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Aakaasha Raaya

Roddam Narasimha in Conversation

(http://bhavana.org.in/roddam-narasimha/)

B.G. Gujjarappa/Bulletin of Sciences

Roddam Narasimha, popularly known as RN, is a multifaceted scientist whose academic career has almost entirely been in India, particularly in Bangalore. He represents a rare combination of a person completely at ease with both the Eastern and Western systems of doing science. He has been at the helm of several indigenous projects instrumental in placing India as an able scientific power. Presently, he is DST Year-of-Science Professor at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore.

In January 2017, he talked to the contributing editors of *Bhāvanā* at length at his home in Bangalore. The conversation, in edited form, appears here as the first of a two-part interview.

India During RN's Childhood

Your father was a writer, one of the first to write about science in Kannada. He was also a scholar in Sanskrit. Was he an inspiration for you to take up science?

RN: Well, it really started at home. My father was a physicist and I think he was the first in our family to go through the British-introduced system, the first one to get a university degree and so on.

Did it all happen here in Bangalore?

RN: It happened here in Bangalore. For my paternal grandfather and his generation, Roddam was the family's home. Roddam was at that time part of the Madras Presidency (now in Andhra Pradesh), just on the other side of the border from the kingdom of Mysore. However, people moved easily across the border, as the region from Pavagada on the Mysore side to perhaps Penukonda on the other side was largely bilingual. It was really close to the heart of Vijayanagara country.

For my grandmother, India was divided into two kinds of administration. One was what she called *Rajaseeme*: the Maharaja's land. That's where all the fortunate people lived. I really mean it—Mysore had a great reputation at the time. And then there were some people who lived in what she called *Kumpṇiseeme*. She did not call it British or anything, and it was still identified with the [East India] Company. So she used to talk about what happens in *Kumpṇiseeme*, and what happens in *Rajaseeme*. I think she had a slight sympathy for the people who were in *Kumpṇiseeme*. [Laughs]

The less fortunate ones!

RN: That's right. At that time that was a fairly widespread view, which may now seem funny, but it was true. For example, I remember my uncle who worked for the Tatas in Allahabad in Uttar Pradesh. He would make a trip here once a year, and the accounts he gave only confirmed to everybody here that this was about the best place in which to live. Of course, I wouldn't say the same thing about today's Karnataka as my parents and grandparents said about Mysore. And there was a certain pride at that time…

… The first electrified state and…

RN: Yes. Many things. And that was fed by what other people said. Everybody who came to Mysore state made statements like "there is no other place like this".

There is an interesting story about the trial of Bal Gangadhar Tilak for sedition. The advocate who defended him was Muhammad Ali Jinnah, who was at that time still part of the Congress party. The British prosecutor's case was that Tilak was spreading sedition by talking about swaraj, and argued that the world knows that Indians are not capable of ruling themselves, did not have the required administrative skills, and that there

would be chaos in this country if it weren't for the British government. Jinnah's main argument was that that was not true, because if one crossed the border to the kingdom of Mysore, one would see that it's better governed than Bombay Presidency was. [Laughs] [1]

RN's parents, R.L. Narasimhaiya and R.N. Leela Devi. COURTESY Roddam Narasimha

So it was at that level.

RN: Yes, but I'm afraid it's no longer true. It's changed a great deal.

Anyway, coming back to my father—he studied for his Bachelor's degree at Central College, which was part of *Rajaseeme*, and eventually settled in Bangalore, and married here. At that time if you wanted anything more than a Bachelor's degree you had to go out, and he went to Allahabad, chiefly because Meghnad Saha was there at that time. He got his Master's degree there, did some work, and came back. I think first he was teaching in a high school in Tiptur. I've got an old photograph I think, with his colleagues, all wearing the common formal dress of those times. Certainly in Mysore state you wore a tie, but you also wore a peta [like a turban] and you wore panches [dhotis].

In true Mysore style. Did C.V. Raman too adopt that?

RN: C.V. Raman adopted that, but he was not wearing a dhoti. Much of the time he was wearing trousers. Of course, my father also wore trousers, but wearing a tie and coat with a dhoti was not uncommon at all. Anyway, he got a position in Central College, and he spent the rest of his career there. He set up a wireless lab, I think one of the first and perhaps one of a small number in India.

Do you remember when he started it?

RN: It was in the 1930s. He came back [from Allahabad] in 1929. He taught in a high school only for a year or so, and then got this position at Central College. From the early 1930s, he became well-known for his work on wireless technology at Central College. He wrote a few research papers and also ran a lab. He was one of the

first people who not only knew wireless technology as something that can be tinkered with, but also knew the principles and relations of electromagnetic theory that underlie it. He even gave courses on electromagnetic theory.

Maxwell's theory?

RN: Maxwell's theory, exactly, Maxwell's equations. I have his notes on electromagnetic fields. He was following a book by an American named Gaylord Harnwell, and taught the course with vectors. This was not common in British courses on the subject. Vector analysis was not as quickly used in British books as it was in American books.

So in some sense there was a lot of physics at home, including some mathematics. By this time, my father had also started writing in Kannada. The new thing I did was that I studied engineering.

So in some sense there was a lot of physics at home, including some mathematics

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Your father knew Sanskrit too. You mentioned that he was one of first who studied in the British system for education. So how did he learn Sanskrit?

RN: See, from one point of view, we came from a relatively orthodox family. We would do pujas and sandhya vandana at home. Hearing those mantras was part of my life at home. Not that we actually did very much, but we were all familiar with those things. We had Sanskrit books at home too. In school, you had to study two languages, and there was no doubt at all that I would benefit from taking English and Sanskrit. Kannada you learned in any case and so didn't need a separate course. That was the view at the time. When I asked my father about Sanskrit, he thought that the Sanskrit I learned at school was not good enough.

I started my elementary education at a school called Acharya Pathashala [APS]. It started in Gandhi Bazaar. It was run by a very remarkable educational entrepreneur, the late Mr. Ananthachar. The story was that he was actually making a living selling vegetables in Gandhi Bazaar market. He was not satisfied by that, and was very good at collecting money, so he decided to set up a school. The school was right behind the area where he was selling vegetables. It was in one of those old houses with a little area around it. The compound had these little thatched-roof classrooms. But it grew very fast to include middle and high school. In fact, I grew with the school. He then rented another building in Gandhi Bazaar. The school was expanding, and with high demand for admission, he collected money and built a big stone building in what became Narasimha Raja Colony. I stayed in this school till my high school matriculation.

The school was remarkable for the teachers it had. Looking back on it, the teachers were, almost without exception, deeply committed. It is not easy to come across such schools now. In fact, APS itself has not been able to maintain the tradition.

Ananthachar

My teachers were really remarkable in many ways. I attribute it partly to that ferment about independence at the time, and the nationalist sentiment that was common around us in the 1940s. Gandhi was in prison and, in a sense, many of the teachers were patriots and nationalists. Some of them were very good teachers and two or three of them made a big impression on me.

The school was run by a very remarkable educational entrepreneur, the late Mr. Ananthachar

Do you remember their names?

RN: Yes. One of them was S. Venkataramaiah—SVR was how we used to call him—who was a bit of a writer as well. It wasn't uncommon at the time for a teacher to teach more than one subject; he taught us essay writing in English in one year, geography in another, and he occasionally taught some chemistry. So he did a variety of things. He also wrote in Kannada, but not on science, for a very popular humour magazine of the time called *Koravanji*. Though he used a pseudonym, all his students got to know that he was the one writing those articles. He had a remarkable sense of humour, but it was almost impossible to see him smile any time. He would stand there and lecture with a face which never wrinkled into a smile, but would cut jokes. The students would laugh, but *he* would never laugh.

RN with his teacher S. Venkataramaiah COURTESY Roddam Narasimha

The way he taught geography was remarkable. At that time, geography was a boring subject as far as I was concerned, but he made it interesting. He insisted that we should not mug up what was in the book. The text at the time was a fat British book about the geography of the world, by Dudley Stamp, if I remember right. As soon as I saw the book I said "Good God, am I supposed to read the whole lot?" But he was remarkable, because he always had maps whenever he taught about some country. You'd see where the equator was, where the tropics and the mountains and the rivers were, and he wanted us to guess what the climate would be in a country from knowing its latitude. Things of that sort. So he introduced reasoning into geography. That was not the way it was usually taught, where you had to just mug things up.

He was also a big influence on my writing. We had to write an English essay every week. He would announce the topic on Saturday morning, and we had to write it in the next hour. I had a problem at that time. All the other students wrote long essays in other classes, and in the exams. I could never write a long answer. When they asked a question to which I thought the answer was relatively simple, I would just write a short answer. So pretty soon I got a complex. [Laughs] All these guys are writing these long answers, and I thought I would flunk because of my short answers. I didn't know what was wrong with what I was doing. I remember the first time he announced the essay topic, he asked us to describe a street scene that we remembered. So I took him at his word, and described an accident I had seen just a couple of days earlier, where some cyclist fell down and injured himself, fortunately not in a serious way. People had gathered around and helped him.

Well, this essay took no more than two or three pages, and we were writing foolscap, so we were writing two sides of the sheets. But some of the other people had written quite a lot. So I was pretty sure I would get low marks for my essay. When he came to class he always made a review of the answers he got in the previous week, and talked about what was good and bad about the essays. The first thing he did was he picked up my essay, and he complimented me for writing a short piece. So this confirmed there was nothing wrong with me! That had a big effect on me. So I stopped worrying, and he said, "See, he has actually described a very realistic situation, and you people are imagining things and writing things which are not true. You shouldn't do that, it should be based on observation."

SVR was also the man who took the initiative to invite C.V. Raman to our school. And you know, C.V. Raman agreed.

My teachers were really remarkable in many ways

Which year was this? 1945?

RN: 1945–46. In 1947, I went to intermediate college, as it was called at the time. So this was certainly 1945 or 1946.

And this happened in the presently existing stone building? That was the setting?

RN: Same setting. When C.V. Raman arrived, we were all supposed to make some experiments, act out a play and so on, which we did. But of course, the highlight was C.V. Raman's talk. It was the first time I had actually seen him up close, rather than just in a picture. He was, I would say, a brilliant speaker, and both the teachers and students were in the palm of his hands. He had them laughing, and so on. Everybody thoroughly enjoyed it and learned something from what he said. And it was SVR who got him to the Pathashala, and I think it influenced quite a few people at that time.

C.N.R. Rao was also there at the Pathashala…

RN: Yes! In fact, we were classmates. We both went to the same school, we were both at C.V. Raman's lecture at that school. But CNR did not start his elementary school there. He only came after the stone building came up, and then we were there together in high school.

In the same class?

RN: Well, same class but not in the same section, because there was a Kannada medium section and an English medium section. I was in the English section and he was in the Kannada. He always tells me about that. [Laughs] But we were otherwise friends, and knew each other very well.

What did C.V. Raman speak on?

RN: He spoke on one of his favourite things—about why the sky is blue, amongst other things.

SVR took the initiative to invite C.V. Raman to our school

Before C.V. Raman's visit, was the Indian Institute of Science [IISc], and the work that goes on there, something that students of Acharya Pathashala were aware of?

RN: Well, I was aware of it in some vague way because my father used to speak about it. He had some friends there. Of course, they would never call it IISc—it was always the Tata Institute. It was quite well-known, but there were no academic links with our school. Except, of course, my father had academic links, including C.V. Raman to some extent. C.V. Raman used to come to Central College, and there were people who had gone from Central College to the Tata Institute. B.S. Madhava Rao was one example. He was a mathematician, but was part of the physics department at Central College I believe. Homi Bhabha took him to Tata Institute, at least for some time. So there were those links.

In 1938–39, Robert Millikan brought his team from Caltech to Bangalore to conduct a cosmic ray experiment. There were some deep questions at that time about the distribution of cosmic rays and its dependence on the latitude. Millikan wanted to make measurements of cosmic rays in different parts of the world. He knew C.V. Raman, and the experiments were made from the grounds of Central College. As a matter of fact, my father at that time was an amateur movie maker. He even took a movie of these experiments with 8 mm film.

Does the film still exist by any chance?

RN: It still exists actually. There's a story about that as well. When we saw the film as boys, we were told who was Millikan, C.V. Raman, and so on. My father knew all the others. Radhakrishnan, C.V. Raman's son, was a young boy running around and helping them. There was another person from the US in the film. That was Bill Pickering, and he had come here to help Millikan. Pickering later became the director of the Jet Propulsion Lab at Caltech, and he was responsible for the first space missions conducted there.

Many years later, after I had come back from Caltech, there was an international cosmic ray meeting here in Bangalore. I was invited to go there, and I told Radhakrishnan that I had an 8 mm movie of Millikan's visit to Central College, which included him, taken by my father. I asked him if he thought they'd like to see it, and he said they didn't know about it and would be thrilled to see it. So I took the 8 mm movie and the projector, and showed it there. And they all said "We've never seen it." In fact, Pickering had come as chairman of a committee to review IISc. This was after I joined the faculty there. The Institute used to have five-year reviews, which was required by its bye-laws. I don't know if that's still true. Usually quite a distinguished committee came, sometimes even Nobel laureates. I remember C.F. Powell, Bill Pickering and James Lighthill on these committees. They spent some time here, met the faculty, looked at many of the labs, and made a report.

They would never call it IISc—it was always the Tata Institute

There were some Indians as well on the committee, and they also had some comments. So, Pickering once came as head of this committee.I used to live on campus at that time, in one of those bungalows, and Satish Dhawan was the director of the Institute at the time. I invited Pickering one evening and asked him if he would like to see a movie where he was also an actor. He had never seen it, and he just didn't know it existed at all.

And I didn't know the archival value of this movie till I went abroad and met these people. Then I began to see that it was something that everybody liked. Pickering took the movie from me, made a 16 mm version of it, and lodged it in the Caltech archives.

Going back briefly to my school—C.N.R. Rao was also there. The two of us were greatly influenced by C.V. Raman's lecture. At that age you don't realize that it's making a big influence on you for the rest of your life, but we enjoyed it like all the other kids.

You talked about your geography classes in school. I wonder if it had any bearing on your later interest in fluid dynamics and other problems.

RN: It had some. In fact, one of the things he would ask us to do was to guess the climate in some place. He would say: "Take the map of Australia. There's this big Tropic of Capricorn there. Very few rivers. Now you tell me what the climate of Australia should be like." These kinds of questions. He wanted you to reason it out. He wanted you to know of the Tropic of Cancer across India. So maybe Australia's climate is something like India? Well, in India the rivers are all long, but in Australia there are no Himalaya mountains and all the rivers on the map are little bits and near the coast.

So what happens in the centre? He wanted you to guess that the centre would be a hot desert, as there is no water there. And then with the few rivers you have, there are cities at the end of those rivers. But no other cities. He wanted you to guess all of this from the map. I have not come across anybody else who had a geography class that great. I'm sure there were other people, but he was certainly an exception in schools those days. Probably even today. But once again it made an impression on me.

Was that when you first started wondering about clouds?

RN: Well, yeah, it might be. It's hard now for me to say, but I certainly was watching clouds a lot, to the extent that occasionally it became embarrassing. I still remember one such occasion. That was during the war [WWII]. It wasn't easy to get things; food was a problem.
We would have to go to get rations, and you would have to go to these stores and co-operative societies with a ration card. Of course, it was quite common. I and my brothers would do it quite often.

… while I was waiting I would be gazing at the clouds

B.G. Gujjarappa

So I would go to this store and I usually had to wait, and while I was waiting I would be gazing at the clouds. And there was this guy who was running the store, who once said, "Aye, Aakaasha raaya!" because I was gazing at the sky. "It's come. The rice is here. Collect it and go!" So I was looking at clouds at that age too.

As a student, you attended lectures by the Kannada writer D.V. Gundappa. Was that during your days at Acharya Pathashala?

RN: No, not while at Acharya Pathashala. While I was at Acharya Pathashala, my father said that the Sanskrit I was learning was not enough, and that I should learn some more. So I went to the Eswara temple in Gandhi Bazaar for special early morning classes in Sanskrit.

Who was the teacher?

RN: The teacher was somebody from the temple, and he came there every morning. We were staying in Narasimharaja Colony at the time. Every morning the classes started at 6 AM, so we would leave home around 5:30 AM. There was one other classmate, also from my school, whose father also probably told him something similar. So we were two students who went to take this Sanskrit class. We would walk there, spend about an hour, and come back.

What was taught in the Sanskrit class?

RN: He went a bit beyond what is usually taught, and he wanted us to mug up the shabdas, and Amarakosha, and so on.

I went to the Eswara temple in Gandhi Bazaar for special early morning classes in Sanskrit

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That's what I wanted to ask you about. I think Amarakosha, Shabdamanjari were quite common in those days.

RN: Exactly. So we did that. That was during my high school years. Then I went to Vijaya College to do my intermediate, as we used to call it back then.

So was it natural for you to pursue science, given that your father was writing about science?

RN: It was very natural. I just assumed that that was what I was going to do.

Did you not consider anything else? Sanskrit?

RN: No. Sanskrit and so on were cultural, it was not really intended to be professional. I don't think my father intended that either. He spent much of his later years writing in Kannada because he wanted to reach the lay reading public.

Perhaps these influences came back to you later on?

RN: In a way. Once again, I never thought it would have any influence on me. I did learn some Sanskrit. Much later I came to think that I had not learned enough Sanskrit in spite of my father's efforts. After I did this Sanskrit course, I went to Vijaya College and then I joined an engineering college.

UVCE [University Visvesvaraya College of Engineering]?

RN: Yes. At that time there were only two colleges in Bangalore. UVCE, which was just called the Government Engineering College at the time, was affiliated to Mysore University, and so did the new college, BMS [B.M. Sreenivasaiah College of Engineering], which was just starting. At first I thought I would do science. Of course, my father was doing physics, and I said I should do physics too. But I didn't do that. At that time, I didn't want to do the usual B.Sc. If I had got admission to B.Sc. Honours, I would probably have done that. I had applied to B.Sc. Honours at Central College, which took twelve or so students each year, and also to the engineering college, UVCE. This was in 1949.

I couldn't get in to B.Sc. Honours. That was partly because I must have been one of the very first batches which was subject to reservations. It was not yet called reservations; it was called Communal GOs [Government Orders]. The country had become free, and one of the first things the government of Mysore did was to

The University Visvesvaraya College of Engineering, where RN did his B.E. COURTESY UVCE

introduce this reservation, and I didn't make it. My father was not teaching in Central College at the time, but he used to go there. He was giving a wireless course for some time at an occupational institute near UVCE. And later on he taught at National College, Basavanagudi for a few years. But I didn't get into Central College. Out of twelve, only two of us were in the merit quota. But I already had admission for the four-year Bachelor of Engineering course at UVCE as they took many more students. I joined there. Later, my father told me that his friends told him that not all the seats at Central College were filled. So if I wanted to join now, I would make it to the merit quota and I could go there. But I said no, as I had already joined engineering. UVCE also had some very good teachers. So that's how I started.

The Government Engineering College was renamed University Visvesvaraya College of Engineering, after the death of Sir M. Visvesvaraya, the engineer and statesman. Was he an influence on you? Was he a person you looked up to?

RN: There was a bit of it, certainly. Visvesvaraya was highly respected at that time, and was the big Mysore hero. My engineering college at the time had a good national reputation. Mysore was known for its engineering. I think a lot of the credit should go to Visvesvaraya. He built the dams—he's the one who built the dam on the Kaveri. Visvesvaraya was spoken of in the same breath as C.V. Raman, although not at the same level as C.V. Raman. One represented science, the other represented engineering.

And you wanted to move into engineering?

RN: That's right. My mother's family was dominated by doctors, but in our family it was basically science and engineering. So I went to UVCE, and I think that the college was also changing. I mean, these changes had already come and, once again, it had some very good faculty. People came from outside Mysore to study there.

Sunday classes at the Gokhale Institute of Public Affairs

How did you sustain your interest in science at this time? Was this the time you attended the lectures by the Kannada writer D.V. Gundappa [DVG]?

RN: I learnt about DVG as I entered the engineering college. At the time, we lived close to Acharya Pathashala. And there was the Mallikarjunaswamy temple in that space near it. I used to play cricket in the open area next to the temple. There were also some rocks on one side. On that rock, a group of five or six senior people would come every evening, of whom DVG was the most conspicuous—by his voice if nothing else. So while playing

cricket there you would hear what he was saying. But there were others too. It was a circle of people which included Nittur Srinivasa Rao and V. Sitaramaiah, who used to live in Chamarajpet. So my first encounter with DVG was while playing cricket. The ball would go towards that group, we would all run to get it, and he would cut jokes. One day I asked my father who these people were, and he told me. Eventually when I started going to UVCE, DVG was running Sunday classes at the Gokhale Institute of Public Affairs. It used to be near M.N. Krishna Rao Park circle at the time. DVG resided quite close to it, so he would just walk every Sunday morning to the class. The road in front of his house is now named after him.

My first encounter with DVG was while playing cricket

B.G. Gujjarappa

What was taught in these Sunday classes? And how many students were there?

RN: Well, I think the number of students in this class fluctuated between fifteen and twenty, and it was open to anyone who was interested. Usually, we studied two books, one in English, and the other one in Kannada or Sanskrit. He wanted to mix these things, and felt that learning English didn't mean that one didn't learn Sanskrit or Kannada. So one of the books was in Kannada or Sanskrit, and furthermore, the subject also kept changing. It might be literature, drama, or maybe political analysis or history, especially in English. It may even be science—not science as a textbook, but general—books by authors like James Jeans, Alexis Carrel, etc.

Was there any book in particular that caught your fancy?

RN: Yeah, one was called *Man, The Unknown* by Alexis Carrel. It was a Penguin book. It sort of looked at man as a whole.

I believe A.P.J. Abdul Kalam was also influenced by this book.

RN: I think you're right. This was written by a scientist, but he wasn't only a scientist. It was a mix of things—a little about history, a little about philosophy, social things, and science. But of course, the theme was the unknown. We don't know Man. That was the thing. And that was a book that made an impression on me. It was very typical of Gundappa that he picked these books—you know, some science, some not. DVG started out as a journalist and was also a public affairs man. He founded the Gokhale Institute of Public Affairs in Bangalore. He was a great admirer of Gopalkrishna Gokhale and the British system of government. So we read some 19th century British philosophers. Britain was transforming itself into a powerful nation, the most powerful in the world at the time, and the power was spreading here. As they say, the sun never set on it. There was a lot of debate in England at that time about what kind of government they should have. Of course they had a democracy of some kind, but it was not current modern democracy. They did not have universal voting rights and there were various issues, like the industrial revolution. Adam Smith was another person that DVG would now and then invoke. One of his favourite British political philosophers was Walter Bagehot, and we read his speeches in parliament. He had written a book called *Lombard Street*.[2]. So you came across that kind of thinking, which you totally did not have in our education system. And I think the main lesson I learned from these is not to make too many divisions in knowledge, and also among languages. English is not necessarily the only thing in the world, that sort of thing. DVG wanted a broad and integrated educational system—science, literature, philosophy, politics and, as the university system did not provide it, he created his own complementary curriculum.

Visvesvaraya was spoken of in the same breath as C.V. Raman

There were some people who were regulars in this class. The people who liked it stayed there for years. Most of them were older than me. I don't think there were too many younger than me—some my own age, some slightly senior, some maybe in their thirties, late thirties. I went there for four years during my whole B.E. course. So that was one sort of change from the engineering college. These classes became complementary, and it put this idea in my head that just because you're an engineer or physicist or whatever, it doesn't mean you should not look at other things.

And this Sunday school would be for around two hours?

RN: Yeah, two hours. We would start with the books. Maybe Sanskrit or Kannada in the morning, and there would be a small cup of coffee served around after an hour during a ten minute break, and then you continued with the other book.

First day cover featuring the Gokhale Institute of Public Affairs, issued in 1988

Were you also encouraged to speak on these subjects yourselves?

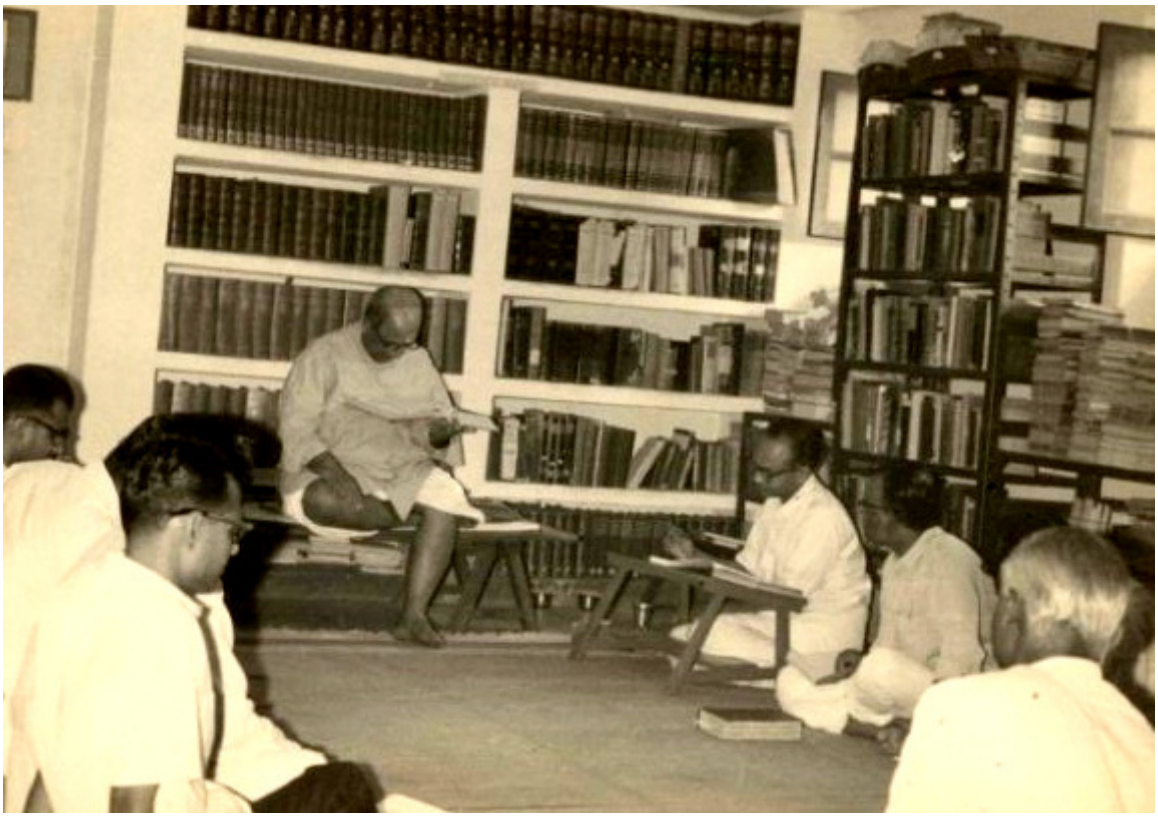
RN: We used to have a kind of exam. After the book was read, all of us had to review the book. We were given five to ten minutes for each book. You had to say something about the book, how it influenced you, what your thoughts were while reading the book, and so on. So that was one way people were supposed to speak. Of course during the rest of it, you could ask questions—that was always there.

Was DVG the singular figure there or were there other people around him too?

RN: There were always other people, but it was never very big. There was always Venkatachalaiah, who was the secretary of the institute, but he was basically the man who ran the place and made the arrangements, made sure rents were paid, dues were collected, and so on. But there were other people who were friends of the Gokhale Institute. When a public lecture was organized, many of them would come.This sometimes included Nittur Srinivasa Rao and my own father, who had been classmates during their B.Sc. Later, N.S. Rao became the president of the Gokhale Institute.

These classes were basically just for public interest—there was no fee involved, right?

RN: Almost nothing. Somehow it was unthinkable that you would give money to DVG! We did give him a gift of fruits, etc., the traditional Indian way.



DVG (sitting on the raised seat) at the Gokhale Institute of Public Affairs COURTESY Gokhale Institute of Public Affairs

DVG wanted a broad and integrated educational system—science, literature, philosophy, politics

Did these influences play a role in your decision to come back after your Ph.D. at Caltech? I hear that somebody took a bet that you would go back to USA in two years?

RN: My friends in the U.S. said I would be back there in six months. They didn't think I would last here [India] for two years!

During my student days, we were part of a small club of about ten students around Basavanagudi. We called it the Cronies Club. What the Cronies Club did was to meet on Sunday evenings and go have SKC—Sweet Khara Coffee—at some restaurant, and chat about something. Many of the members were associated with Acharya Pathashala; some were from other schools and colleges but known to us somehow.

At the time, there was this business about independence, Mahatma Gandhi, Nehru and so on. It was also the kind of thing that our own teachers said at school. They did not say that people shouldn't go abroad. People did go abroad, but the numbers were very much smaller than now. But the Cronies Club thought things should be done here. If you do it abroad, well, that's what *they* are doing. What have *you* contributed? There were some in the club who were studying physics at Central College. It was not uncommon for this group to say, for example, about Subbaramaiah, who taught quantum mechanics, that, "You know, if Subbaramaiah was in the US, he

would be like—" (some well-known person). Because he's in Bangalore, you see, he does not have those opportunities. And so he would be admired for having stayed here. Somehow, there was this kind of feeling that we should do it here.

In principle, I could have gone abroad after my B.E. However, I came to the Institute [IISc], and I took this Master's course in aeronautics. It was called a diploma course at that time, a two-year Masters of Engineering. I learned to love fluid dynamics in those two years, and found that aerodynamics and fluid dynamics interested me. At the end of those two years I had to decide what I wanted to do. An uncle of mine, who had been to the US, said that I should go abroad since I've already done a two-year Master's at the Institute. And they said, "You know, Dhawan is there [at IISc]. You just tell him, and you'll get admitted straightaway to Caltech. Why do you want to stay here?"

The Cronies Club thought things should be done here

But we also had a German professor, Oskar Tietjens, at the Institute. He was the chairman of the aeronautics department. He was the man who first taught me a fluid mechanics course. I had had a hydraulics course in engineering, but no fluid mechanics course. The division between the two subjects was still there in India. Tietjens had been at the Institute for three years before I joined, and he knew what Indian students knew and didn't know. So it was from one point of view a kind of first course, an elementary course on fluid mechanics. But he also wanted to emphasize that you have to reason. So he went to great lengths to show that all of this is logic and so on. He did not cover a great deal of ground, but he covered the fundamentals thoroughly.

I think he had made up his mind on this approach after he got to know the level at which India was educating its engineers at that time. Aeronautics was very new in India. It was a creation of the Second World War. There was hardly anything before that. So he prepared to spend a lot of time with the objective of making the fundamentals of the subject very clear to everybody in the classroom. So that's where I was first exposed to fluid mechanics and he was, of course, typically German—I never saw him smile. That was just his style. He would always wear a suit and he came in this huge car, a Buick. He lived in Bungalow No. 11 on the Institute campus, where I lived later on. He would drive from his bungalow to the department just close by. He used to invite students to his house once a year for a little party. His wife would make ice-cream, and the other students went there if only for the ice-cream—it was not very common those days. But she always added Indian flavours, so it was particularly good.

Anyway, we sort of knew Tietjens, but he never talked directly to his students; he usually did it through an intermediary, Joga Rao. At the end of my Master's course, he asked Joga Rao: I want you to ask Narasimha to come and meet me. So Joga Rao came and said, you know, professor wants to meet you. In those days, there was only one professor there, and "professor" also meant the head of the department. I thought, "Good God, what would he want to meet me for?" I went there, and he asked me, "Well, you know, your two years will be over pretty soon. What do you want to do afterwards?" By then meteorology was already an option for me. I said, "Maybe I'll work in the aircraft industry. I'll also apply to the Met department. But otherwise I have been

thinking about it, and I don't have anything very specific.". He said, "No, you should do research." I had done very well in his course. "But what's more," he said, "for your research, you should go abroad. And there are only two places I would recommend: Göttingen and Caltech. If you want to come to Göttingen, let me know, I'll make sure you get admission."

RN (extreme right) with classmates at IISc. COURTESY Roddam Narasimha

This was the University of Göttingen?

RN: Yes. But Göttingen is a strange place. It was the centre of aeronautical research and development, of which the university was one distinguished part. Ludwig Prandtl held three positions at the same time. He was a professor at University of Göttingen, which was the job he first got when he came to Göttingen. Then he was the director of the aeronautical research establishment, Deutsches Zentrum für Luft- und Raumfahrt (DLR) which was a government agency, somewhat like NAL. He was also director of what at the time used to be called the Kaiser Wilhelm Institute, the current Max Planck Institute. This was the Kaiser-Wilhelm-Instituts für Strömungsforschung. It was all under his control. He was the king.

The Kaiser.

RN: Kaiser, yes!

I suppose going to Göttingen meant you would have to learn some German.

RN: Well that you would have to do. However, during my two-year Master's course at IISc, I had to learn some German, especially in aeronautics. You know why? It will come as a big surprise to many people. It wasn't just because Tietjens was a German. It was because at that time, there was more advanced literature on aeronautical matters in German than in English.

This was ZAMM [The Journal of Applied Mathematics and Mechanics, also known as Zeitschrift für Angewandte Mathematik und Mechanik]?

RN: Exactly. Many more of the biggest advances came from ZAMM than from British or American journals. The British were ahead of the Americans in science to some extent. But the Germans were ahead of the rest of them. After all, who set aeronautics up in the United States? It was one of Prandtl's students—Theodor von Kármán—who set it up. Even after the war [WWII], for a short time, Germany carried on the reputation of what they had done in the first half of the century. Germany was still a strong place.

You said that when you were called by Professor Tietjens to his room, you told him that you were already interested in meteorology.

RN: I actually applied for a position at the India Meteorology Department.

How did that interest arise?

RN: Well, that was because I used to read some things about meteorology. I realized that a large part of it was actually fluid mechanics. I wanted to study fluid mechanics, either in engineering or in meteorology. So I saw meteorology as a kind of applied physics. And I had been gazing at the skies…

"Why don't you stay here for two years and do some research, and we can have some fun?" That's the way he usually talked

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Was Satish Dhawan teaching you during your Master's at IISc?

RN: Yes, of course. That's when I got to know him. In fact, he was a big influence on my life. He had studied at Caltech and he was really a singular man, a singularity on the campus.

I have written about Dhawan. He was just the opposite of Tietjens, for example. Dhawan never wore a coat or tie, and liked colourful shirts. Tietjens came in a Buick, Dhawan came in a small MG sports car with an open top, a convertible. He would quite often walk from his place, but he also parked a car at the Department. He was not married at that time. After he parked his car, he would seem to jump out of the car. Then he would run up the stairs. He was a young man, very agile, and he completely changed the atmosphere.

From one point of view, they were both good men. But Tietjens was at one end of the spectrum and Dhawan was on the other—a very informal Californian.

At that time, he was building these little supersonic tunnels, the first in India. He was very good with his hands. More or less soon after he came, he was teaching a course on gas dynamics and supersonic flows because that's what was really new at the time, and he had done it at Caltech. His first project was to build this supersonic tunnel where he could show his students shock waves. He wanted to do it just with whatever was available in

the workshop at the Institute. He made a one centimetre square section wind tunnel, and that was built by the mechanics in the workshop. Those mechanics were very good, much better than you would now get. They were all very proud mechanics.

They didn't build it with advanced machinery at the time?

RN: No. They all wanted to do a good job. Now, the wind tunnel had a small test section of one centimetre square area. Because this was after the end of the war [WWII], there were a lot of spare things you could get in disposal—from the Indian Air Force and so on. There were a lot of DC3 Dakotas, for instance. All kinds of things were recovered from the Dakota. It carried two oxygen tanks, so we could put something into it for pressure. Dhawan bought two Dakota oxygen tanks, connected them with piping, put some valves, put some compressed air into those tanks, put a little wedge in the test section, and set up a very small but simple optical technique to measure density changes. In this tunnel, he was making shock waves at Mach 2, and the students were thrilled. Because otherwise, you just saw it in the books, and you didn't know what it was.

Satish Dhawan COURTESY Roddam Narasimha

One day he came to me and said, "Say, would you want to work with me on supersonic flows?" I said I would love that. So I designed some of the things for the wind tunnel experiments, and so on. This was outside my Master's curriculum. It was just for fun. Fun for him, fun for me. During the summer after the exams were over, I was thinking whether I should do research, and if so where I should do it. Working with Dhawan was an option. And he solved the problem for me by saying, "I don't know what you're going to do. Why don't you stay here for two years and do some research, and we can have some fun?" That's the way he usually talked. So I joined him for research, spent two years here, and then moved to Caltech.

But getting a steady job must have been important. Wasn't there some suggestion that you should join the Railways?

RN: Some of my friends, and my father's friends, told me that. At that time, aeronautics was not a very popular field because there were few opportunities in it. It was not seen as something with a big potential for growth. In fact, in the previous Master's batch in aeronautics there were no students at all. So one of the reasons I stood first in the class was just that it did not attract the best students! [Laughs] The best students had two big options for them. It was a bit like IT [Information Technology] nowadays. There were two petroleum refineries then, Burma Shell and Caltex. They paid very well. So when an ambitious student wanted to make a career in engineering, and especially in mechanical engineering, he went to Burma Shell or Caltex. If you did not make it to one of them, you went to IRS [Indian Railway Service]. That was number two. If you didn't make IRS, you went to Tata Iron and Steel. This was the hierarchy. But I was not interested in any of those options, so I didn't even apply for them.

That's how I stayed at the Institute for my research. Family pressure was not there. One of my father's colleagues, P. Srinivasa Rao, was a faculty member in the aeronautics department. He was a physicist, but during the war he had worked on aviation instruments. At that time there were no specialists in instrumentation in India, but physicists could quickly learn something about instruments. He actually had quite a bit of experience handling those instruments, and he was hired as faculty when the Institute started the Diploma course in aeronautics.

Was this when Dhawan suggested you go to Caltech?

RN: He did not suggest it right at this time. But he said, “You know, why don't you do some research? Would you be interested in doing research?” I said yes. I was also influenced by two friends who were students at the Institute. They were the kind of people who would say it should be done here. After a discussion of this kind which I had with my own friends, I thought this was a good opportunity to see what I can do with research here. One of my more distant uncles, who had been to the US and had spent some time at Caltech, had come back. He was shocked to find that I had chosen to stay in the Institute and he said, “What are you doing here? You know Satish Dhawan, he's your guide. Didn't he send you to Caltech?” But I went along with my thinking at the time to do something here. And Dhawan had shown how to do some research.

But you also said that there were no jobs in aeronautics at the time.

RN: Yes. When I talked to Srinivasa Rao, he said, “Don't be a fool. Aeronautics has no prospects. You wouldn't be able to make a career out of it.” He said “”Last year there were no students at all in the Master's course.” One thing that students did at that time was that they came to the Institute not to get a degree in that subject, but to have access to the library to prepare for the IAS [Indian Administrative Service] and IRS exams. Not many actually came to aeronautics to do aeronautics. Of course quite a few did end up doing it. Anyway, I went back to my father and said, “You know, your friend says I shouldn't go. There are no prospects in the field, he says.” Then he asked me, “What do you want to do?” I said that this is still the subject I wanted to study. He asked me to go ahead and do what I wanted to do. That was the end of the discussion. So there was no familial pressure.

So your father was both an inspiration and a support.

RN: Yes, he was both.

How did it come about that Satish Dhawan recommended you to go to Caltech?

RN: It was very typical of him. At the end of two years he said, "You know Narasimha, there's nothing more I can teach you. You want to go to Caltech?" Had Satish Dhawan not been there, I might have done something else. I doubt whether I would have gone abroad. So the fact that Satish Dhawan was there changed my mind.

"You know Narasimha, there's nothing more I can teach you. You want to go to Caltech?"

You earlier described Göttingen as a vibrant research ecosystem with a good university. But you chose Caltech over Göttingen.

RN: I chose Caltech over Göttingen because, well, first of all there was no language problem. And, you see, although Göttingen was still vibrant, it was not the old Göttingen. When the Allies defeated the Germans, it all became part of the Allied territory. And the first thing they did was to say that the aircraft industry in Germany should close down. One of the clauses of the treaty signed when Germany accepted defeat was that Germany would not continue building aircraft. So all of a sudden, in 1945, the aeronautical industry was not required there. In fact, one of the reasons Tietjens came to Bangalore was that there was not much to do in Germany.

Actually, he first went to the US, and then he came to Bangalore when this professorship was vacant at the Institute.

You have previously described this German influence on Indian aeronautics during its early days. I believe the first designer of the HF-24—the first jet fighter developed in India—was Kurt Tank, a German.

RN: Kurt Tank, yes. He was the designer of the HF-24 over the first phase. So the German influence on aeronautics in India in general, starting with the HF-24, has been very significant.

So because of this situation in Germany, you felt Caltech may be better?

RN: Well, by the time I came to IISc, the first chairman of the aeronautics department had gone back to HAL [Hindustan Aeronautics Limited]. He was not only the first chair of the department, he was also the first chief designer at HAL.

Left : RN during his Ph.D. days at Caltech. Right : RN receiving his Ph.D. degree. COURTESY Roddam Narasimha

This was Vishnu Madhav Ghatge?

RN: Yes. And he was Prandtl's Ph.D. student, so the German connection there was quite strong. The connection between Caltech and Göttingen was also strong, because of Theodore von Kármán. He was the man who founded the aero lab at Caltech, the Guggenheim Aeronautical Laboratory (GALCIT) [later renamed the Graduate Aerospace Laboratories], which was in some sense an offshoot of Göttingen. There was not much difference between the two of them, at least in Tietjen's mind. But by the end of the war, I would say that the Caltech aero lab was ahead of what was happening in Germany. As I said, this was not because the Germans were not smart, but because they had lost the war and they were prohibited from doing anything related to the aircraft industry. So America was the better option.

Hans Liepmann, your Ph.D. advisor, was also German.

RN: Yes. He was actually a German physicist. He did not have a direct Göttingen connection, but he knew those people. He got his Ph.D. in physics, with a man named Richard Bar. But he was scientifically quite close to a man named Meyer, who was at that time quite well-known. The story Liepmann tells is interesting. You see, Liepmann was part-Jewish—and he had a wonderful sense of history.

After he got his Ph.D. he had to decide what to do. It was 1938, and the war was just about to break out. Hitler had been in power for some time and it was clear that the Jews were having a pretty rotten time. Now, Liepmann's family was almost completely Germanized, and didn't think of themselves as Jewish. But he had already found out from the experts who worked for the Nazis that he would have been classified as quarter-Jewish. And I think his sense of history was pretty good. He thought there would be a war pretty soon: it was inevitable.

Just a year before it broke out?

RN: Just a year before. So at his Ph.D. party—this was a story he used to tell—Meyer asked him, “What are you going to do now? You got your Ph.D.” Liepmann says that they all had some drinks at the party, and he blurted out: “Hydrodynamics!” His advisor said, “All right, I know von Kármán very well. I'll write to him. Why don't you go join Caltech?” In the next few months preparations were made, and he set out on a boat to the US—first to Washington, then across the country to the West coast. This was just before the war in 1939. He's written some personal memoirs which contain those interesting incidents. He used to tell these stories. He had travelled to the US on one of these big ocean liners which used to cross the Atlantic. On the ship, there were parties and people had a gala time, with dances and so on. He was struck by what these people were doing. “They don't know. It's amazing,” he said. “The war may break out any time, but these guys are having fun.” He just didn't understand it. I think he tried to tell some of them but they were dismissive and said “Have fun when it's possible.” About a month after he landed in the US, war broke out in Europe. So his guesses were right.

Hans Liepmann with his wife Dietlind COURTESY Roddam Narasimha

Liepmann was part-Jewish—and he had a wonderful sense of history

Chaos and Fluid Dynamics

You mention that fluid mechanics was a very popular topic of research in the 1920s or so. Was there a dip in interest in fluid mechanics after that?

RN: I think there was a dip in the interest of physicists in fluid mechanics. I think it had to do with the advent of relativity theory and quantum mechanics. These became very exciting. Amazing new, revolutionary ideas were changing physics in a fundamental way. Well, Heisenberg was a typical example. When he first decided what he wanted to do, fluid mechanics seemed like the most interesting thing to do. He wrote his thesis on flow instability, and Arnold Sommerfeld was his advisor. But by the time he got his Ph.D. degree, there was, first of

all, relativity theory, which had just begun to be accepted. This was the early 1920s, so quantum mechanics was not quite there but questions were being posed. I think after his thesis he decided that he would switch to the new physics.

Stephen Hawking turned 75 this year. And he has been, at one point of time, the Lucasian professor of mathematics at Cambridge University, as were other illustrious names such as Isaac Newton, Charles Babbage, Paul Dirac, George Stokes and James Lighthill. The last two were fluid dynamicists at some point. In particular, Sir James Lighthill in 1986, in the *Proceedings of the Royal Society* wrote an article whose title was dramatically put, "The Recently Recognized Failure of Predictability in Newtonian Dynamics".[3]

RN: I know that article, yes.

How much of an impact, much later in your career, did the arrival of this new thinking called chaos, and the new language—with ideas perhaps hitherto unknown to engineering communities, of fractals, strange attractors, and nonlinear dynamics—have on your research?

RN: Well, it did have an influence. For some years, between five and ten let's say, I was looking those things up. I attended some lectures and actually did some research on it. I have a few papers about chaos and fluid dynamical systems.

But I had one problem with chaos and dynamical systems as they were being done at that time. You see, for flow turbulence there was always one philosophical problem, namely, how one gets such apparently stochastic solutions. Why does this stochastic behaviour come up when the Navier–Stokes equations are apparently deterministic? I think the advent of dynamical systems theory answered that philosophical question. However, after all of that, if you ask today how much dynamical systems theory has helped in solving the turbulence problem—I would say not a great deal. Because the number of degrees of freedom in a typical fluid flow problem is huge. And the problem you want to solve is in this limit where number of degrees of freedom goes to infinity.

Although there had been very pretty experiments at relatively low Reynolds numbers, understanding the path to fully developed turbulence has not been easy using dynamical systems. Therefore, after I spent some five or ten years doing this, I came to the conclusion that it doesn't look as if this is the way I'm going to understand fully developed turbulence. So I stopped doing much work on chaos theory.

When was this—during the 1960s, 70s or 80s?

RN: In the 1970s and 80s. See, when the chaos thing started, from my point of view, it started with Edward Lorenz. He wrote a famous paper in 1961, when I was still at Caltech. My advisor, Liepmann, characteristically came to where I was sitting and said, "Here is a very interesting paper", and just slapped it on my desk. Lorenz was from the department of meteorology. I graduated in 1961, and I got interested in it while I was leaving Caltech. I didn't do any significant research in it immediately, but I kept track of it by reading papers and attending meetings. After that, I kept visiting Caltech every year. I had a sort of open two-term invitation to go there. I usually went there during the summer months here, so I could see what was going on in this subject. In

my visits during the 1970s and 80s, many people visited Caltech and spoke about it, and there were some people who came here to the Institute. We also organized some short term courses and workshops at IISc. I actually gave a course on dynamical systems at Caltech in the early years of its strong influence on fluid mechanics. But apart from that, apart from one model which we made at IISc, the fully developed systems that dynamical systems people worked on behaved differently from what you see in a fully turbulent system in a typical engineering situation; for example, flow past a flat plate. In Lorenz's paper, he simulates with only one value of the control parameter. But later on, other people did it with different values of the control parameter. There was a book written on the Lorenz equations, and it had a large number of computer simulations. They found out that as the control parameter was increased, the chaos was killed in the Lorenz attractor. Here is a system which has chaos, and has something to do with turbulence. But it can't have something to do with real turbulence, because if I increase the control parameter, it disappears. So I said no, this can't be it. Anyway, I kept track of this field and made a model where you can keep on increasing the control parameter and the system will remain turbulent. This was work with G.S. Bhat and Steve Wiggins that appeared in the *Physics of Fluids*.[4]

Was Lorenz's paper the beginning of the influence of numerical simulations on fluid mechanics?

RN: It was in a way, you're quite right. He did it on one of those early computers—there were not many at the time. You probably already know this story. There was this other man Barry Saltzman, who was looking at convection. He found that he was getting strange regions where no matter how many terms he took it didn't help—he was getting crazy solutions. Apparently, Lorenz used to stop by at Saltzman's lab and ask him, “So how is your system behaving?” Saltzman would say, “No, it's still crazy.” After a while, it began to occur to Lorenz that maybe it *is* crazy. Maybe the real solution is a crazy solution. So he just took those nonlinear equations and, he didn't expand it, but just took their first terms. It was a fully nonlinear system described by three ordinary differential equations. He did that analysis and found out on the computer that even that simple system had chaotic solutions. So there: it did not have to do with big things about convergence and so on.

It is a great paper because it is remarkable how many things he [Lorenz] foresaw

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It is a great paper because it is remarkable how many things he foresaw. He foresaw from the traces he had that there were things that did not look completely random.There were spikes which were not periodic, but in some sense may have structures in it. He foresaw the strange attractor of which he made a sketch. And he foresaw the role that maps will play by looking at the maximum and minimum positions and plotting them. He found that they are correlated by this map which is, you know, exactly the shape of the tent map. So all of that is there in Lorenz's paper.

One thing that is seen in turbulent flows are these so-called coherent structures. They are surprising because the flow itself doesn't impose any structure, and these structures are in some sense emergent. Have you used proper orthogonal decomposition as a tool to uncover such things?

RN: I haven't used proper orthogonal decomposition very much. I have a problem with proper orthogonal decomposition. I am looking at it as somebody interested in turbulence problems. It is a very interesting technique. It gets a hierarchy of structures, with the first one being the one that contributes the most to the energy. But quite often, there is quite a bit in the energy which does not come only from the first round. And while the structures that they calculate do resemble what happens in certain turbulent flows, it doesn't completely sketch them. It doesn't give you a complete feel for them. What I find incidentally more useful is analyzing images of a flow using wavelets.

The Indian Monsoon

Wavelets have links to self-similarity and time-frequency analysis. Is this what makes them particularly useful for fluid dynamics?

RN: It is, in a way. Actually I don't think it's been exploited sufficiently in fluid mechanics. So I'm starting one more project on wavelets now.

In the meteorological context?

RN: I have used it quite a bit in the meteorological context.

Is this related to MONTBLEX [Monsoon Trough Boundary Layer Experiment]?

RN: It is related to MONTBLEX and monsoons in general. There are questions that you can ask about the periodic components of the monsoons for which the standard methods such as Fourier series don't quite work. And the meteorological system is very jittery. So, for fun, I thought we could take the statistics of rainfall from the Met department and just put it through a wavelet—let's see what kind of wavelet transforms it has. In the earlier days, people had not done this sort of thing. Of course now everybody knows wavelets.

Let's take a simple example. You can take either the monthly or annual rainfall across many years in India and submit it to a wavelet analysis. I had a student, Sudarsh Kailas, who actually liked to compute things. At that time you still couldn't get wavelet software like you do today with MATLAB. We had to write the code by ourselves, and Kailas wrote it. This was for fun, as nobody had asked this question. See, we don't ask questions about what happens in India *here*. [Laughs] I said, "How come nobody has looked into the monsoons? Let's take the monsoon data and run it through wavelets." It gave very interesting results. And it explained why a certain kind of argument keeps going on, about whether the monsoon is periodic or not.

Did it add to the predictability of the monsoon?

RN: It added to predictability for certain short durations. It is not predictability forever. We found that the wavelet transform of the monsoons change with time.

Will the transforms themselves change with time? Or the coefficients?

RN: The coefficients change with time. Then you could display all of it on a wavelet map. You can then see that sometimes the cycles are clear, and sometimes not. A lot of this is possible only with wavelets, not with Fourier series, for example. I saw there was something very interesting there. So I spent about ten years applying wavelets to monsoon problems. If you ask about the periodicity, we can tell you what kind of periodicity the system had at what time.

One more popular question that has been asked for a long time is whether sunspots and solar activity influence monsoon rainfall. Some people say yes, some people say no. But at that time, the proper meteorologists were very skeptical. A lot of analysis was done with moving averages and so on, whose conclusions were never really convincing. They didn't rule it out, but they were not convinced either.

I had one student, Subarna Bhattacharyya, who worked on it. She came here for a wavelet seminar and apparently got very attracted to it. She wanted to work on wavelets, and someone pointed her to me. We did a wavelet analysis on whether the sun influences our climate. I decided to go ahead with wavelets, looked for periodicities in wavelet maps, and we made a statistical test, all on the real rainfall record. We very convincingly proved that there is a solar cycle component in the Indian monsoons.

We very convincingly proved that there is a solar cycle component in the Indian monsoons

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Our paper[5] was accepted in *Geophysical Research Letters*, and the journal complimented us and said they believed us because we worked on real data. We went on to discover what other periodicities were there in the rainfall. We found that the El Niño also influences rainfall. But the Met department formula, which predicts rainfall depending on many parameters of which El Niño is one, finds the predictions go wrong every now and then. So the connection between El Niño and rainfall was a question mark. We made a study of three variables —rainfall, El Niño, and solar activity. It turned out that the solar activity affects the rainfall in two different ways: one, you may say, through El Niño—because El Niño is also affected by solar activity—and the other way is through the other variables in the model.

It is a highly coupled system.

RN: That's right.

Aryabhata, Brahmagupta, and the Sāmkhyas

So you were basically looking at data, taking past observations, and either trying to study the relations between these observations, or predict future observations. Just out of curiosity, was this the time that you were studying Nilakantha and the Kerala school of astronomy?

RN: That was always going on, on the side. Absolutely. Around the time.

Were you influenced by that school of thinking?

RN: Yes, in a certain way. I thought there seemed to be only one way of doing science. And that was the way science had grown in the last few centuries.

I began to see it's murkier than what I had been led to believe

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This was the Western way?

RN: The Western way. Back then I would have said that's the only way. But when I started reading these Indians in the original, my mind began to change slowly, for two or three reasons.

The first thing was that it was clear that those guys were smart. Not only because of the actual results they got, but the attitude they had and the confidence with which they said these things. And then they were rational. There is the mistaken view in India that all of that is, you know, hocus pocus, that ancient Indians believed that the eclipses occur because of Rahu, Ketu and so on. Then I found out that there were Indian astronomers who made fun of those stories—they said it's not Rahu and Ketu, it's shadows. Aryabhata, for example, says—in 499 CE—that the solar eclipse was due to shadows. And he was taken to task for saying it's shadows [this was later by Brahmagupta].

He said that if you measure the height of the shadow made by a stick and observe how it changes with time, you get an idea of the Sun's orbit. And you can see that the Earth is round because as the shadow develops, you can see it's circular. So he said that the Earth is round, and he also guessed that the Earth is rotating around its axis. Maybe day and night are due to its rotation around the axis. You could not say all this was irrational, but it was clearly not the Western method of doing it. You can take Aryabhata and Ptolemy and see the difference. The difference is huge and can't be ignored. I actually went back and read Ptolemy after I read Aryabhata. I said "Okay, what were the Greeks doing?" You know, the first book, or first chapter, of Ptolemy is all about the assumptions he makes. He makes lots of assumptions, most of which are actually false. However, he would get results which were pretty good. So I began to see it's murkier than what I had been led to believe.

After that, I read quite a few other people. Now, Brahmagupta was a contrast to Aryabhata. Brahmagupta—though I don't know what he actually believed—took Aryabhata to task for rejecting the Rahu-Ketu theory and talking about shadows. But Brahmagupta did not reject the shadow idea. Either he made a compromise with the Pouraniks, and let those Purāṇic stories remain. Or he actually thought that that was the way it was. My personal belief is that it was the former, because he was very smart, and undoubtedly a very good mathematician. It's very unlikely that he would have said it has to be Rahu and Ketu. It's possible he felt that if he rejects the Rahu-Ketu business, he might have been accused of disrespect towards traditional knowledge.

Aryabhata said that the Earth is round, and he also guessed that the Earth is rotating around its axis

See, in Indian history, there are basically two schools—Siddhāntic and Purāṇic. Siddhāntics are people like Aryabhata, people who actually made calculations. The Purāṇics are people who had these stories. The common public believes the Purāṇic stories, especially back then and even today. The common public don't know what Aryabhata said. Even educated people don't know what Aryabhata actually said because it's not in the curriculum anywhere—which I think is extraordinary. If you read Aryabhata's works, where is God mentioned in it? I asked myself this. Aryabhata's was the first great Sanskrit text in astronomy. He hardly ever mentions God. Whereas God or some force enters into Ptolemy's works—there is a demiurge, you see, which likes everything to be perfect, the belief that no demiurge would create ugly things, etc. The only place where God appears in Aryabhata's astronomy is towards the end of the book, where he basically says that—"By the grace of Brahmā, the precious jewel of excellent knowledge (of astronomy) has been brought out by me by means of the boat of my intellect from the sea of true and false knowledge by diving deep into it." [6] That's the way he sees it. He's not thanking Shiva, Rudra, Vishnu or anybody. He goes back to creation—Brahma. He is basically saying, "I was created by some force and given this brain, but I'm not trying to tell you anything from anywhere else." In other words, this is reasoning. "You please look at the results," he says. And it is uttered with such confidence about both the correctness of what he is saying, about the results really coming out of thinking and not out of revelation.

Aryabhata's was the first great Sanskrit text in astronomy

Were you reading these things about Aryabhata during the 1970s and 80s when you were active in turbulence research and began getting interested in meteorology?

RN: The 70s and 80s yes, but it was very slow. I didn't spend a lot of time because there were other things I had to do. I was always doing on the side something or the other in the history of Indian science. After a while it became a recreation for me. I enjoyed doing it. Earlier when I was younger, I used to get that by reading novels. But when my interest in history began, I lost my interest in novels almost completely.

Who would you read? Robert Ludlum, Alistair MacLean…

RN: I used to read quite a few people of an older generation and, yes, Alistair MacLean. He also wrote books that were kind of history, experiences in the Middle East and so on. I used to read detective stories too, including those by Erle Stanley Gardner. I remember how one year, while doing my engineering degree, I first came across Arthur Conan Doyle's complete books, Sherlock Holmes. One of my classmates gave that to me

said, “Do you like Sherlock Holmes stories?”; I said I love them. “Okay, I have one thick volume here,” he said, “but you'd have to give it back to me in two days.” Well, I almost read day and night, and I couldn't complete the volume, but I read a lot and gave it back. But that slowly faded out because I found that the history of Indian science is actually more interesting—it was about things that really happened and there were these differences between what we were given to believe and what I actually found from my reading.

You were talking about the Siddhāntic and Purāṇic schools of thought. So there were multiple schools of thought…

RN: There were multiple schools of thought, but they were in two classes. The Siddhāntic class and the Purāṇic class.

And in one of your articles[7] I think you outlined six major schools of analytical thought, as in, not derived from scriptural knowledge.

RN: No, there are six philosophical systems. These are called in Sanskrit as ṣaḍdarśanas. Darshana is the word that's used in Sanskrit which normally translates as “philosophy”. But darshana is really *seeing*, *view*. So these are six ways in which, you can say, we have viewed life, reality, philosophy, and all kinds of things, in classical times. All these schools are part of our tradition. They don't agree with each other on all matters, but everybody agrees that our view of the world is largely contained in these six schools. Some of these schools are old, and some are more recent—meaning maybe a thousand years ago, or thousand five hundred years ago. The six schools were a revelation to me in spite of the classes that I took with D.V. Gundappa and the others. DVG himself taught classes on the Upanishads. But at that time I still hadn't heard of the Sāmkhyas, for example—and Sāmkhyas were a revelation to me. I heard of the Sāmkhyas from the astronomers and the doctors. You see Charaka, Chanakya, the astronomers and the mathematicians, they are talking about Sāmkhya, indirectly. And it's quite clear that the Sāmkhya was the school which, in many ways, I frankly believe, is actually true, which is actually rationalist in a very interesting way. It's not quite rational in the way that the West is. It is, however, very rational and the views are expressed, as quite often in Sanskrit, in extremely terse shlokas. And well, I did not discover the Sāmkhyas—I mean they are very well known, lots of scholars have studied it greatly. But I never encountered it in my contact with Sanskrit philosophers. I thought it was something similar to the other schools but it's not similar at all. In Sāmkhya, first of all, various things are listed.

It is called Sāmkhya because of the phrase “Sankhyām Prakurvati”, which translates to “Puts number in front” That was roughly what the Indian mathematicians thought at that time, that number was first for them. And then it also talks about the Vedas. It says the Vedas are a human creation, that they couldn't be revelation. Why? Because the Vedas themselves say so. Because in every sūkta and maṇḍala there, Viswamitra or somebody else is named, so it must be a human creation. It is not anti-Vedic. That's the most important thing. It is not a criticism of the Vedas. It is a criticism of the Vedas as the storehouse of all knowledge, and a criticism of the idea that it came from some extraordinary source.

RN receiving the Padma Vibhushan from President Pranab Mukherjee in 2013 COURTESY Roddam Narasimha

This seems to have parallels with the rejection of scriptural wisdom in Europe.

RN: Except that this is much older. Sāmkhyas are almost as old as the Upanishads.

I see. So these agreements, these disagreements, they coexisted through all of that.

RN: Exactly. Not only did the disagreements among these schools of thought coexist but an educated Indian of those times was expected to know all six of them. He might prefer one—that was perfectly okay.

For example, Neelakantha, who was an astronomer, had also the title ṣaḍdarśana pārangata—he knew all the six systems. It was not considered self-contradictory at all. It was just part of your knowledge that you had to be aware of these different views although you may prefer one of those schools. It looks to me—although I've not seen Neelakantha say it openly, from the other things he says—that he was probably a Sāmkhya. Because he has one statement where he proves, he demonstrates, a certain result and at the end of that result he says, *evam sarvam yukti mūlam, na tu āgama mūlam*, which translates to "All of this is rooted in Yukti. Not rooted in the Aagamas." [8]

This is yukti, which is to say, human intelligence, skill doing this, not sourced from the scriptures. So he is echoing the thought that Aryabhata had. And you'll find that many Indic scientists do something very similar. Bhaskara has another interesting phrase—he has a certain invocative verse which has two or three meanings. One in praise of numbers, one in praise of Sāmkhya philosophy. But there is also the word "Isha" there, just so that the people who believe in God are not forgotten since you could also interpret it as "Ishvara". So it was a very clever verse. If asked, he would probably say—and I think it was a common attitude in India at the time—

that all these philosophies are very interesting. If you ask which one is the truth, we won't be able to tell. But we should know all of them. You make your choice, you say this is what you like, you make that choice. It's up to you. But that choice may be criticized, but certainly not punished ever.

Certainly not persecuted. Contextuality, living contextuality…

RN: Yes, that's right.

Indic Philosophy and Axiomatic Reasoning

There's something you said about Aryabhata which just struck me. You mentioned that when Aryabhata reasoned that the Earth must be round, that the eclipses are not caused by Rahu and Ketu, he came up with an inference which we know today to be true—that the Earth is round. On the other hand, for instance, there was Aristarchus who, starting from axioms, proved that the moon is half the size of the Earth. What led Aristarchus to an erroneous inference?

RN: Ah, right, that's the deeper question. The Greeks of course were greatly influenced by Aristotle. They think questions have a specific answer—either yes or no—with no other options, that the world is binary, in some sense, and that the way to obtain knowledge is through the axiomatic system which basically goes back to Euclid. You make a small number of axioms, and you deduce truths as consequences from there, by the kind of logic which Euclid and Aristotle made permanently Greek, so to speak. If you asked an Indian philosopher why he is not doing it that way, he would say: "How do you know that the axioms are true? Where did you get the axioms from?" So you've already decided that in this universe there are some things that are self-evidently true and are revealed to you somehow—I don't know how—and then there are others which are consequences. He would doubt your axioms—how are you sure about your axioms? Even Neelakantha makes a statement somewhat like that: How do you make hypotheses, how do you make axioms? The Greeks, however, were so fascinated by what Euclid did—and it *is* fascinating, I must say; when I went to school I was also fascinated by what Euclid did. I didn't realize these were all big things which had been argued endlessly long ago for centuries—it's amazing. This guy [Euclid] makes only these five statements, and he said he proves all these things.

In terms of actual numbers, till early 19th century, the Indian predictions were at least as good as what the Europeans were using

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So, when you look at the Greeks, it almost became, as we say in computer science, garbage in, garbage out. You make your axioms, you get your conclusions. But if your axioms are garbage, your conclusions are garbage too. And because proof by the axiomatic method became so fashionable, people began to make all kinds of funny axioms and came to all kinds of funny conclusions, which you normally don't see in accounts of Greek history. Now, I first discovered them in a book about Babylonian astronomy which Otto Eduard Neugebauer wrote.[9]

He's written about Babylonian mathematics, and some Greek mathematics, with comments and so on. In that book, he makes a brief statement—doesn't dwell on it much—about how the Greeks prove all kinds of theorems. By taking the right kinds of axioms, they would prove the moon is half the size of the Earth. If you read Ptolemy, he makes a lot of statements about what he believes—all the rest of the results come from there. But today we know that most of those things are not true. There was a Greek homospherical model that they believed in for a long time. You know about the homospherical model—that the universe is a finite sphere?

There are concentric spheres with Earth at the centre?

RN: Shells, yes, with Earth at the centre. But that ran into a problem with the idea of vacuum. Vacuum, they said, can't exist. But you can see through the sphere, and the sphere is finite, with all the stars stuck on the inside of the sphere. So the shells must be transparent. But what should it be made of? According to Aristotle, nature abhors vacuum. Therefore, they said, it must be glass, or crystal. But they also thought that the planets were moving around the Earth at different velocities. How can that happen? So they said there must be shells of glass sliding past each other, and built quite an elaborate picture out of this. As far as Ptolemy and other people like him were concerned, it was all consistent.

But then you could ask: where is this glass, where are the shells? This is not to ridicule Ptolemy. His work was, I think, the height of what was done in Greece in some way in terms of astronomy, and many of the predictions he made are pretty good. They were pretty good till recent centuries. But at the same time, we must also remember that the Indians never talk about this kind of model— almost never. They say: I don't know if there is glass or not, and I have no problem with vacuum and I can see through it. They had no problem with zero, vacuum and so on. We don't mind infinity either. So we were not surprised by big numbers, we were not surprised by infinities, zero and so on. Such assumptions as glass shells never make an appearance in Indian astronomy at all.

And they made predictions which are valid.

RN: And they made valid predictions. Exactly.

There is one point which confuses me. On the one hand, John Playfair had pointed out that astronomical calculations in India fit observations about as accurately as Newton's did. Except that India's predates Newton's by about a thousand years. But didn't that also mean we had to have more accurate observations than the Europeans?

RN: They were pretty accurate observations till almost the 1820s or so. It's only then that things began to become more accurate in Europe.

I see. Now, I think [Johannes] Kepler and Tycho Brahe were crucial in making very accurate observations of the planetary positions. Do you know if there was a similar person in India who made accurate observations?

RN: Well, with Copernicus and others, the effect of their observations in astronomy had not yet reached a scale of accuracy in mathematical sophistication till the early 19th century. In terms of actual numbers, till early 19th century, the Indian predictions were at least as good as what the Europeans were using.

But how were the Indian observations so much more accurate? Could it be the geographical location, with India being closer to the equator?

RN: I don't know. But the equator might have some effect, it's possible. I haven't thought about it that way. But what is clear, however, is that they believed in observations. The first thing you have to do when you get your shishya is to teach him to make observations carefully. They therefore knew what was the accuracy of the results they had. The driving consideration was that you should not make unnecessary hypotheses. You know, we call this Occam's Razor today. Occam's Razor was a principle in the Sāmkhyas for a long time. If you have a simpler explanation, instead of something which was superfluous to you and more complicated, don't invoke God. This was virtually what they said. So the Sāmkhyas were actually neutral about God. There were two schools there. One is the Nirīśvara school. It's not atheistic, it is non-theistic. The Nirīśvara school people say: "Where is the evidence?" The evidence is not convincing, that's what they say. To me, that seems far more rationalistic than any philosopher said in Europe till only very recently. Certainly it was more rationalistic than what the Greeks said.

The Indic Approach to Logic

You said that for the Greeks the answers were either yes or no. But what other states could an answer be other than yes or no?

RN: According to the Indians—there are many Indian schools here, including the Buddhist school—it could be yes or no; both yes and no; or neither yes nor no. There are four possibilities. Whereas the Jains believe there are seven possibilities. In other words, it was certainly not true that everybody said it has to be yes or no. Not true. Many people

would argue that you know, you can't just do it by yourself. Why? But you can say, no that just doesn't make any sense. It was because they were extremely conscious of the weaknesses of language. How are you sure that you have something which you can reach with your language? Let me take a very simple example—if you take a glass and half fill it with water, can you say it's half-full or half-empty? Tell me one answer.

Both.

RN: Exactly. You see, you are therefore, instinctively, an Indian, believing in the Chatushkoti system—there is no "paradox".

I see.

RN: If you asked the Sāmkhyas, "Is there a God or not?", they would say they don't know. They accept "we don't know" as a valid answer. In Greece it wouldn't be possible—it had to be either yes or no.

So quantum mechanics hit the West harder than it hit us?

RN: Absolutely correct. You are 100% correct. Doubt is possible in India. In other words, Indians have been saying: We're not sure we can understand all of knowledge. And knowledge also has to do with language. On the one hand, there were people like Panini who studied Sanskrit in such extraordinary detail, unmatched according to Western scholars till around 1800 in Europe. Unmatched. At the same time, they also knew the weaknesses of language. There are concepts that you can't reach with the words that you have at your control.

In fact perhaps Panini himself mentions this. He has these vyākaraṇa viśeṣas , that there are certain verbs which fit into some rule, and that there are some which are exceptions.

RN: Exceptions, exactly. They are exceptions to the rule he has stated. Therefore, it can also be thought of as a new rule. He has some 3800 plus rules or something, in all of Sanskrit—which is an extraordinary enterprise. But he was also conscious that there are things which happen in this universe for which you don't have words. In Sanskrit, there's a word anirvacanīya—it basically means it is beyond words.

Panini has some 3800 plus rules or something, in all of Sanskrit—which is an extraordinary enterprise

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This has a strain of, I think, some of the things Wittgenstein speaks about.

RN: Exactly. Wittgenstein made a statement which the Indians would have thoroughly approved. Just as they would have had no philosophical problem with quantum mechanics. Of course, now, unfortunately what happens in India today is that because we have no philosophical problem with quantum mechanics, people would say we invented quantum mechanics—which is not true. We did not invent quantum mechanics. But we are not philosophically disturbed by quantum mechanics at all.

There's a story about Hideki Yukawa, the first Japanese Nobel Prize winner. He was once asked: "You come from Japan. What do you think of quantum mechanics, the fact that something can behave sometimes like a wave, at other times like a particle. Doesn't this confound you?" He said "You see, we in Japan have not been corrupted by Aristotle."[10] So it never struck him as a problem.

So, what is this one statement of Wittgenstein that you felt ancient Indians would have approved of?

RN: He said Western, Greek logic is tautology. You know, Wittgenstein wrote in sutras, short sentences, and there's one where he says that logic is tautology.

But what does he mean by that?

RN: What he means by that is like the old Indian objection—my interpretation of it—where did you get your axioms from? And once you got your axioms, all the rest of the statements have no more information than the same axioms. You're not saying anything more beyond the axioms, it's tautology from those axioms. You're just repeating that axiom in different forms, in infinite forms.

In information theoretic context, you are not learning anything more than what has already been said. You are just rephrasing it.

RN: I think that's what Wittgenstein would have said. And that would be something which, once again, like quantum mechanics, Indians wouldn't have been surprised about. That's why we don't believe in axioms.

Now, the question that all of this doesn't answer is the following: How come, if we were so good, we are not a force in the world today? See, that is the question which all of us have to think about. That is the real question.

As of, let's say, three or four centuries ago, say around 1600, the Indian system, and also the Chinese system, were actually ahead of the West. They had no need for Europe, no great respect for whatever the Greeks said. And you know, we were smug—approximately like the West is smug now in the last hundred years or so. Therefore, when the events began happening in Europe, we didn't think that there would be anything very new we could learn from them, and that carried on until 1600 or 1700. We were not curious about what they were doing.

The Rise of Western science

What events do you mean?

RN: Scientific developments. Take Newton for example. Newton was in the 17th century, and he did revolutionize science, you have to admit that. See many Indians today—the Indians of this other school saying we knew everything—they don't admit that. I think they are making a big mistake. We have to find out the secret of European science, after having understood the methods and the logic of the Greeks. I feel that's also a fascinating question because, as I said, around 1600, no Indian would have thought that there was anything we needed to learn from Europe. He would, for centuries, have become used to his knowledge going east to Southeast Asia, to China, to Middle East, and from there through the Arabs to Europe.

Around 1600, no Indian would have thought that there was anything you needed to learn from Europe

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Now let's go back to Newton's times. What happened in Newton's times? I think the best thing that happened was Francis Bacon. You have to read Francis Bacon—what he says has the answer to why Western Science is ahead, as far as I can see. He sees what's happening in Europe, and he says Europe is in bad shape. It's rather like what our Indian leaders said in the 19th century, that we're in bad shape. He says that if we go back to the

Greeks for our knowledge, we find that they were quacks—you should see the words that he used for those Greek philosophers. They just use words, they don't do anything—they don't observe, they do not respect experiment. Aristotle was a quack, he says. Things of that sort. And Bacon says we have to change. We really have to change.

Raja Rammohan Roy was like our Francis Bacon, or Francis Bacon was their Raja Rammohan Roy. Just as Raja Rammohan Roy said we better read English, Bacon said we don't get the proper way of doing science from the Greeks. And they could see that there was technology from the East they had never heard of, for which there were no Greek words. Exactly as the situation in India now. You see, we have no Indian words for the technologies we use today. So the Europeans borrowed words from the Arabs, because the Arabs translated them from the Sanskrit. That's why we have so many Arab words in science today—algorithms, algebra and so on. They are all derived Arab words really. They found that there was no word in Greek for these things. They began to say okay this is coming from somewhere else. Descartes, meanwhile, was confused about algebra.

You mean Descartes was convinced that the Greeks somehow knew algebra?

RN: Yeah, he said the Greeks knew algebra, but they were mean. [11]

They didn't want to tell future generations about this discovery they had made. That was one of his explanations. But these things you never hear if you read the standard books on Descartes. Now if you want to read what he thought of the Greeks and algebra, you would have to go to those people who have actually made a serious study of such scholars. I feel that what we think about the West is coloured by a poor education system. It doesn't worry about history. When it worries about it, it gets information from a second hand source which is not reliable and so on.

I wrote an article called "The Chequered Histories of Epistemology and Science".[12] If somebody asks me who was the greatest scientific power in the world, I would ask them: When? At what time? And the way of doing science is also chequered, it's not been the same throughout. Sometimes one has been more effective than the other. It is changing even now I think.

Mumford came to me and said, "You know, this idea of proofs… too much has been made of it"

In physics, you mean?

RN: Even in mathematics, for example. I mean, Gödel's theorem puts logic in a different light. Now, at a seminar in CMI [Chennai Mathematical Institute] some years ago, David Mumford had come. I gave a lecture about proofs and so on. At the end of the lecture, Mumford came to me and said, "You know, this idea of proofs… too much has been made of it." So I think that the view in mathematics has also changed. Now you

see computers have become very important. And many things will come straight from computers, we will accept that. That's once again a method which would not have caused any surprise in India. That's what we were doing for a long time.

But I want to emphasize both things, because that's where we are losing out in India now. There are people who claim all kinds of things for India, which we know are not correct—in some cases we can prove it is completely wrong. And then there are these other people who think nothing interesting happened here. This is not what happened at all, as I see it. And I don't think it takes any great insights to come to these conclusions, if you just keep your mind open. I can't make any other guesses about how these things have happened. I mean, you can't explain why, for example, as Needham said, for 1400 years there was no science in Europe. You see, we forget that. There was no new science in Europe for a long time during their more than thousand years of the Dark Ages. It was all here in the East. So I say the last 300 years or so have been our dark ages.

I have read A.K. Ramanujan's essay, "Is There an Indian Way of Thinking?".[13] You brought up this notion that Nilakantha, for example, was comfortable knowing six different schools of Indian philosophical thought. Ramanujan talks about his father, who tells him that "there are two lobes in your brain, so of course you should know both your Gita and your physics."

RN: Exactly, that's right. You know, whatever is not consistent with our current ruling paradigm, people tend to take that as false or irrational, mumbo jumbo and so on. I don't think that's necessarily correct. At different times there are different ways of doing things. None of them is necessarily wrong, but they may not be effective at some time for whatever reason.

In fact, A.K. Ramanujan had this imagery of Indians having this toolbelt of different ways of reasoning.

So I say the last 300 years or so have been our dark ages

RN: Exactly. Well, as Ramanujan says, context is important in India. When I read newspaper commentary about politics, I feel that they could all take a course on Ramanujan or read somebody like that.

We were wondering if we can have another sitting sometime. We find it very hard to believe that three hours have gone by. We would love to pick up from here and resume the conversation another time for the second part of this article.

Footnotes

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10. R.S. Cohen, J.J. Stachel. Niels Bohr's Contribution to Epistemology [1963h] (https://doi.org/10.1007/978-94-009-9349-5_36). *Selected Papers of Leon Rosenfeld*, pp. 522–535. Springer, 1979.
11. M.S. Mahoney. *The Mathematical Career of Pierre de Fermat, 1601–1665*. Princeton University Press. 1994. ISBN 9780691036663. The exact quote is: “But when I afterwards bethought myself how it could be that the earliest pioneers of Philosophy in bygone ages refused to admit to the study of wisdom anyone who was not versed in Mathematics, evidently believing that this was the easiest and most indispensable mental exercise and preparation for laying hold of other more important sciences, I was confirmed in my suspicion that they had knowledge of a species of Mathematics very different from that which passes current in our time… Indeed I seem to recognize certain traces of this true Mathematics in Pappus and Diophantus, who though not belonging to the earliest age, yet lived many centuries before our times. But my opinion is that these writers then with a sort of low cunning, deplorable indeed, suppressed this knowledge.”
12. Chapter 6 in *Different Types of History*, ed. Bharati Ray. Vol. XIV, Part 4 of *History of Science, Philosophy and Culture in Indian Civilization*. Series ed. D.P. Chattopadhyaya. Pearson Longman. 2009. ISBN 9788131718186.
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