. Failures have been converted to rich learning experiences followed by eventual triumphs. I have sat in control rooms with accelerating heart beats when bold new missions like *Chandrayan* and *Mangalyan* had taken off and shared the exhilaration when the missions succeeded. I have watched the politicians of the day proudly acclaiming ISRO's feats nationally and internationally, almost as if those were their personal achievement! I have gleefully noted the reluctant acceptance of the achievements of ISRO by advanced countries who were unwilling to share their knowhow with us.

And we are nowhere near the end of our story. We have lofted heavy payloads into distant orbits with our own rockets, carrying the state-of-the-art spacecraft. Much beyond what Sarabhai envisaged, we have gone beyond earth orbit to explore our neighbouring planets. We have plans to explore the Sun and have embarked on plans to carry Indian astronauts aboard manned spacecraft launched with our rockets from our own soil.

This will be a fitting tribute to the man who started it all!

doi: 10.18520/cs/v118/i8/1199-1202

Vikram A Sarabhai Community Science Centre

Dilip Surkar*

Vikram A Sarabhai Community Science Centre, Ahmedabad 380 009, India

Genesis

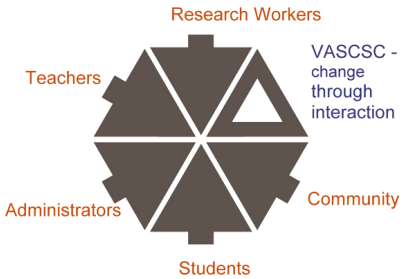
Dr Sarabhai was concerned about the quality of science education in India and felt that it did not adequately provide familiarization with the scientific method or the acquisition of knowledge through experimentation. To address these challenges, he initiated the 'Group for Improvement of Science Education (GISE)' in Physical Research Laboratory, Ahmedabad. Activities of GISE took shape of the 'Community Science Centre' in 1966 as a facility where those concerned about the quality of science education could come together to experiment and try out new ideas and techniques for teaching science. After Sarabhai's death in 1971, the Centre was renamed as the 'Vikram A Sarabhai Community Science Centre' in his honour.

Vision

VASCSC aims to nurture young minds and direct them towards scientific thinking with methods and techniques which make the process of enquiry and learning a fun-filled, enjoyable and lasting experience. It works to stimulate interest, encourage and expose the principles of science and the scientific method to students, develop the ability to solve problems and make clear the social implication of science and technology; thereby improving the quality of science education.

Symbol

VASCSC's symbol illustrates the mandate of spreading the joy of science to different groups. The five arrowheads therein represent groups comprising teachers, students, researchers, administrators and the community, while VASCSC is represented by Delta – the mathematical symbol of change as it works to bring about change by providing a common platform to these groups.



Facilities

The Centre is open for all and has facilities like well-equipped laboratories in Biology, Chemistry, Computers, Electronics, Mathematics, Physics and Model Rocketry; Innovation Hub; Science Playground; Library; Workshop and Science Shop.

Some firsts…

VASCSC has pioneered concepts such as the first interactive exhibition space, open laboratories, mathematics laboratory, science playground, actively use computers in science education and develop interactive (animated) educational programmes based on Indian school science curriculum.

Activities

VASCSC's activities focus on experiential learning to create interest and develop understanding of science and mathematics among children. Consequently, they are motivated to pursue higher studies or research in pure science. Activities have been initiated to create spirit of innovation and making them future-ready through developing their skills in emerging technologies, critical thinking, design thinking and problem solving.

Capacity building of science educators is a major focus area. Teachers training workshops on 'Hands-on approaches in science and mathematics education' are conducted for professional development of teachers and to expose them to hands-on methodology for effective teaching-learning process.

Whether helping to instill scientific temperament or encouraging people to explore and innovate, VASCSC has been playing a significant role in developing a rational outlook by improving the basic understanding of science.

*e-mail: dilipsurkar@vascsc.org

Some major activities of the Centre include the popular Science Express (project of the Dept of Science and Technology, Govt of India). This exhibition train made 9 rounds across the country from 2007 to 2017, during which 18.2 million visitors were received. Also, VASCSC is furthering its reach to remote areas in Gujarat through the Mobile Science Lab which takes the lab experience to students right in their school. It has also helped develop programmes for Satellite Institutional Television Experiment (SITE) in 1971. The Teaching Learning Material developed by VASCSC is used by schools across India.

For its innovative work, the Centre has received several awards including the 'National Award for Outstanding Efforts in Science and Technology Communication' from the Dept of Science and Technology, Govt of India (2008) and the 'Times of India Social Impact Award' for Education (2011).

Guidance

Dr Sarabhai not only provided leadership in Centre's development, but also took an active interest in implementation of various programmes, setting up of its facilities including the design and construction of the building. He visited the Centre regularly and interacted with participants and team.

Many distinguished scientists and personalities have been directly associated with the Centre in different contexts. These include Prof. C. V. Raman, Dr A. P. J. Abdul Kalam, Prof. M. G. K. Menon, Prof. M. S. Swaminathan, Prof. P. C. Vaidya, Dr Yash Pal, Shri Krishna Kripalani, Prof. A. R. Rao, Dr Madhav Gadgil, Dr. P. R. Pisharoty, Dr K. S. Karnik, Dr K. R. Ramanathan, Smt Vijaya Mulay, Shri V. G. Kulkarni, and others. Prof. K. Kasturirangan currently chairs the VASCSC Board of Governors.

doi: 10.18520/cs/v118/i8/1213-1214

The man with big ears, and big dreams that took India to the moon*

Amrita Shah**
1024, New Haven, Dasanapura Hobli, Off Tumkur Road, Near Golden Palms Hotel, Bengaluru 562 123

On 12 August 1919, a baby boy was born in the home of Ahmedabad's leading textile mill-owner; his siblings looked at him and declared he had big ears, 'just like Gandhiji', which they wanted to fold like betel leaves. The baby was Vikram Sarabhai. Monday marks the birth centenary of this remarkable figure, even as Chandrayaan-2, steadily surging towards the moon shines a light on the Indian space programme which he founded.

Vikram's was a charmed life. Born in the lap of luxury, he went to an esoteric experimental school set up by his parents equipped with a workshop to nurture his scientific inclinations. At 18, he went to Cambridge with a recommendation from family friend Rabindranath Tagore. When World War Two intervened, he moved to the Indian Institute of Science in Bengaluru to continue his research under Nobel Laureate C. V. Raman. Here he was thrown into the company of a brilliant young scientist Homi Bhabha similarly stranded by the War and met classical dancer Mrinalini Swaminathan with whom he fell in love. 'Science is so similar to art...both spiritually aware of the indivisible wholeness of the cosmos... Vikram as a scientist and I as a dancer shared a "togetherness" that was hard to define,' Mrinalini would write.

When American physicist and Nobel Laureate Robert Millikan was in India to acquire data for his world survey of cosmic ray intensity, Vikram helped with his balloon experiments whetting his own interest in exploring cosmic rays and properties of the Upper Atmosphere. A decade and a half later, when scientists would see satellites as a viable tool to study space, Nehru and Bhabha would support the setting up of an Indian National Committee for Space Research with him as chairman.

This charmed life had its dark side. In his childhood, Vikram's aunt Anasuya, who had formed a labour union, brought home stories of the daily struggles of textile mill-workers. The freedom movement came knocking, his mother and sister were jailed which made his younger sister Gita at least, 'desperately miserable'. A few years later Vikram's brother died from a sudden illness. It is likely that these experiences instilled in him a strong social conscience manifested in his determination to use sophisticated technology, particularly the space programme to improve the lives of India's poor. Perhaps they also engendered in him an acute awareness of life's transience which is one way to explain his prolific parallel career as a builder of institutions such as The Indian Institute of Management (IIM-A), the Darpana Academy of Performing Arts, and the National Institute of Design. He also ran successful businesses, was a visiting professor at Massachusetts Institute of Technology and piloted the Atomic Energy Commission at a crucial stage after Bhabha's death.

But even while he engaged with multiple fields, Vikram remained at heart a scientist. Not just the practise of science or a particular area of research but the business of being a scientist and thinking like one shaped his approach. 'A person who has imbibed the ways of science injects into a situation a new way of looking at it', he said.

A 'new way of looking' and all that went with it – innovation, enterprise and improvisation – were hallmarks of Vikram's modus operandi. The early days of the space programme, for instance, unfolded in the former fishing village of Thumba near Thiruvananthapuram, a stretch of wilderness with no infrastructure, cycles and rusty buses and an office in an old church building without even a roof to keep pigeons out. In these primitive conditions and with an absence of indigenous precedents, a team of young Indian scientists created bits of technology, propellants, nose cones and payloads from scratch.

Vikram's methods were tough, he could create competition on the one hand (one team called its propellant 'Mrinal' after his wife to curry favour), and encourage staffers to push with the 'thin edge of the wedge' on the other. 'We were in the air all the time, thinking big', says Vasant Gowarikar, who was working on explosives. 'The insistence on indigenization all the time was a great motivation.' In November 1963, the first blast-off took place and Vikram sent home a telegram: 'Gee whiz wonderful rocket shot'.

Vikram died unexpectedly in his sleep on 30 December 1971 at the age of 52. By this time, the space programme had swelled to a staff of thousands and he had worked out a blueprint for its future course both technologically and with applications in agriculture, forestry, oceanography, geology and cartography. In a brief life span, Vikram had contributed enormously to the shaping of modern India and he had done it with verve. Hobnobbing with the world's most distinguished one day, whistling and flip-flopping in his chappals up the steps of his laboratory the next and always carrying his own briefcase to avoid getting into 'feudal habits'.

He was also, to use a word rarely applied to Indian achievers, a 'dreamer'. His daughter Mallika recalls how he was often lost in a reverie chin on his hand, like 'Rodin's Thinker' ruminating, one presumes, on ideas like using a borrowed American satellite to transmit educational content to 2400 villages in India's backward regions or a spectacular scheme of building agricultural complexes serviced by atomic power and desalinated sea water.

Fifty years after his death those dreams are taking us to the moon.

*Source: 'The Times of India'. **Twitter: @amritareach

doi: 10.18520/cs/v118/i8/1190

Photo Gallery

Vikram Sarabhai at sea shore

With parents and sister Geeta

Farewell by the family to Vikram and his elder brother Gautam who went to Cambridge, UK, for further study in 1937

With Prof. C. V. Raman at PRL, Ahmedabad, in 1970

With Dr Homi Bhabha at TERLS, Thubma

With Prof. C. V. Raman at the Indian Institute of Science, Bangalore

Marriage with Mrinalini Swaminadhan in 1942

With family members

With PM Nehru at the inauguration of ATIRA and PRL at Ahmedabad in 1954

With Smt Indira Gandhi at the Pugwash Conference, Udaipur, February 1964

Attending a UN Conference on Atomic Energy

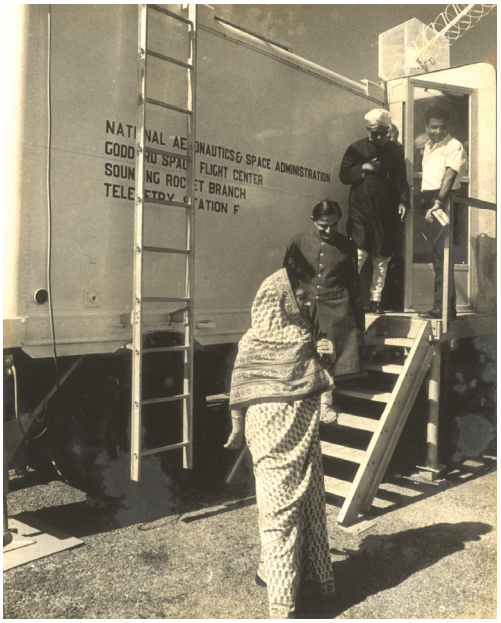
Vikram and Mrinalini with Shri Rajaji

PM at TERLS

Inauguration of the Tarapore Nuclear Power Reactor

At TERLS

At TERLS



PM's visit to TERLS

Prime Minister Smt Indira Gandhi dedicated TERLS to the United Nations on 2 February 1968

At TERLS

Vikram Sarabhai died on 30 December 1971 at Kovalam, Trivandrum, the Governor of Kerala visited the hotel