Praise for *India's Science Geniuses*

'A remarkable insight into some of the stellar work being done by Indian scientists across disciplines, from some of the top experts in the country. The lucid language makes for excellent reading. For the young, a snapshot into Indian S&T and great inspiration, too.' – **Hasan Jawaid Khan, Chief Scientist, Council of Scientific and Industrial Research-National Institute of Science Communication and Policy Research**

'We are going through the most glorious phase of almost all branches of science, spurred by generous support from society and an atmosphere of goodwill across people of the world. This is a very valuable book that will teach students (and their parents) about the intellectual pleasure that lies in following your dreams and your curiosity.' – **Professor Dinesh K. Srivastava, Homi Bhabha Chair Professor, National Institute of Advanced Studies**

'Kudos to all the trailblazer scientists who are working in the forefront of research in science and technology to unravel the unrevealed mysteries of this Universe. Written in such a simple style that even a layman would have no difficulty in understanding. Highly recommended!' – **Sudhanshu Mani, creator of Train 18 (Vande Bharat Express)**

'An eye-opening book that shows us all the amazing work India's scientists are doing and teaches us about the most cutting-edge research too. I thoroughly enjoyed it.' – **Professor Ashutosh, Sharma, Former Secretary, Department of Science and Technology, Government of India**

India's Science Geniuses

India's Science Geniuses

(And the Problems They Are Solving)

Archana Sharma
with
Spoorthy Raman

juggernaut

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Dedicated to all students who continue to challenge our imagination and creativity to find new ways of sharing and learning. And to all the inquisitive minds, doing something incredible, somewhere …

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Preface

This book has grown from its predecessor, *Nobel Dreams of India: Inspiring Budding Scientists*, where I recount my interactions with over 100 outstanding scientists from our country! Working on the book gave me an insight into how scientists have evolved from their humble backgrounds and carved a way for themselves. There's a common thread in all the stories: rigour and persistence. That's where the thought

From the author's personal collection

Classroom of my Jhansi school, 1976

arose, to edit this compilation, to speak in detail to 30 (actually 31, if you wish to include me!) of those scientists working in Nobel-winning niche fields of science.

The stories have been selected to showcase a representative diversity of scientists from our country working on cutting-edge scientific research. They represent big science: physics, astronomy, chemistry and biological sciences that need infrastructure and support from funding agencies. The dream is to further the capacities of our budding scientists, take leadership in MegaScience projects across the world and achieve sustainable development goals for our country. And it is possible! I have witnessed that science is a great redeemer despite being geographically uneven. Perseverance is the key. We must listen to the background score when we think there is too much white noise around us. In this book, you may see something beautiful, you may hear someone speak to your heart and that will change everything in your course.

I was a young girl growing up in Jhansi, a quaint Indian town. I didn't dream of becoming a doctor or an engineer like most of my friends. I was also curious and that led me to do experiments at home with my siblings and like-minded friends, instilling in me an eternal passion to learn new things. As the daughter of two teachers, my academic achievements were my topmost priority. I was born into a middle-class Indian family, with meagre means, but that did not dim the little light in me. Focusing on both my education and my career was important to my parents and me. Picking the opportunities around me, I continued to give my best,

From the author's personal collection

Receiving a prize at Banaras Hindu University, 1980

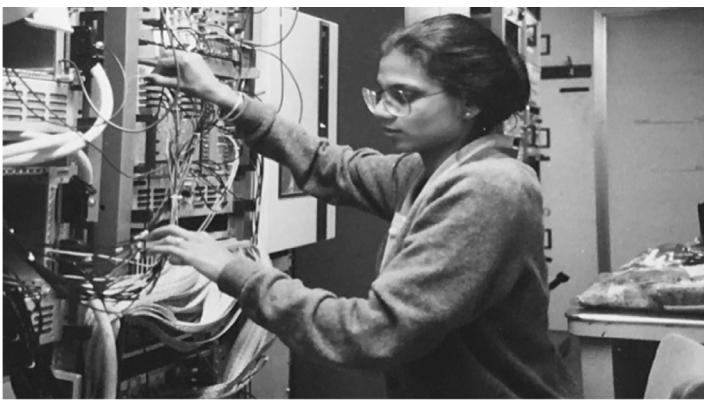
whether it was academics or sports. The desire to excel was deep-rooted in me.

I had a physics teacher in school who not only introduced me to the world of physics but also encouraged me to focus on other science subjects. My teachers were my role models; they inspired me to become a teacher. The concept of Particle Physics intrigued me greatly. I wanted to learn more, to know the how and why of matter. The feeling of learning something new made me even more excited. It was like peeling an onion, every layer being different and magical.

Even at the university, I was fortunate to have teachers and mentors always available. Many of them were women, and they soon became part of the role model group that was forming in my mind. They consolidated my love for teaching. But still, the journey through science was a long, arduous

one, full of challenges. I graduated from Banaras Hindu University (BHU) in Varanasi, India, but I was not done or satisfied. My thirst for knowledge, fuelled by motivating teachers, made me pursue Nuclear Physics for my research. I was so excited when I got admission to do my PhD at Delhi University, which I duly completed in 1989.

It was during my doctoral studies at Delhi that I was invited to the Conseil Européen pour la Recherche Nucléaire, or European Council for Nuclear Research, (CERN) to participate in a workshop, which had a lasting impact on my career.



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At the lab of Nobel Laureate Georges Charpak, CERN, 1987

While at the workshop, I saw other scientists in different specializations – physics, data analysis, engineering, instrumentation and many more – working towards attaining a common goal together. This, to me, was inspirational and I hoped for an opportunity to work at CERN. My hope turned

From the author's personal collection

Building detectors for the CMS Experiment at CERN, 2004

From the author's personal collection

A very first Fast Timing Detector, patented in 2016

to reality when I got a letter saying that I had been admitted for a three-year fellowship at CERN to work in the radiation detector unit headed by Group Leader Georges Charpak, who eventually won the 1992 Nobel Prize in Physics.

Due to lack of infrastructure and hands-on training back in India, there was a huge gap in my knowledge, which I had not realized even though I had been the best in class with good grades.

This lack that I felt in my training, working in an electronic detector laboratory, was quite stark, resulting in a long-lasting imposter syndrome, one of the challenges I had to overcome. It took me a lot of time to finally take charge by asking questions and being unhesitant to fail. It prompted me to enrol for a second PhD, at the University

of Geneva, Switzerland, in 1992 . During this period, I focused on experimentation and studying gas detectors for radiation, which later became my expertise. Through this, I carved a different path for myself. By then, I was sure that research was my calling and decided to stick with it for the rest of my career.

Being in a place surrounded by physics and particles on the one hand and technology and engineering on the other is an adventure. I was privileged to be a part of this big world that is CERN. Every single day brought opportunities to learn new things and overcome new challenges, along with receiving small rewards in many varying ways. My major focus was Particle Physics – the study of the smallest constituents of matter and how these particles interact. Particle physicists study these elementary constituents. Everything around us, including us, is made from particle matter. One of the things I loved about CERN was how the physics programme at the laboratory was broad based, from nuclear to high-energy physics, from studies on antimatter to the effects of cosmic rays on the clouds, and each day, I continued to learn a lot.

From the author's personal collection

During installation of RPCs at CMS CERN, 2021

My work at CERN was to

design and build tools called radiation detectors needed to study elementary particles. In 1987, I had my first research assignment, and it was to carry out electronic measurements in wire chamber detectors. I also had to do simulations to understand their properties. For me, it was a big win since I never had the chance to work in an actual lab with electronic equipment while I was in India. Learning to create and use the tools, both software and hardware – as they were important for my research – was one of my biggest achievements over the years. My career began to grow and I set off to establish myself as a 'detector physicist'.

One of the biggest research works I was privileged to be a part of at CERN was the search for the Higgs boson. In 1964, Higgs, Englert and his colleagues presented a theory stating that there must be a mathematical explanation for why other particles have mass, why things hold together and why the Universe exists at all. The key was the Higgs boson, nicknamed the 'God particle'. This discovery required a large number of people, literally thousands, to work in tandem. Some worked on preparing the accelerator, the Large Hadron Collider (LHC) that accelerates the protons to high energy collisions. The LHC is the world's largest and most powerful accelerator, consisting of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way. Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam

pipes. Thousands of magnets of different varieties and sizes are used to direct the beams around the accelerator and then made to collide at the large experiments placed at interaction points on the ring. Trillions of electron volts produce enough energy to create the Higgs boson.

Then came experiments like A Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) with detectors (complex mobile cameras) needed to take pictures to see and record these particles. That is where my work from over two decades came in handy. I had been designing and building detectors, together with my team, since the 1990s and through the aughts. By installing and operating these detectors, one could detect muons (another elementary particle), which could tell whether a Higgs was produced or not. To make a discovery, we need muon detectors since they can pass through metres of iron and provide a clean signature. We installed hundreds of detectors like the Resistive Plate Chambers that started taking data at the switch-on of the LHC in 2010. The discovery of the Higgs boson in 2012 was one of the major achievements of Particle Physics. For the discovery of the 'God particle' by ATLAS and CMS experiments at CERN, Professor Higgs and Professor Englert were awarded the Physics Nobel Prize of 2013.

For the last twelve years I have been the privileged Project Manager for a new detector system that I conceived and built from scratch. With the help of a large team, we worked on and then introduced a new technology – the Gas Electron Multiplier (GEM) – for muon detectors, designing and

building radiation detectors for the CMS experiment. The collaboration spanned 16 countries and 40 institutions. In the 2020–21 period, we completed the installation of these detectors; commissioning is ongoing so that data taking can begin when the LHC restarts later this year (in 2022).

A good number of institutions from India have collaborated in the CERN projects and continue to be actively engaged in more such research work. When I joined CERN in March 1987, very few Indian scientists worked there; over the decades, this number has grown. More than 250 scientists and students from India are now associated with CERN, and over 400 of Indian origin, if we consider the whole world. Starting in the 1990s, India formally engaged with CERN first as an Observer State and later, in 2017, as an Associate Member State. More researchers and institutions from India are joining hands and collaborating with CERN in the accelerator programme, experiments and other sectors.

But many institutions in India continue to face the lack of infrastructure and tools to carry out experiments and, as a consequence, students lack practical knowledge. However, these challenges can be overcome. One of my goals is to help aspiring scientists become experienced and skilled with relevant expertise.

As a budding scientist today, there are many opportunities to grab, and one must not overlook them. Persistence and consistency are the keys to success. In my field of work, I had to engage twice as hard to be noticed or taken seriously as

a woman scientist. It was also one of the challenges I faced while working in Geneva as a scientist. My parents never treated me differently from my brother; they saw us as equals. It was a challenge knowing how different the perception was in the outside world and at work. Even though I was highly qualified for every position that I held, I was still not taken seriously by male colleagues until my work began to speak for itself. I have worked very hard to break the stereotype that women cannot succeed in male-dominated Science, Technology, Engineering and Medicine (STEM)-based careers. Due to social responsibilities, women are required to work harder to prove that they can hold their own and be as successful as a man in their chosen career paths. Stereotypes are the bane of women, especially in the scientific field, and in the past decade, the effort has been to break the mould.

From the author's personal collection

Overseeing the GEM detectors at P5, CMS CERN

When I first moved to Geneva, if I told someone I worked there, they automatically assumed I worked as a secretary or a translator for the United Nations (UN). As much as I respect the

professional secretaries and translators, I wasn't really excited about these assumptions.

In the last couple of decades, things have changed for the better. Women are taking the lead and choosing career paths that were often male-dominated. Women are getting into science and are being recognized as scientists everywhere. I have met such inspirational women scientists and engineers at CERN, who are confident and capable in the positions they hold. One such woman is Fabiola Gianotti, our director-general. Thanks to her and many other women at CERN who became my role models, I could also grow with confidence. I continue to learn, bettering my technical knowledge as well as self-development; my field of work offers me the opportunity to learn each day. I recently completed a course on High Impact Leadership from the Cambridge Institute of Sustainable Studies and another on Business and Climate Change: Towards Net Zero Emissions.

There are many women in the world today who lack the confidence to grow, made worse by people around who tend to not take them seriously and discourage them to go ahead in science. One must never let these small obstacles come in the way of one's goals. I managed to succeed in my career path because I refused to back down. In India today, women are excelling in many different fields. They have before them inspiring role models in science who have won Nobel Prizes. Marie Curie and Irene Joliot-Curie are two of them in the past; Andrea Ghez and Jennifer Doudna are the more recent names. I believe Indian women scientists have

a bright future ahead of them and every challenge comes with a solution.

During my entire career at CERN I have interacted with various students from different countries, many from India. International exposure is very important from an early age. I have been privileged to have had this opportunity; it would be a crime if I did not use it to the benefit of aspiring children of my country. Interactive sessions helped shape my career when I first decided to take up research. Now I spend an hour or two each week interacting with students and teachers in India and sharing my knowledge with them. The pandemic has provided opportunities to reach out and share democratically.

It has been really exciting to share my work and experiences at the world's largest laboratory with students. I knew how much it would intrigue students and make them interested in studying science or choosing a career in STEM.

From the author's personal collection

My first GEM station installed at CMS CERN, 2019

For students, boys and girls, men and women who aspire to become scientists some day, the future is bright. If the scientists of the past had not taken the risks that they had taken, science would not have progressed. Einstein's imagination and curiosity resulted in unimaginable rewards that we use every single day, whether it is the GPS we deploy to plan our journeys or the green energy that is helping us now to tackle climate change! Marie Curie's work on radioactivity gave us a new field of study – Nuclear Physics, now Particle Physics – with an impact on society that is hard to conceive. Imagine having to fix a broken bone without having the X-ray as a tool! These are being refined in laboratories even as we speak.

If you think it, you can find a way to make it come to fruition. No one knew what the humble electrons and photons would mean when they were studied and discovered. Today they are literally changing the whole world with the help of engineering and technology.

Today, in India, laboratory infrastructures have improved greatly, institutions have stepped up as well, but we still lack some necessities to do science. The challenges students of STEM face in India are numerous. There could be centralized facilities for all students to use in all fields of science. My dream is to make this small difference possible in India. How I still do not know, but it is one goal I intend to achieve.

There are many MegaScience projects that will benefit and positively impact not just India but the world as a whole. By taking the risk and making the right choices, by

building our curiosity and finding answers to our scientific questions, we can change the world. To my reader who may be an aspiring student or learner, my advice would be never to doubt yourself. There is always a possibility that you will win when you take risks. Pursuing a career in STEM is important, regardless of gender, regardless of the challenges you may face. By choosing a career in STEM, you are opting to change and impact the world, one step at a time. There could be a small fire burning in you right now; do not doubt your ability to grow and sustain that flame. Feed your intellect, and it will grow. You have the ability to fulfil your dreams. Do just that.

I was an ordinary girl from Jhansi (Uttar Pradesh), curious, who wanted to know more, who had questions and needed answers. Today, I have followed a career in Physics and realized my dreams. I continue to tackle challenges and obstacles, and I have realized these form an integral part of the journey.

I hope that this collection of fascinating stories of scientists will inspire you to make the right choices, take risks

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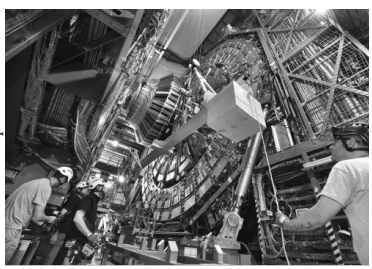

From the author's personal collection

Left and Right: Commissioning of the newly installed GEM stations by my team, 2021

and carve your own path. The stories have emerged from individual interviews with the scientists and we have tried to showcase their science and life in the most inspirational manner.

Do not forget: the flame of curiosity burning in you cannot be put out!

Archana Sharma
20 April 2022