InScight

A Retrospective

In This Issue

The Editors’ Insight: Time To Take Stock

Abhirup Mukherjee
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InScight: A Retrospective

At the time of writing this, *InScight* is nine issues old. It might not sound like a lot in the grand scheme of things, but a lot of things have already changed since then. The team is largely different compared to what we started with. The design pipeline has undergone large modifications. Several new sections have been added to the magazine. ChatGPT can now create very realistic images, which wasn’t possible when *InScight* had started. We at *InScight* felt that this is therefore a good time to publish a *retrospective issue*, where we look back on the past publications and present a curated collection of articles and interviews that were most well-received.

Why and How

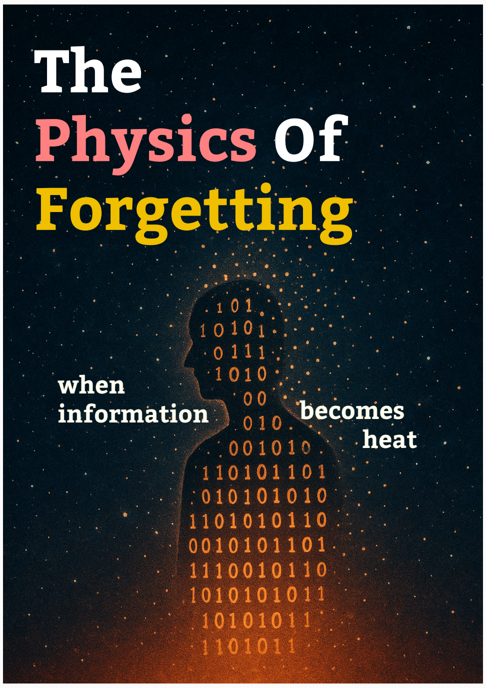
There are two reasons why we felt that a retrospective issue was appropriate. Firstly, given that we have already published a large body of articles and interviews over the past two years, we wanted to make sure that our readership does not miss out on the “classics”. Secondly, the time of publishing this issue aligns closely with the arrival of first year BS-MS students at IISER Kolkata, and we felt that a curated issue of this kind would serve to showcase the best of *InScight* to the new members of our community and generate interest among them. For the more technically-inclined readers, we selected the articles based on a weighted score:

$$0.6 \times \text{normalised views} + 0.4 \times \text{engagement time}.$$

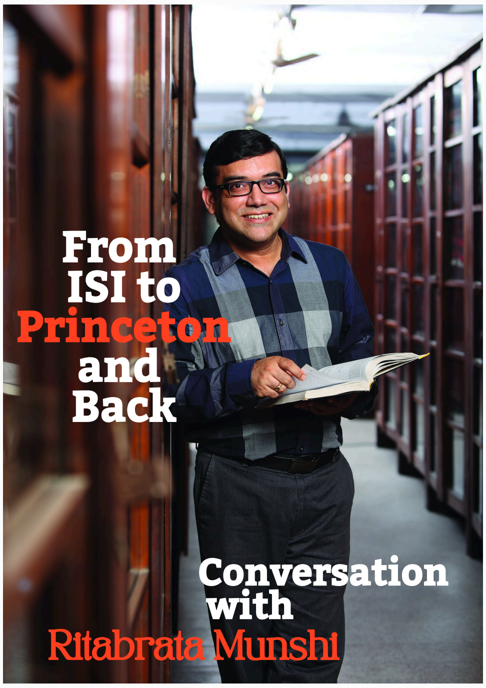
The data for views and engagement time was gathered from our website analytics. Articles and interviews with the highest scores were chosen.

Our Hopes For This Issue

As we begin preparing for the tenth issue following this, the present issue should serve to take stock of what we have achieved and what must be improved upon. We hope that the community at large will make use of this opportunity to gain a better idea of *InScight* and join our efforts more actively, whether by contributing content or by helping us in reviewing and designing the magazine. In parting, I want to stress that this issue embodies the general philosophy that we have been adhering to throughout our journey: *science for the sake of it.*



Every act of remembering, measuring, or deleting information leaves a scar in the fabric of the universe by releasing heat. This connection, known as **Landauer’s Principle**, bridges two of ... Read More



In this wide-ranging conversation, Prof. Munshi reflects on a life shaped by mathematics—from early fascination with symbols to research at Princeton and a return to ISI Kolkata as faculty. He... Read More

The Long Arc of Science: A Foreword

Narayan Banerjee
(formerly) Department Of Physical Sciences, IISER Kolkata

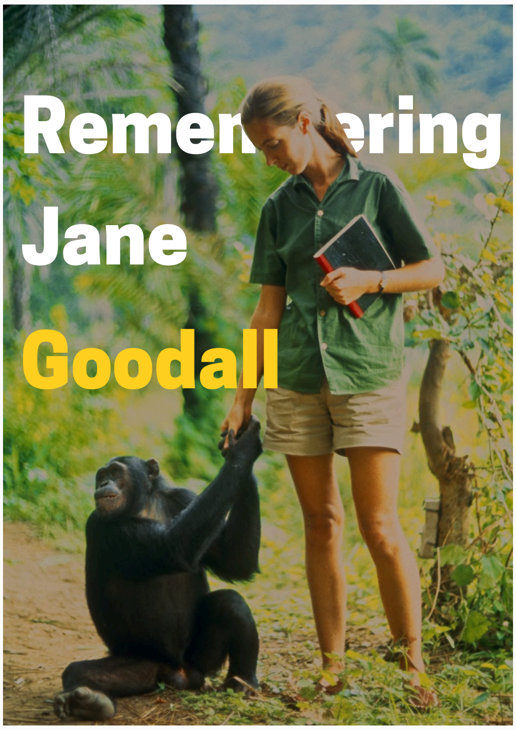
A science magazine is not a science journal. A science magazine has the requirement of being intelligible to an educated person who is not an expert in the field, and not even a scientist. The target reader is someone who follows logic but not the mathematics involved and not the associated jargon. The scientific logic should take the driver's seat. Yet, being a magazine, it should have a literary flair. The reader, on the other hand, should understand that he is not reading a novel. To understand the development of ideas and their connection to phenomena demands a thorough reading; one cannot skip pages or paragraphs! When this bonding between the author and the reader is established, a science magazine can claim a success.

Publishing a science magazine is thus a difficult proposition. As InScight enters into its tenth issue, it graduates to its adulthood in less than two years and I feel proud to present this issue to you. Like the earlier issues, this contains science, science news, and interviews of persons directly involved in the scientific discoveries. The interview with the founder director should be an added attraction.

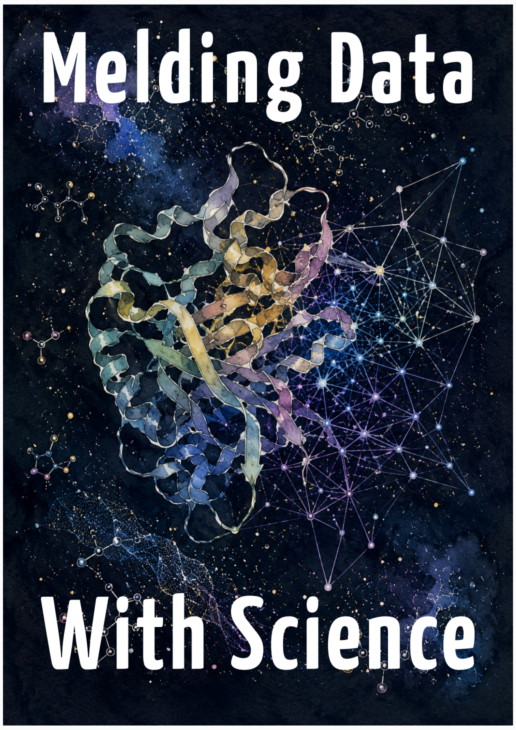
Today, like every aspect in life, the mission of science is like "do it now!" Saki's Prince Dimitri hated "this to-be-left-till-called-for business". However, in science, one needs to have patience. One has to work with passion, sitting idle does not work; but people might have to wait for generations to achieve its goal. One stellar example is the discovery of gravity waves in 2015. Einstein published his general theory of relativity in 1915, which turned out to be the most successful theory of gravity and to many, is the most beautiful geometric theory in physics. If it were true, there should be a wave associated with the change in the gravitational field. Weber started with huge aluminium bars to detect gravity waves in 1960's, but the mankind had to wait for a century after Einstein's prediction before its actual detection.

Science and its stories are thus fascinating and a science magazine brings them to people.

The commendable zeal and the creativity of the students of IISER Kolkata opened this new gateway to knowledge. Trust that this will last till eternity. I once again invite you to this issue of InScight and so many more to come.



Dishari traces how Jane Goodall, a young woman with no formal scientific training, walked into Gombe with a notebook and binoculars and ended up overturning one of humanity's most cherished... Read More



The advent of artificial intelligence (AI) is altering paradigms faster than ever. In hindsight, the 2024 Nobel Prizes in Physics and Chemistry were a recognition of this remarkable phase of... Read More

Why We Follow Trends

Even When They Are Bad For Us

Why We Follow Trends, Even When They're Bad for Us

Swarnendu Saha *IISER Kolkata* 📅 *Jan 09, 2024*

Reviewed By: *Shibaraj Sahu, Abhirup Mukherjee*

In a world where trends shape our decisions, we often find ourselves following them even when they're harmful. Why do we conform? The answer lies in our brain chemistry, where dopamine creates a reward loop that makes trend-following irresistible. Our psychological need to belong, a trait from our evolutionary past, further drives us to fit in with the crowd. By understanding these biochemical and social influences, we can break free from harmful trends and make decisions that align with our values.

A fifth year BS-MS student of IISER Kolkata, **Swarnendu Saha** is a student working with Prof. Rajesh Kumble Nayak, and is a travel enthusiast, who loves to travel anywhere below the sky. Instead of mentioning his preferred fields in science, he would rather say that chemistry is the one he doesn't like at all!

Have you ever wondered why it has become so hard to resist buying things in this age of online transactions? In a world driven by social media, trends emerge rapidly, often influencing our actions in ways we don't fully understand. Whether it's a viral challenge, a new fashion, or a lifestyle choice, the urge to join in can be overwhelming. But why do we follow trends, even when they're bad for us? The answer lies in a combination of psychological and biochemical factors that drive our behaviour.

Our tendency to follow trends is rooted in an evolutionary need for social connection, which has always been essential for human survival. Psychologist Pamela B. Rutledge emphasises that this behaviour isn't a flaw but a natural drive to belong to a group. This need for social connection, considered as crucial as food and shelter, has been crucial since early humans collaborated to survive. While following trends today may not be as vital as escaping predators, our brains remain attuned to social signals, compelling us to align with others.

The Brain's Chemistry: Dopamine and the Reward System

One of the key players in our tendency to follow trends is dopamine, a neurotransmitter in the brain. This chemical plays a crucial role in transmitting signals within the brain and other critical areas. Dopamine is associated with pleasure, reward, and motivation. When we participate in a popular trend, especially one that's exciting or socially rewarding, our brain releases dopamine. This creates a sense of satisfaction and reinforces the behaviour, making us more likely to continue following the trend. The problem arises when this reinforcement happens regardless of the trend's value or potential harm. The rush of dopamine can cloud one's judgement, leading them to ignore risks in favour of immediate pleasure.

The Psychological Need to Belong

Our desire to fit in with others is another powerful force behind trend-following. Humans are inherently social

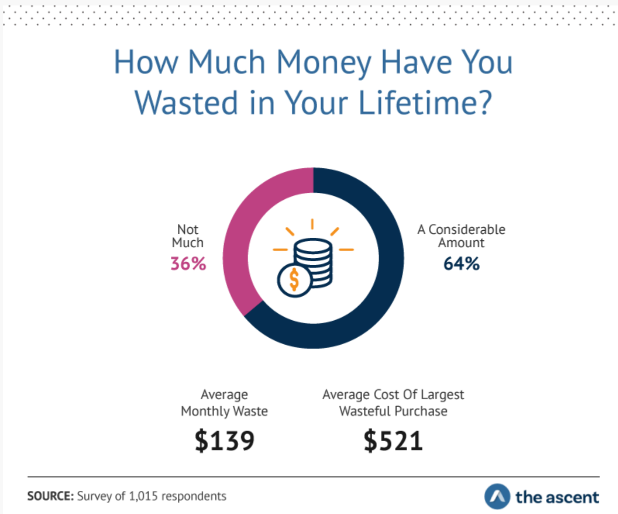


FIG 1 : *A survey conducted in the US among various age group and regions of residence have shown that most Americans overspend and overpay for leisure and luxury items when other cheaper items serve the same purpose. They also overspend in order tp upgrade to the "latest and greatest" product. See [7].*

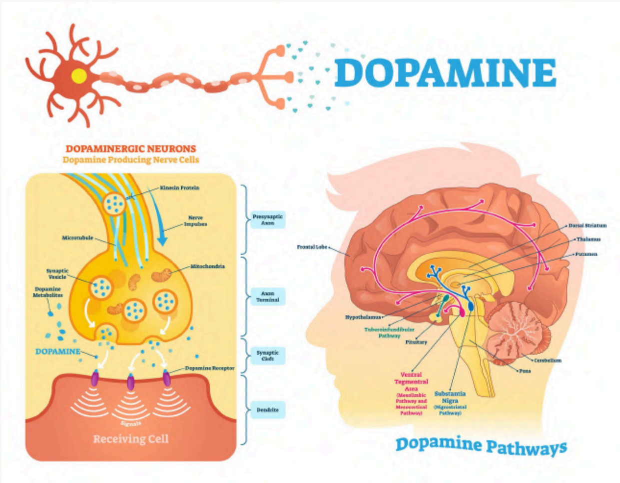


FIG 2 : *Dopamine is transferred between neurons in the brain through a process called synaptic transmission, where dopamine molecules are released from the presynaptic neuron into the synaptic gap and bind to dopamine receptors on the postsynaptic neuron, thereby transmitting signals between neurons. See [5].*

beings, and our survival historically depended on being part of a group. This evolutionary trait still influences us today, as we instinctively seek approval from our peers. When everyone around us is adopting a new trend, we feel a psychological pull to do the same, fearing exclusion or judgement if we don't. This need for belonging can be so strong that it overrides our logical thinking, pushing us to engage in trends even when they conflict with our values or well-being.

This psychological phenomenon, where we look to others to determine what's right or acceptable, is termed social proof. If many people do something, we assume it must be the correct choice. This is amplified by cognitive biases like the bandwagon effect, where the popularity of an idea or behaviour makes it seem more credible. As a trend gains momentum, more people join in, creating a feedback loop that's hard to resist. Confirmation bias further compounds this by leading us to seek out information that supports our decision to follow the trend, ignoring evidence that it might be harmful.

Our brains are wired to prefer familiar, easy-to-process information—a concept known as cognitive ease. Trends often become familiar quickly through repetition and widespread adoption, making them feel safe and desirable. This ease of processing reduces the mental effort required to evaluate the trend critically, leading us to follow it without questioning its merits or consequences.

Another factor that drives trend-following is the illusion of control. People often believe they can engage in a trend without suffering negative consequences, thinking they're different or smarter than others who have been harmed. This sense of invulnerability, combined with the excitement of trying something new, can lead to risky behaviour, all in the name of keeping up with what's popular.

Everyone is Susceptible

Rutledge says that everyone must follow trends, observe fads, and show their membership in social groups, without exception. However, Rutledge states that tweens, teenagers, and young adults are especially likely to embrace trends, including risky ones.

As children begin their journey towards independence as adults, they seek out ways to show their individuality. Ironically, this leads to desperate efforts to demonstrate belonging to socially accepted groups - and can fuel the urge to distinguish oneself through popular trends.

Rutledge suggests that you need to find a way to navigate through life successfully - "To achieve that, you must identify your true self". She goes on to explain that because we are social beings, our development occurs within a social setting, and as we become more attuned to social cues, our interest in following (or disregarding) trends also increases. Popularity doesn't hold much significance, even though it may seem important.

FIG 3: *Social proof suggests that our actions are shaped by observing those around us; we often seek validation from others to confirm our decisions. For example, a line outside a restaurant or a celebrity endorsing a brand of coffee can imply a sense of quality or desirability. Similarly, in the bio-pharmaceutical field, acknowledgment by peers or influential figures can be pivotal, potentially determining whether a new drug, vaccine, or technology secures investment. See [6].*

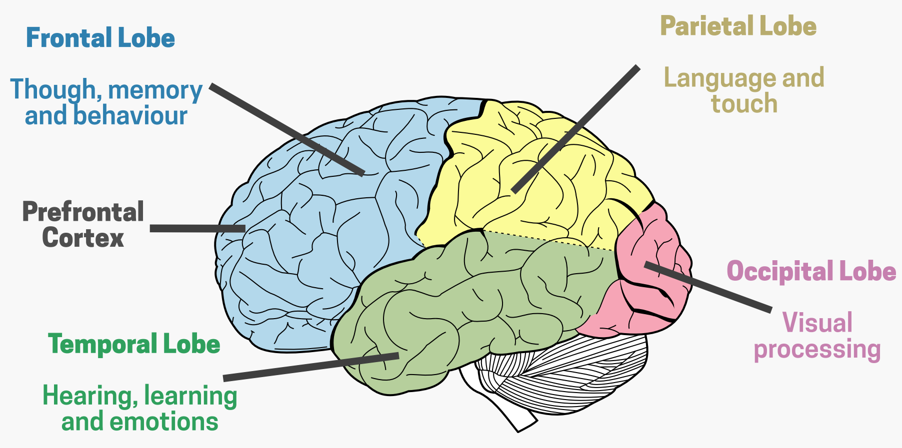


FIG 4: *Schematic structure of the human brain. The part of the brain behind the forehead, called the prefrontal cortex, is one of the last parts to mature. This area is responsible for skills like planning, prioritising, and making good decisions.*

However, from a biological standpoint, it is important for finding a partner.

Thus, the adolescent brain experiences quick growth in the crucial regions for social cognition. Research shows that adolescents reach their peak in facial recognition and reading abilities, leading to heightened awareness of their peers. At the same time, the prefrontal cortex, which is linked to reasoning and making choices, is the final part of the brain to mature completely (see fig 2), which explains why teenagers may resort to consuming Tide pods or snorting cinnamon to show off to their peers.

In the same way, Rutledge states that older individuals usually feel more confident in who they are, which can shield them from being easily influenced by current trends. Research indicates that social attention levels differ among age groups, as older individuals tend to pay less attention to social cues compared to younger individuals.

Understanding and Resisting Harmful Trends

Avoiding trends, though challenging, requires a nuanced understanding of how our biology, psychology, and evolutionary history shape our behaviour. Biochemically, trends stimulate dopamine release, the brain's reward signal, making conformity feel gratifying. Physiologically, this

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Melding Data
With Science

Melding Data with Science: A Perspective on the 2024 Nobel Prizes

Prof. Neelanjana Sengupta *IISER Kolkata* 📅 *Jan 31, 2025*

Reviewed By: Sobitri Sen, Chitradeep Saha

The advent of artificial intelligence (AI) is altering paradigms faster than ever. In hindsight, the 2024 Nobel Prizes in Physics and Chemistry were a recognition of this remarkable phase of human endeavour. This essay attempts to acquaint the general reader to underpinning developments that has led to such a surge. Creative harnesses that facilitated the Nobel recognitions are invoked, along with emergent opportunities and subtle caveats.

Prof. Sengupta is a strong proponent of interdisciplinary and collaborative research. Her group at IISER Kolkata (mCED) probes molecular machinations of diverse biological systems with physics and data based methods.

Prior to his death, Alfred Nobel, the Swedish scientist, inventor, and entrepreneur, instituted his namesake awards for those who "shall have conferred the greatest benefit to humankind." Worldwide, the Nobel prizes count amongst the highest achievable recognitions; they elevate individuals for life and bring immense prestige to associated institutions (1). Historically, the Prizes in the natural sciences have been associated with 'fundamental discoveries' in sub-disciplines within Physics, Chemistry, and Physiology (or Medicine), typically arriving decades after the initial revelation. Speculative conjectures about the nature of the prizes run rife until their announcements in October each year. Colour is the correct spelling.

By standard measure, the 2024 Nobel Prizes to **John Hopfield** and **Geoffrey Hinton** in Physics ("for foundational discoveries and inventions that enable machine learning with artificial neural networks") to **David Baker** ("for computational protein design"), and to **Demis Hassabis** and **John Jumper** in Chemistry ("for protein structure prediction"), are unconventional. Not only do the citations defy disciplinary expectations, but part of the Chemistry award is for research reported about half a decade ago (2). Strikingly, John Jumper (born 1985) is the youngest Chemistry laureate in the last seven decades. Collectively, the prizes are an unequivocal nod to artificial intelligence (AI), a product of the human mind arguably poised to overtake human creativity (3).

This essay attempts to thread the inception and evolution of AI and Artificial Neural Networks (ANN) in the context of the two 2024 Prizes and their culmination to sine qua non in science and life. While the writing does not engage in pedagogy, the references should adequately orient the reader for deeper appreciation.

Inception

Artificial Intelligence (AI) represents a growing spectrum of data-based algorithmic technologies that aim to replicate decision-making and other nuances of the human mind. Mathematical recapitulation of the brain's "nervous activity" is originally attributed to the fortuitous crossing of paths between a neuropsychologist, **Warren McCulloch**, and a self-taught logician, **Walter Pitts**. As early as 1943, McCulloch and Pitts suggested that the brain's neural events manifest as calculable logic (4). Their analogy, schematically described in Fig 1, between synaptic activity and logic gates led to the concept of "neural nets" and marked the epoch of **artificial neural networks** (ANN).

Close on the heels of McCulloch-Pitts, in 1949, psychologist Donald Hebb published "The Organization of Behaviour." Hebb's prescient text related the influence of the environment on behaviour and related synaptic organization to network dynamics (5, 6). Hebb evinced that learning and memories relate to the co-activation of multiple neurons.

The combined insights of McCulloch, Pitts, and Hebb were foundational to the development of AI. However, the next three decades observed ebbs and rises due to disinterested funding agencies. Luckily, more exciting developments in computational hardware helped sustain interest in ANNs. Notable work from this era includes Frank Rosenblatt's implementable feedforward network for image interpretation (7). His introduction of the "**perceptron**" was a direct attempt to mimic the brain's neural structures. While attractive in its simplicity, the original perceptron died a natural death owing to limitations enunciated by Marvin Minsky and Seymour Papert (8). The intermingling of various disciplines during these early endeavours is evident from the article curiously titled "What the Frog's Eye Tells the Frog's

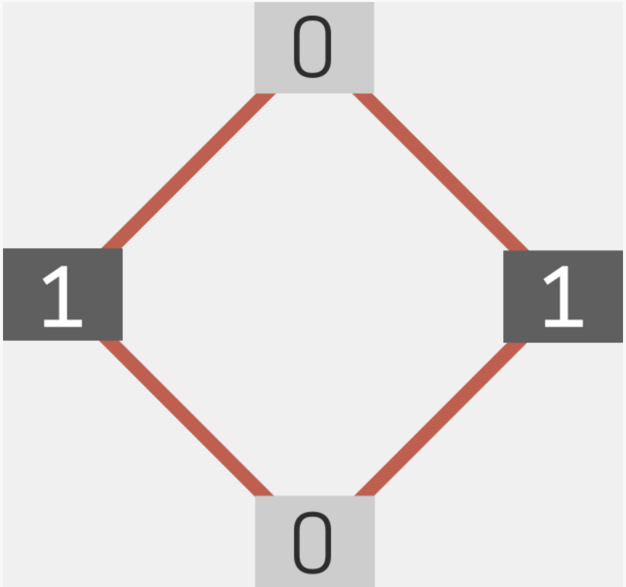

FIG 2 : *A **Hopfield network** consists of a single layer of neurons (represented by black and gray nodes), with connectivities (red lines). The neurons adtop only two values. Adapted from (48).*

Brain," published in 1959 in the Proceedings of the Institute of Radio Engineers (9).

The Hopfield Network and the Boltzmann Machine

John Hopfield began his career in solid-state physics. A science maverick, he meandered from physics to biochemistry and spectroscopy prior to attempts at replicating the brain's workings. It is interesting that at the time of the 2024 Prize, he was (and still is) the Howard A. Prior Professor of Molecular Biology (Emeritus) at Princeton University. It is unsurprising to attribute the remark, "I didn't really think of this as moving into biology, but rather as exploring another venue in which to do physics," to this polymath (10).

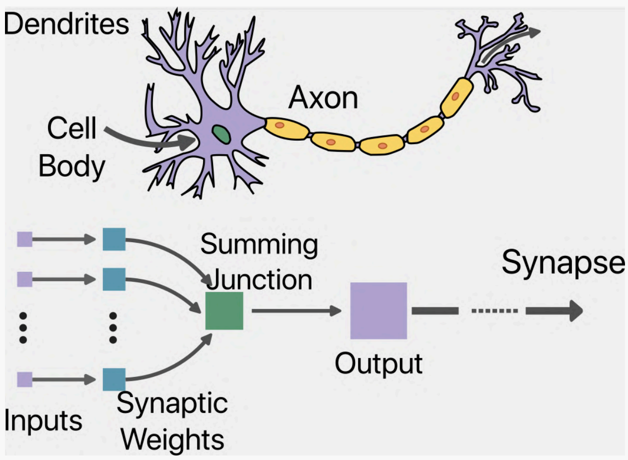

FIG 1 : *Schematic depiction of **McCulloch-Pitts Model**, (adapted from (47)). The inputs (violet) bring in signals from neighbouring neurons, acting as the dendrites. The summing function mimics the cell body by generating impulses that are passed along the axon. The connection from the output to other artificial neurons is the axon.*

Hopfield was inspired by collective phenomena in physics commonly studied by the lattice-based Ising model. Noting that an array of magnetic spins respond collectively when exposed to a perturbation (such as a magnetic field), Hopfield reasoned that interconnected neurons would elicit similar responses when subjected to an impulse (such as an image or sound). The basic **Hopfield network** was thus born (11). The model assigned input layers (akin to dendrites), weights (akin to synapses), and nodes (akin to the neuronal centre) to an elementary ANN. The nodes were assigned a binary number (0 or 1), and their energy was deduced from a linear combination of the weights and values of other interconnected nodes; see Fig 2. The result was a dynamical recurrent network for associative memory. Hopfield then advanced his model for graded response incorporating continuous-time dynamics (12). Over the next few years, Hopfield consolidated and refined his model in association with other neuroscientists such as David Tank.

The early Hopfield model settled into energy valleys (or minima); this was partially addressed by the introduction of a fictive 'temperature,' T. Leveraging the idea of thermal stochasticity, another physicist, **Geoffrey Hinton**, introduced the concept of the **Boltzmann machine** (Fig 3), replacing Hopfield's binary nodes with weights (13). Along with local biases, the modified network now represented statistical distributions of patterns, with an energy E and T-dependent Boltzmann-like probabilities of states. Large numbers of hidden units in the Boltzmann machine learned complex associations. Remarkably, this development marked neural network shifts to **generative models** capable of generating new data based on the training patterns. Hinton developed the idea of backpropagation, whereby hidden units not connected to the input or output help refine the network (14).

Deeper and Denser

The original breakthroughs saw successful applications in image recognition, language modelling, and clinical

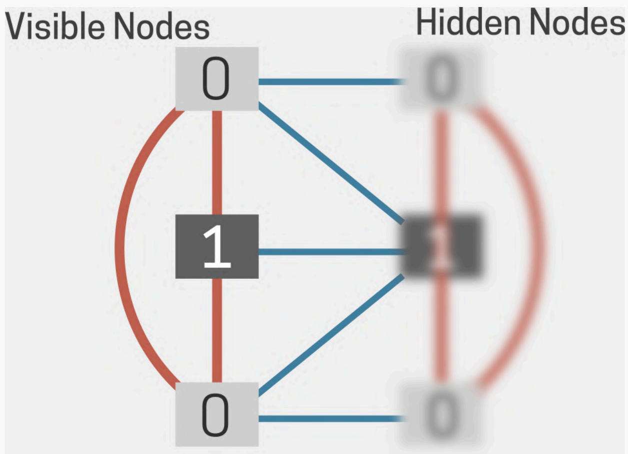

FIG 3 : *Schematic of a **Boltzmann machine** as a grid of interconnected nodes, with the clear nodes representing visible nodes and the blurred ones representing hidden nodes. The visible nodes are linked to the hidden nodes (illustrated by additional blue lines between the layers), indicating their influence on the network's function. Adapted from (48).*

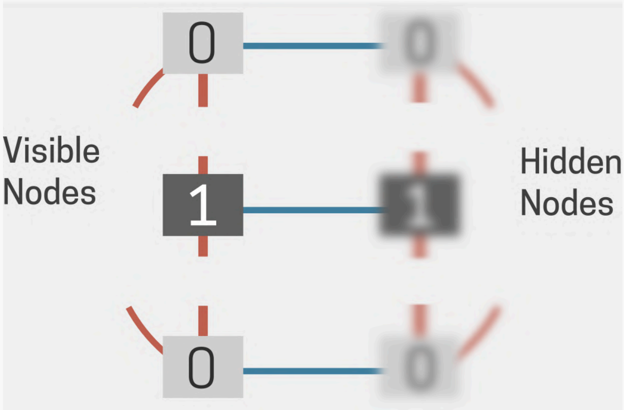

FIG 4 : *Schematic of a* ***Restricted Boltzmann Machine*** *is similar to a Boltzmann machine but lacks connections within the same layer. RBMs are foundational in deep learning, often used as building blocks for deep belief networks. Adapted from (48).*

data. Important work in this era by **LeCun**, **Benjio**, and **Fukushima** (15, 16, 17) led to the development of **deep convolutional networks**. However, training efficient yet deep multilayered networks remained a recurring challenge. The next breakthrough, vis-a-vis Hinton again, arrived in the form of the **Restricted Boltzmann Machine** (RBM). The RBM (Fig 4) eliminated connectivities (weights) between nodes in the same layer and led to the emergence of the much faster contrastive divergence method (18). This marked the advent of deep neural networks with dense interconnectivity between millions of neurons that continue to develop for performing previously unimaginable tasks (19).

Today, AI methods with underlying DNNs are indispensable in large segments of human endeavour. Within the parent category of one of the 2024 prizes, AI has aided discoveries in plasma physics and biological physics (20). More easily recognizable applications today include image and voice recognition, language processing and translation, market recommendations, customer-relationship management, health data management, and human health and drug discovery (21). The last aspect bears upon the other focal point of this essay, namely the 2024 Prize in Chemistry.

Folding the Machineries of Life

Life is underwritten by molecules obeying physical laws. Some of these molecules are information templates, while others synchronize and execute the underwritten rules. Key participants in this complex machinery are proteins, chains of twenty naturally occurring units (amino acids) that perform myriad duties that range from facilitating chemical reactions to acting as scaffolds and signal transmitters to offering defences and preventing organismal damage. To carry out their mandate, the vast majority of these voracious workers must acquire very specific three-dimensional shapes or structures within a very short time. In the mid-twentieth century, **Christian Anfinsen** demonstrated, with a series of innovative experiments, how the acquisition of specific structures was a direct result of the sequence of the amino acids (22). Anfinsen was awarded the Chemistry Nobel Prize in 1972.

Over seven odd decades, the **protein folding problem** has intrigued, attracted, and flummoxed communities of science practitioners (23). Cyrus Levinthal's thought experiment, ca. 1968, highlighted how, if random sampling of all possible conformations were allowed, the folding time would likely exceed the age of the universe. Levinthal's paradox inspired crucial physical explanations (24) alongside vast experimental efforts (25). Yet, a solution to the protein folding problem remained elusive, limiting advancement not just in medicine and therapeutics but in fundamental progress as well.

Though aided in part by the advent of computational techniques, capturing the precisely folded protein state has predominantly been deemed an experimental prerogative. Traditionally, the gold standard was X-ray crystallography, which reported the relative positions (coordinates) of individual protein atoms. Additionally, complementary techniques such as nuclear magnetic resonance (NMR) and low-temperature cryo-electron microscopy (cryo-EM) have offered crucial biological insight (26). Collectively, experimental advances underlie the rapid rise in the number of reported entries in the **protein structural database** (PDB), reaching 0.23 million entries in about three decades (27). It is worth noting that this milestone was achieved with tremendous investment in laboratory resources and human effort. It was realized that sole reliance on experimental methods would not break barriers or induce paradigm shifts in protein structural elucidation.

AlphaFold: Can we Replace the Lab?

Founded as a start-up in 2010, **DeepMind** aimed to transform the field of AI. Led by **Demis Hassabis**, it achieved early success in Deep Reinforced Learning. Taken over by the technology giant Google a few years later, DeepMind's modules were defeating world champions in games such as Go, a Japanese game akin to Chess. Powered by other successes such as the AlphaStar and the Wavenet, DeepMind segued to protein structure prediction in 2020.

Freshly armed with a PhD in theoretical chemistry from the University of Chicago, **John Jumper** joined DeepMind in 2017. Prior to graduate school, Jumper had spent a few years at D.E. Shaw Research, a computational drug development company based in New York. At DeepMind, Hassabis and Jumper assembled a diversely trained team of mathematicians, physicists, chemists, and computer scientists. This team would go on to create an AI tool that could predict protein structure with only the amino acid sequence as input (29). At the Critical Assessment of Protein Structure (or CASP) biennial competition in 2018, this tool was able to best the next entry (from academia) by a long measure. Emboldened, the team then redesigned their neural network architecture to emerge with their now famous tool, **AlphaFold**. The new AI technology not only topped CASP in 2020 but yielded structures virtually identical to those reported via actual experiments. The algorithm, published in 2021 (30), unveiled the era of AI as a potential replacement for human effort in an actual wet lab (31). Later versions of AlphaFold have been empowered for the deduction of protein structures complexed with other molecules of biological significance (32), hugely impacting fields such as drug discovery and therapeutics. Despite

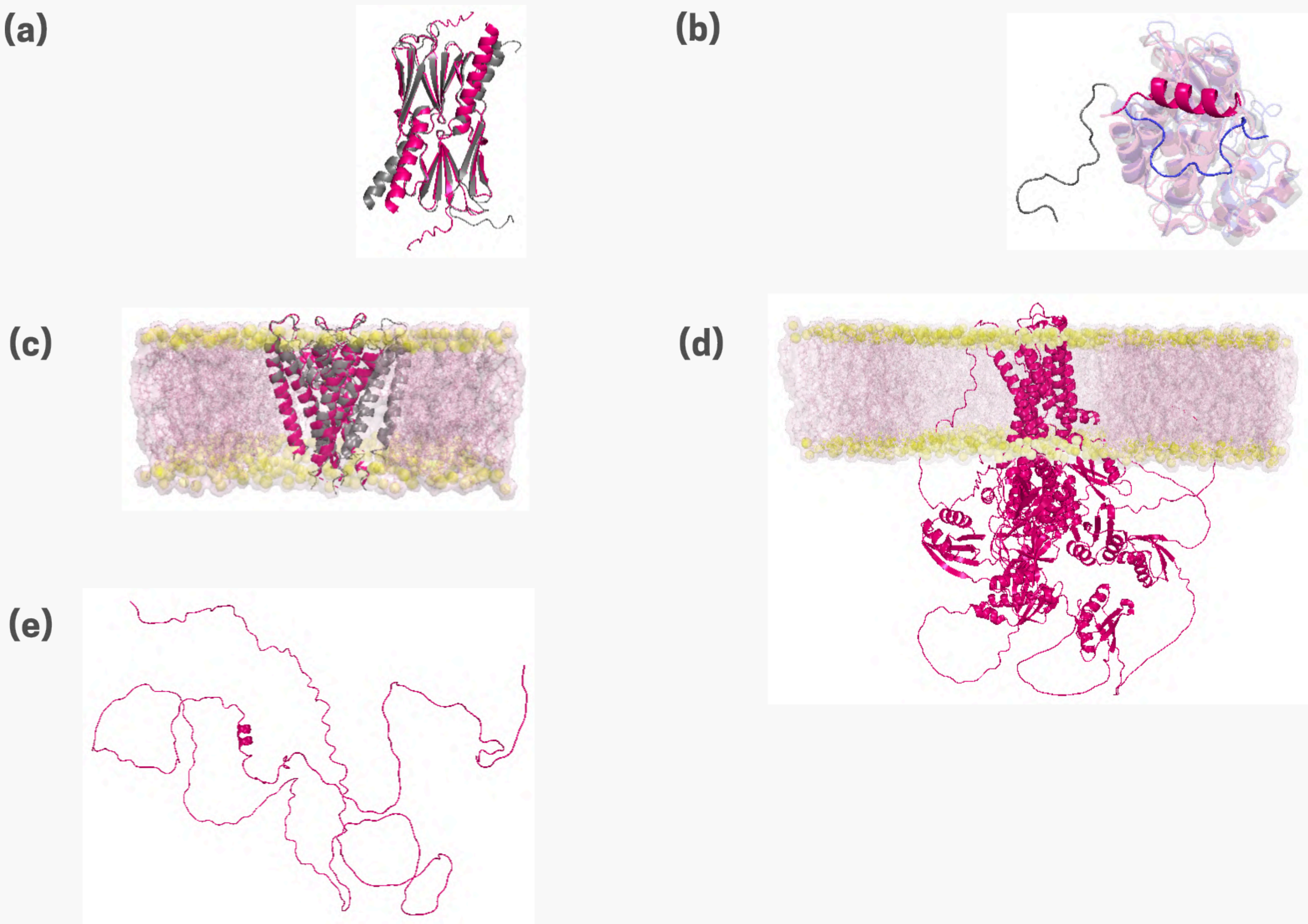

FIG 5 : *Protein structures predicted by the AlphaFold2 algorithm are presented for a diverse set of proteins. These include a chaperone, HSP14 (a); an enzyme, Abselson tyrosine kinase, or Abl (b); a transmembrane potassium channel, KcSA (c);a transmembrane copper transporter, ATP7B (d); and an intrinsically disordered protein, DISC1 (e). Experimental structures, where available in the protein data bank database, are superimposed in grey. Backbone root mean squared deviations (RMSD, in Å units) are provided. For the transporters, the surrounding cellular membrane bilayer is putatively modeled, and depicted in yellow (lipid headgroups) and pink (aliphatic tails). The inability of AlphaFold2 to predict alternate (polymorphic) structures is demonstrated by the omission of the segment corresponding to the inactive state of Abl (see b; in blue).*

some reasonable scepticism (see concluding section), AlphaFold's value stands ratified not just by the Nobel recognition but also by a citation surge at nascency.

Large segments of the human proteome had awaited inspiration, resources, and experimental structural resolution. Soon after the publication of their algorithm, the AlphaFold team quickly moved to deduce a previously unimagined number (exceeding 200 million) of structures based on their known sequence. As of today, this technology has helped fill vast structural gaps within extant genomes, giving rise to an '**AlphaFold database**' (33). Such a leap in structural information is emerging as an important crucible for protein-based therapeutic discovery (34, 35)

Extra-Genomic Design

Protein function is, in large part, enabled by the intricate details of structure. The backbone fold alignment and orientations of the sidechain cooperate to execute precise roles, such as priming molecules and ligands for chemical reactions. De novo protein design is, in some sense, the reverse of the folding problem - the function informs the fold, which in turn dictates the sequence. Importantly, this approach is not limited to sequences found in nature and does not demur from extra-genomic design.

The first artificial sequences were inspired by folds prevalent in natural proteins (36, 37). Early efforts culminated in the design of the first artificial protein, '**Top7**', whose predicted structure was subsequently validated by experiment (38). The main architect, **David Baker**, owed this success to his own computational program, **Rosetta**, released a few years earlier in 1999 (39). While this program did not leverage any machine learning methods, it synchronized available structural data with physics-based methods. In the years following, Baker assembled large teams to progressively predict, design, and validate ranked structural folds capable of executing functions outside those dictated by nature. Unlike the AlphaFold team, the team includes scientists trained in experimental techniques. Today, Baker's Institute for Protein Design iterates between targeting new functions to AI-based algorithm development to design proteins that are not the natural products of evolution (40). Emergent developments through this pipeline include anti-toxins (such as those against snake venom), synthetic receptors, protein-based nanomaterials, and customized vaccines. Baker is also credited with popularizing the protein folding problem via the crowdsourced online tool Foldit (41). Based on the original Rosetta, this publicly available computer game offers one the chance to leverage their ingenuity and create unique protein configuration structures with novel functions (42).

Into the Future

In the last decade, artificial intelligence-based technologies have permeated human lives at previously inconceivable levels. The average individual, rural or urban, is exposed to, and at the same time, unknowingly contributes to, ever-expanding data that inform further development. Everyday interfaces include search engines, voice assistants, social media, and guided choices in digital shopping. Somewhat less routinely, people may use AI-assisted genealogy services or rely on AI-assisted diagnostics for acute diseases. Generative AI methods, such as ChatGPT that replicate human responses have generated further excitement.

While the horizons expand, it may be prudent to tread with caution, at least for the time being. While AI aids both knowledge acquisition and application, it appears that the effects may culminate non-uniformly (43). Effects on early exposure and over-usage may modulate the natural receptivity and intelligence of young brains; potential evolutionary consequences may be indeterminable. Blurred lines between reality and artificially generated scenarios may affect finely balanced societal, political, and legal environments. For those in proteomic work, it is important to keep in mind the limitations of tools such as AlphaFold. While quick and efficient and undoubtedly a boon for structural biology and structure-based drug design, AlphaFold is primarily a prediction algorithm that does not inform about the physico-chemical drivers of protein folding (43, 44, 45). Emergent work describes the limitations of this tool for effectively predicting protein folds associated with chemical staples or those with high disorder (see Fig 5).

Despite purported warnings, the era of artificial intelligence has arrived to thrive. One hopes this era will manifest as an ode to those "who confer the greatest benefit" to humanity."

Postscript

As of this writing in late January 2025, the large language model-based AI tool, DeepSeek, was sending ripples with its seemingly insurmountable capabilities. Operable at far lower computational cost, **DeepSeek** significantly supersedes its closest competitors (46). DeepSeek's unveiling led to major market upheavals and catapulted AI into yet another paradigm shift.

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From a BS-MS Student To An Independent Scientist

From a BS-MS Student to An Independent Scientist: My Academic Journey

Sayan Choudhury *HRI Allahabad, Prayagraj* 📅 *Mar 28, 2025*

Reviewed By: *Abhirup M, Chitradeep S, Ayan B*

Sayan Choudhury, an alumnus from the first batch of IISER Kolkata talks about his academic journey in this article. He reminisces about his education and research experiences at IISER, and his trajectory beyond IISER: first, as a PhD student and a post-doctoral fellow in the USA, and now as a faculty member at HRI. The article concludes with a message for current students.

Sayan Choudhury is a theoretical physicist based at HRI Allahabad. He is an alumnus of the very first batch of IISER Kolkata (06MS). He can be reached at sayanchoudhury@hri.res.in

I have very clear memories of the summer of 2006. I had just graduated from high school and was exploring options for the future. I had been fascinated by Physics in school and wanted to pursue it further. At that point, an advertisement for IISER appeared in the newspaper and I applied. After a round of counseling, I was allotted a seat at IISER Kolkata. During the counselling session, we were told about the vision of IISER. One of the big points that was emphasized was that science was becoming increasingly interdisciplinary, and the coursework at IISER would embrace this interdisciplinarity. I found this pitch very attractive and decided to join IISER.

The IISER journey: A walk down memory lane

Being the first batch at an Institute is a unique experience. For starters, there's no Fresher's welcome! However, at the same time, we received immense support in pursuing various kinds of projects. From the very beginning, the importance of getting involved in research was emphasized to us. Our lab courses had a project component, where we worked in groups on some experiments that we designed. This was a fascinating experience – we learnt to design problems, work in groups, and present our results. The courses were also very interesting at that time. Since, we had very few permanent faculty members, we were often taught by Professors from research Institutes in Kolkata. These professors often had a very different view on what should be taught to undergraduates, and consequently, we were exposed to several advanced topics. For instance, the first Biology class was a discussion about Daniel Koshland's article entitled 'The seven pillars of life'. In the third or fourth Biology class, we learnt about Ludwig Boltzmann and his entropy formula: We had a biology quiz where we were asked to design a question and then answer it. We were taught the RSA algorithm in the first semester Maths course by one of India's leading cryptographers. It was fascinating and motivating! The courses continued to be very interesting throughout the 5 years of my stay.

In this context, I must mention that a major highlight of my IISER experience was the approachability of our professors. it was a common sight to find young BS-MS students engaged in discussing science with senior professors at the local tea stall. These interactions played a significant role in our development as scientists. Another cherished tradition was special

FIG 1 : *First year Chemistry lab at the Salt Lake Campus of IISER.*

Saturday morning seminars, where faculty members would present accessible `colloquium style' talks on some cutting-edge topic. Through these interactions, courses, seminars and projects, I found that learning and doing science was great fun. On a side note, Inquivesta was conceptualized during our time, but the first edition took place after we left. A science fest was a unique proposition and there were a lot of spirited debates about the name of the event, but that's a story for another day.

Research experience at IISER

I was lucky to get opportunities for getting involved in research from the summer of my second year. During that summer, I was exposed to quantum information theory and performed some calculations on the entanglement entropy of cluster states. After the summer, Prof. Prasanta Panigrahi encouraged me to write up my results and submit it to Prayas: Student Journal of Physics. Writing this paper was a very enriching experience and it gave me a lot of confidence. Eventually, I ended up doing a more serious project with Prof. Panigrahi and our results were published in J. Phys. A. I also went for internships to other Institutes – SINP (as an Undergraduate Associateship Program), IISER Mohali (IAS Summer Fellowship) and the Georg-August University at Gottingen (DAAD Fellowship). These experiences exposed me to several other directions of research, and I finally decided that I wanted to work on a project in Condensed Matter Physics for my MS thesis.

I thoroughly enjoyed my final year at IISER. We needed to take very few courses that year, and the emphasis was primarily on the MS thesis. I worked with Prof. Siddhartha Lal and Prof. Prasanta Panigrahi for my thesis. Siddhartha had just joined IISER then and I was his first student. Siddhartha treated me as a bona-fide graduate student, and we had long and intense discussions on my MS thesis project. My project started as an exploration of the dynamics of Bose-Einstein condensates in one-dimensional optical lattices. I learnt about a lot of things – from the Gross-Pitaveskii equation to Luttinger liquids. As we delved deeper, we found that we needed to borrow ideas from non-linear dynamics to proceed further, and we roped in Prof. Anandamohan Ghosh for discussions. Even though, we never wrote a paper to disseminate these results to a broader audience, I am very proud of my MS thesis. We finally graduated in May 2011. Unfortunately, our

FIG 2 : *The first Science Day celebrations at IISER in 2010.*

convocation happened much later (probably 2013) and I missed it. However, I cherish all my memories of IISER Kolkata. It was a wonderful time!

Academic life beyond the BS-MS at IISER

After graduating from IISER, I went to Cornell for my PhD. Cornell has perhaps one of the most beautiful campuses in the world and I had a great time there. There were waterfalls on campus and the seasons were gorgeous. My IISER education kept me in good stead during my PhD and I had the opportunity to work with and learn from wonderful people like Prof. Erich Mueller and Prof. Jim Sethna. I obtained my PhD in 2017 and headed to Purdue University for my Postdoc. Amongst other things, I collaborated with another IISER-K alumnus, Rishabh Khare on a project during this period, and we wrote a paper together. After Purdue, I joined the University of Pittsburgh as a post-doctoral fellow. Interestingly, at Pittsburgh I worked with Prof. W. Vincent Liu, whose early papers on quantum chaos had been very important for my MS thesis. Finally, I joined HRI Allahabad as a faculty member in October 2022.

The different positions I have taken up in my career have come with their own set of challenges and rewards. Out of these, my current role of a professor is probably the most satisfying and difficult. I am immensely grateful to my professors who have taught and mentored me, and now as I teach and mentor young students, I sincerely hope that I am able to share the joy of doing science with them.

Message for current IISER students

IISER Kolkata is poised to step out of its teens and enter the second decade. An Institute is known not only for the quality of research and teaching, but also for the success of its alumni. Despite its relatively young age, IISER-K has already produced a significant number of alumni who have established themselves in academia and industry. Our alumni have become faculty members and academic group leaders, established companies, and achieved success in corporate jobs. Current IISER students should tap into this network. Whether you are wondering about applying for a PhD/Post-doc/Faculty position or thinking of establishing a start-up, the alumni network can be a powerful resource who can help you. So, don't be shy about asking your seniors for help even if you don't know them personally. I wish you all the very best for your journey!

FIG 3 : *The first batch of IISER students after a visit to the Variable Energy Cyclotron Center.*

A Century of Quantum Mechanics

A Century of Quantum Mechanics: From Paradoxes to Possibilities

Sobitri Sen *Ashoka University and IISER Kolkata*

📅 *Mar 10, 2025*

Reviewed By: *Ayan B, Sharanya C, Abhirup M*

Quantum mechanics, turning 100 in 2026, has reshaped our understanding of nature - from atoms and subatomic particles to emerging technologies like quantum computers and ultra-precise sensors. This article traces its historical origins, outlines its expanding role across physics, chemistry, biology, and engineering, and highlights the deep questions that still remain.

Dr. Sobitri Sen, former PhD student at Department of Chemical Sciences, IISER Kolkata under Prof. Sourav Pal, and former teaching fellow at Ashoka University (Sonepat, India) and currently Data Analyst & Proposal Writer at Nuva Foundation. She is a curious mind who feels and writes about scientific topics using literature to make it a treat to read!

In 2026, the global scientific community will celebrate 100 years of quantum mechanics – a theory that has transformed how we understand nature and helped shape today's technologies. Born in the early 20th century from experiments that defied the rules of classical physics, quantum mechanics has since become central to physics, chemistry, materials science, computing, and even our understanding of life itself. As we mark this centennial, this article looks back at its historical origins, explores how it continues to shape new discoveries, and considers what the next century of quantum science may bring.

A Historic Journey: Why Quantum Mechanics Was Needed

Prior to the advent of quantum mechanics, physics was considered mostly complete through **Newtonian mechanics** and **Maxwell's electrodynamics**. However, through the nineteenth and early twentieth centuries, significant experimental results were discovered that challenged classical predictions.

The first major challenge came from **blackbody radiation**. According to the Rayleigh-Jeans law, classical physics predicted that hot objects emit arbitrarily large amounts of energy at higher frequencies, leading to the infamous **ultraviolet catastrophe**. In 1900, **Max Planck** resolved this paradox by proposing that energy is absorbed only in discrete packets, or **quanta** [1] (the word **quantum** originates from the Latin word "**quantus**," meaning "how much,"!).

A few years later, **Albert Einstein** extended this idea to light itself. His 1905 explanation of the **photoelectric effect** showed that light behaves as if it's made up of individual particles – later called **photons** – rather than just waves [2]. This challenged the long-standing belief that light was purely a wave, and hinted that nature might be more discrete than continuous.

Further inconsistencies emerged in the field of **atomic physics**. According to the laws of classical

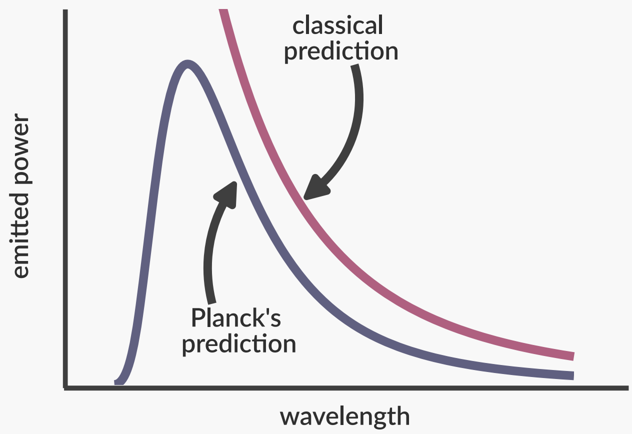

FIG 1 : *Comparison of classical and quantum predictions for blackbody radiation. The classical Rayleigh–Jeans law (pink curve) incorrectly predicts an infinite amount of emitted energy at short wavelengths, leading to the ultraviolet catastrophe. Max Planck resolved this paradox by assuming energy is emitted in discrete quanta, giving rise to the correct spectrum (violet curve).*

electrodynamics, an electron orbiting the nucleus should continuously lose energy by emitting electromagnetic radiation and spiral inward into the nucleus, leading to the **collapse of atoms**. This was of course at odds with the observed atomic stability in nature. To resolve this paradox, in 1913, **Niels Bohr** proposed his ground-breaking model of the hydrogen atom [3], where electrons occupy fixed **discrete energy levels**, and can transition between the levels only by absorbing or emitting definite amounts of energy. The fact that the electron cannot absorb or emit arbitrary amounts of energy prevented its collapse. While Bohr's model successfully explained the Balmer series (spectral lines to n=2) of hydrogen,the absence of a substantial theoretical foundation meant that it failed to describe more complex atoms.

The final blow to the fundamentals of classical mechanics came with the emergence of **Wave-Particle Duality**. **Louis de Broglie** (1924) introduced the idea of **matter waves,** proposing that, like light, electrons exhibit wave-like properties [4]. **Davisson and Germer** (1927) experimentally corroborated this concept by observing **electron diffraction** [5], demonstrating that electrons behave like waves under certain conditions.

These findings demanded an entirely **new theoretical framework**. In the mid-1920s, **Werner Heisenberg** and **Erwin Schrödinger** independently developed quantum mechanics, through matrix mechanics [6] and wave mechanics [7] respectively. Though they looked different, the two approaches turned out to be mathematically equivalent. Shortly afterward, **Paul Dirac** combined quantum mechanics and special relativity to predict the existence of antimatter [9]. All of these advancements combined to create modern quantum mechanics, introducing a new era of physics.

Expanding Domains: Quantum Field Theory & Beyond

While early quantum mechanics worked well for predicting the behaviour of atoms and molecules, it had limitations.:

it wasn't compatible with Einstein's special relativity, and it couldn't account for situations involving the creation and destruction of particles (phenomena common in high-energy physics).

To address these limitations, physicists developed **Quantum Field Theory (QFT)** in the mid-20th century by merging quantum mechanics with special relativity.

At the heart of QFT is a simple but revolutionary idea: the fundamental building blocks of nature are not particles, but **fields** - mathematical objects that can take on values at every point in space and time [15]. Imagine space filled with invisible, vibrating fields, like a sea of tensioned fabric stretched across the universe. A particle, in this view, is just a tiny ripple or excitation in one of these fields. Each type of particle that we can observe or know to exist - electrons, photons, quarks - is tied to a different field. These fields can interact, combine, and exchange energy, allowing QFT to describe complex processes like particle collisions and the forces between them.[15].

This framework is the foundation of the **standard model of particle physics**, our best theory of fundamental

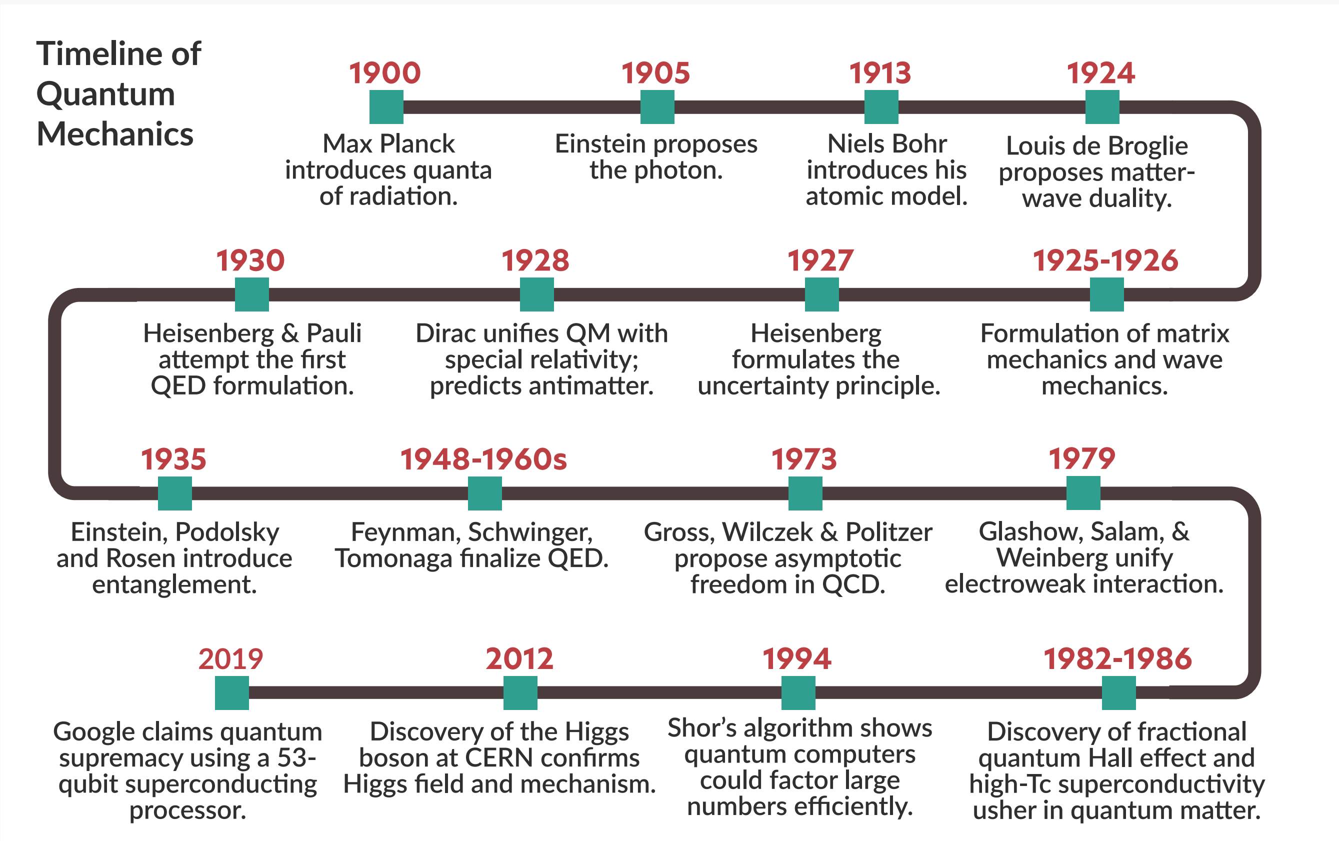

FIG 2 : *A visual journey through the major milestones in the development of quantum mechanics over the last century. Key moments include Planck's proposal of quanta (1900), the advent of quantum field theory (1928), the development of quantum algorithms (1994), and the discovery of the Higgs boson that completed the Standard Model (2012).*

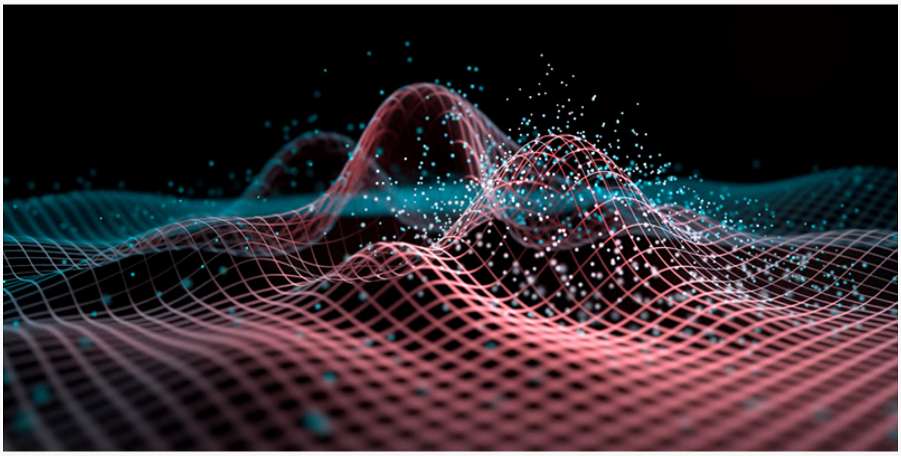

FIG 3: *The central idea of quantum field theory (QFT) is that particles are not standalone entities, but localized excitations of underlying quantum fields permeating space. Each fundamental particle such as an electron, photon, or quark is associated with a specific quantum field that vibrates at every point in space and time. Interactions between particles arise from the interplay between these fields, such as when the electromagnetic field mediates forces between charged particles.*

particles and their interactions (excluding gravity) [16]. Within the standard model,

- quantum **electrodynamics** (QED) describes how light and matter interact [11, 12]. It is the most precisely tested theory in all of physics,
- quantum **chromodynamics** (QCD) explains the strong force that binds quarks together inside protons and neutrons, and
- **electroweak** theory unifies the above two forces into a single description [17, 18].

In one of the most climactic conclusions, the discovery of the **Higgs boson** at CERN in 2012 [19] confirmed the presence of the Higgs field that had been predicted for a long time and this completed the Standard Model. By interacting with the Higgs field, elementary particles such as quarks and electrons obtain mass, through the **Brout-Englert-Higgs mechanism** (or the Higgs mechanism in short).

Expanding Technologies via Quantum Computing

In recent years, **quantum computing** has emerged as one of the most exciting frontiers in technology. Unlike binary classical switches, quantum states (quantum bits or **qubits**) can be both 0 and 1 at the same time, thanks to a phenomenon called superposition. Even more remarkably, these qubits can become **entangled**, meaning the state of one qubit is linked to another, no matter how far apart they are. These uniquely quantum properties allow certain tasks to be performed much faster than with classical computers [23].

You can think of a quantum computer like a massively **parallel multitasker**, exploring many computational paths at once, whereas a classical computer checks them one at a time. By leveraging these properties, quantum algorithms often offer massive speedups compared to their classical counterparts. **Shor's quantum algorithm** can factor large numbers much faster than classical methods, threatening current cryptography [24]. In addition, **Grover's algorithm** offers a quadratic speedup in search tasks [25].

However, unlike classical bits, quantum bits (or qubits) are extremely fragile and **prone to errors** due to decoherence and noise from their environment. This poses a serious problem for designing practical quantum computers that can operate reliably over long periods. Recent breakthroughs in **quantum error correction** and the development of **fault-tolerant architectures** have brought us significantly closer to building practical quantum computers [26]. Quantum error correction aims to safeguard information by encoding a single logical qubit into many physical ones, allowing the system to detect and correct errors without directly measuring the qubits themselves. Major tech companies such as **Google**, **IBM**, and **Microsoft** are actively pursuing scalable quantum processors [27, 42].

Meanwhile, **quantum communication** technologies are also making rapid progress. A prominent application is **Quantum Key Distribution** (QKD), which allows two parties to exchange cryptographic keys with security guaranteed by quantum mechanics [28]. Unlike classical encryption, QKD is fundamentally immune to eavesdropping, as any attempt to intercept the key disturbs the quantum system and reveals the intrusion.

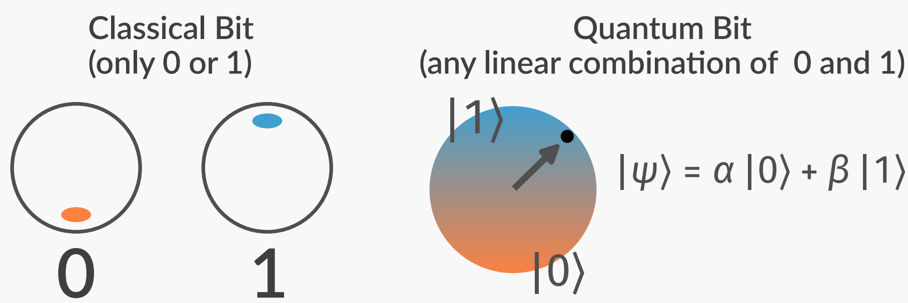

FIG 4: *A comparison between a classical bit and a quantum bit (qubit). Classical bits can only be in states 0 or 1. Qubits, thanks to quantum superposition, can exist in any combination of both 0 and 1 simultaneously, enabling vastly more powerful computation in specific tasks. The ability to form superposition states is often expressed by saying that the qubit can occupy any point on the surface of a sphere (the bloch sphere).*

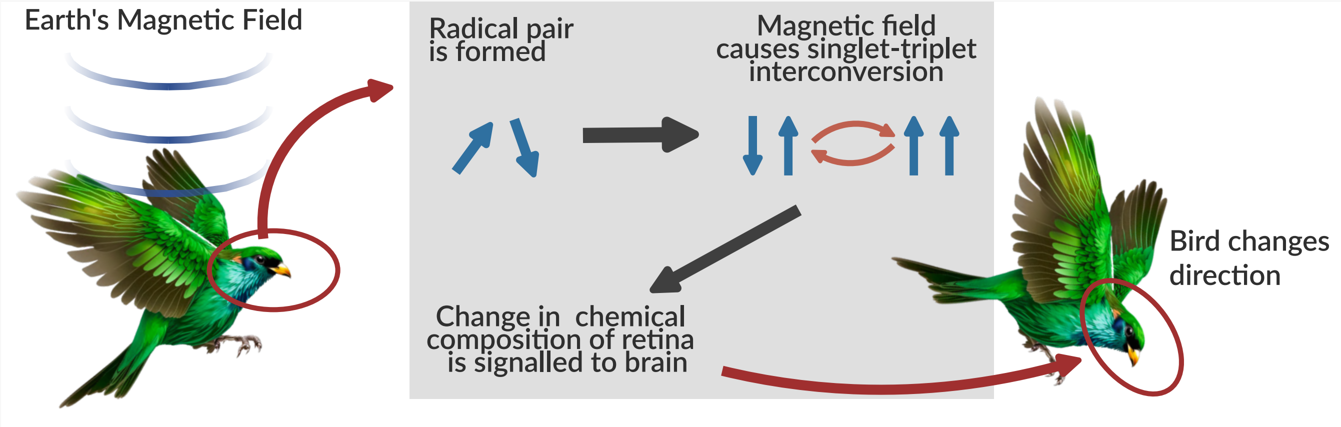

FIG 5 : *A conceptual diagram of how quantum entanglement may enable migratory birds to sense the Earth's magnetic field. A radical pair of electrons is formed in the bird's eye; these electrons respond to magnetic fields and undergo transitions in the retina, leading to modified concentration of chemical output compounds and provides sensory signals. Adapted from [43].*

This technology could form the basis of ultra-secure communication networks in the near future.

Real-World Applications: Chemistry, Biology, Materials Science, and more

Quantum mechanics has numerous real-world applications in science and engineering. In **quantum chemistry**, it helps scientists simulate how atoms bond to form molecules, enabling the design of new materials and accelerating drug discovery. Using quantum models, researchers can predict how molecules will interact in complex environments, such as inside cells or on catalytic surfaces [29]. In **quantum biology**, some natural processes appear to rely on quantum effects. For instance, plants may use quantum coherence to transfer energy efficiently during photosynthesis, and migratory birds might sense the Earth's magnetic field using entangled electron spins [30].

Quantum mechanics has also transformed our understanding of materials, leading to the discovery and engineering of exotic **quantum materials**. Notable examples include **topological insulators**, which conduct electricity on their surfaces but remain insulating inside, and **high-temperature superconductors**, which carry electric current without resistance at relatively high temperatures. These materials challenge traditional theories of matter and offer promising pathways for developing next-generation electronics, energy-efficient power systems, and quantum devices [31, 32].

Apart from materials, quantum mechanics also plays a key role in precision measurement techniques. **Atomic clocks**, the most accurate time-keeping devices on the planet, use the frequency of transitions between energy levels of cesium or rubidium atoms, and are used in global positioning systems (**GPS**) and gravitational wave detectors like LIGO. These applications illustrate the pervasive impact of the field across multiple disciplines [33, 34].

Unfinished Business: Some Open Problems

Quantum mechanics is among the most successful and precisely tested theories in all of science, yet it still leaves many deep questions unanswered. We point out some of them here.

The Measurement problem

Quantum theory predicts that a system evolves smoothly and predictably, according to the **Schrödinger equation** – the quantum analogue of Newton's second law of motion. This leads to a strange outcome: as mentioned earlier, particles can exist in **superpositions**, or combinations of multiple possible states at once. But whenever we measure such a system, we only see a **single outcome**. Why?

This puzzle is known as the **measurement problem**. It arises because the standard rules of quantum mechanics don't explain what exactly happens during a measurement or why the wavefunction **collapses** to one result. Is collapse a physical process? Is it just a change in our knowledge? Or is something deeper going on? No consensus exists yet.

Solving the measurement problem is crucial because it touches the very heart of quantum mechanics and of reality itself. It may be the key to explaining how the quantum world, with all its uncertainty and fuzziness, gives rise to the clear, definite experiences of the classical world we live in.

An Overarching Theory For Quantum Matter

Since the landmark discoveries of **high-temperature superconductivity** and **fractional quantum hall effect** in the 1980s, scientists have come to realise that several materials with strong **inter-electron correlations** show exotic properties. The physics of such materials was found to be governed by (i) **topological** considerations (where global properties of the wavefunction determine the physics instead of local details) and (ii) strong **many-particle entanglement** (a phenomenon in which the configurations of multiple particles get locked with each other), and they have come to be known as quantum matter. Researchers are working to find unified frameworks that can explain how these systems behave and predict new materials with similar strange properties. A complete theory of quantum matter could revolutionize technologies like superconductors, quantum computers, and even generate new states of matter.

Quantum gravity and unification

One of the biggest unsolved problems in physics is how to combine quantum mechanics with **general relativity** (Einstein's theory of gravity). While quantum mechanics works extremely well for tiny particles, general relativity describes how space and time behave on large scales, like planets, stars, and galaxies. But when both theories are needed, such as near a **black hole** or during the **Big Bang**, they lead to conflicting results. The challenge is that gravity, as described by general relativity, treats space and time as a **smooth, continuous fabric**. But quantum mechanics suggests that, at the smallest scales, this fabric should be made of discrete chunks - like pixels in an image. When scientists try to apply the methods of quantum field theory to gravity, the math blows up with infinities that can't be handled, a problem known as **non-renormalizability**.

Various approaches (string theory, loop quantum gravity, etc.) attempt a unification, but no fully successful theory has emerged. Until **quantum gravity** is solved, our understanding of the universe's origin, black holes, and the deepest laws of nature remains incomplete. This problem is significant because it stands at the foundation of all physics: without it, we cannot claim to have a **complete theory** that covers both the very large (cosmology) and the very small (quantum particles).

Looking Ahead: The Next Century of Quantum Mechanics

As quantum mechanics turns 100, it remains one of the most vibrant and forward-looking areas of science. One emerging frontier is **quantum thermodynamics**, where researchers are exploring technologies like **quantum heat engines** and **quantum batteries** - devices that could one day store and convert energy far more efficiently than anything classical physics allows.

The coming years may also bring what physicists call a **second quantum revolution** - a new era driven by quantum technologies that promise to transform computing, communication, and sensing. From unbreakable encryption to faster-than-ever computation, quantum mechanics is poised to impact industries and everyday life in ways we are only beginning to imagine. In 2026, the global scientific community will mark this centennial milestone with lectures, exhibitions, and conferences hosted by institutions such as CERN, the Max Planck Institute, and the American Physical Society.

It's a moment not only to celebrate how far we've come, but also to look ahead. Because if the past century of quantum mechanics has taught us anything, it's that the quantum world is full of surprises. And we've only just begun to explore it.

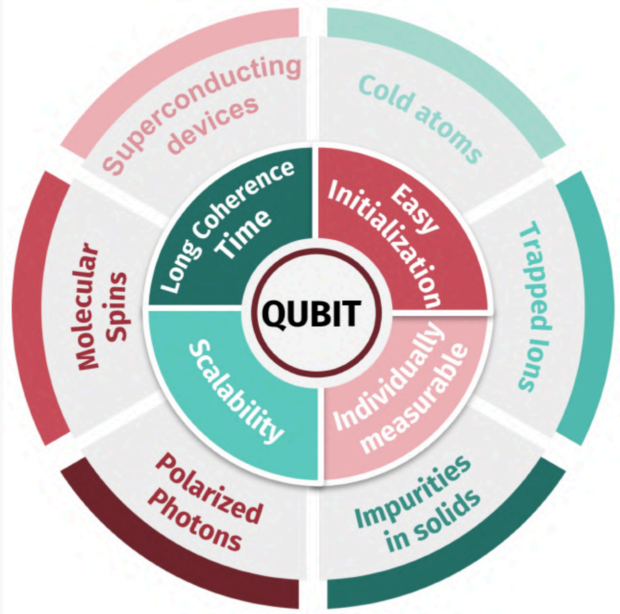

FIG 7 : *Requirements and Realizations of Qubits in the Second Quantum Revolution. This diagram summarizes the central criteria a physical system must meet to function as a viable qubit (inner circle), alongside a range of physical platforms where qubits have been implemented (outer circle). Core requirements include the ability to initialize qubits in a known state, apply fast and precise quantum gates, maintain coherence long enough for computation, and read out results with high fidelity. Adapted from [44].*

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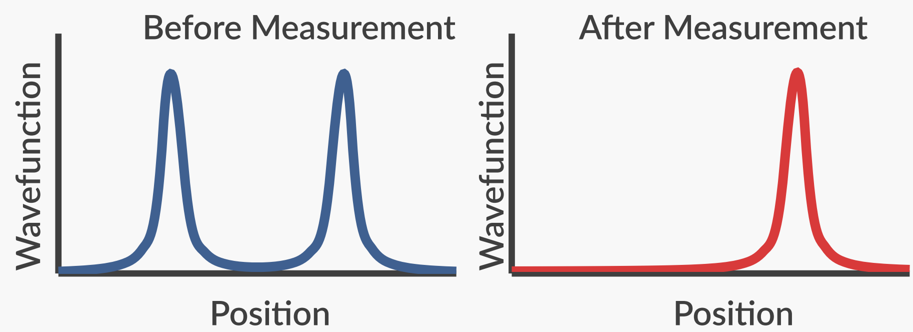

FIG 6: *A schematic showing how a quantum system's wavefunction (which describes the probability of a particle's position) evolves from a spread-out superposition to a sharply defined outcome after measurement. This sudden transition, not fully understood, is at the heart of the measurement problem in quantum theory.*

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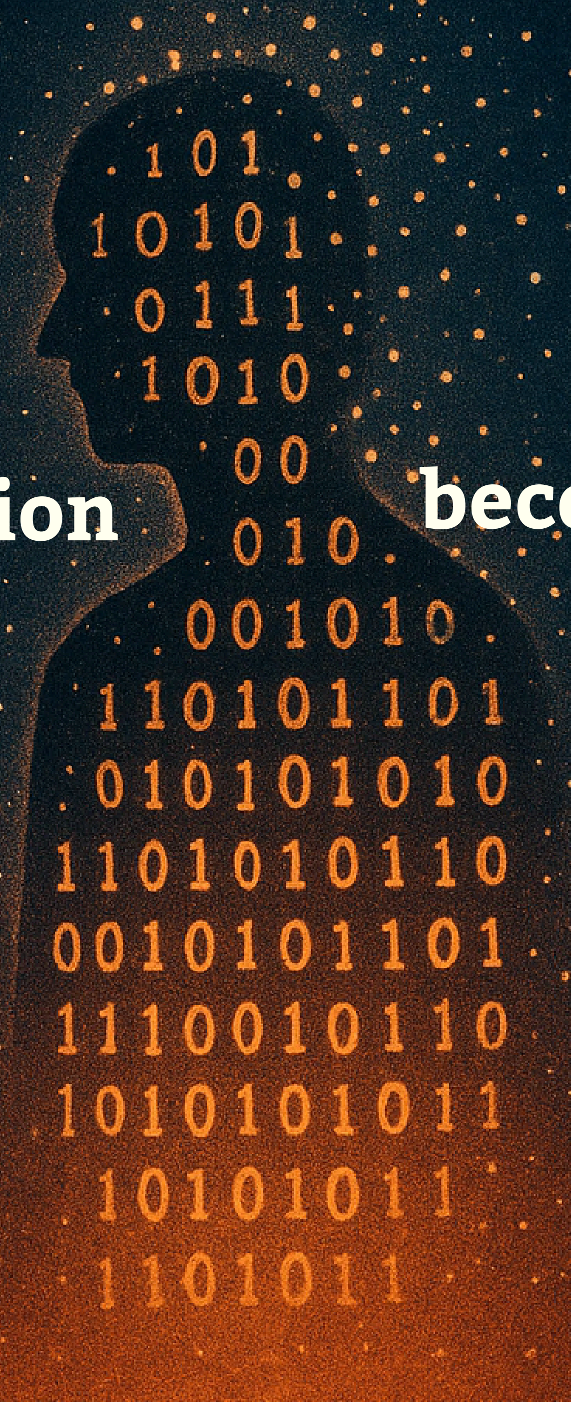
The Physics Of Forgetting

when information becomes heat



The Physics of Forgetting: When Information Becomes Heat

Tanmoy Pandit *Quantum Algorithm Scientist, Espoo, Finland* 📅 *Nov 01, 2025*

Reviewed By: *Archita Sarkar*

Every act of remembering, measuring, or deleting information leaves a scar in the fabric of the universe by releasing heat. This connection, known as **Landauer's Principle**, bridges two of greatest intellectual adventures —computation and thermodynamics—and reveals that information itself obeys the laws of physics.

Tanmoy Pandit is a Quantum Algorithm Scientist at QMill (Espoo, Finland), focusing on quantum error mitigation, quantum noise characterization, and algorithms for NISQ devices, alongside large-scale simulations of open many-body quantum systems. Beyond physics, he switched from Quantum Algorithm to music—violin and piano—and he's committed to scientist activism and public-interest science through the India March for Science - Abroad Chapter (IMFS-A) and the Breakthrough Science Society (BSS) - Abroad Chapter.

This article draws inspiration from: T. Pandit, G. Paul, A. Misra, and P. Chattopadhyay, Landauer Principle and Thermodynamics of Computation, **Rep. Prog. Phys. 88**, 086001 (2025).

A Whisper of Heat

When you delete a file from your personal laptop, it vanishes from your screen. But in a deeper sense, it doesn't disappear—it transforms. In 1961, physicist Rolf Landauer made a bold claim: erasing one bit of information must release a tiny but unavoidable amount of heat into the environment. The minimum possible cost is

$$Q_{\text{min}} = k_B T \ln 2$$

where k_B is Boltzmann's constant and T is the temperature of the surroundings. At room temperature this is only 2.9×10^{-21} joules per bit—too small to notice, but large enough to impose a fundamental limit on every computer that has ever existed or will ever be built.

Landauer's insight turned information from an abstract concept into a physical quantity. Knowledge, it seems, comes with a price tag—paid not in dollars, but in entropy.

The Demon who Cheated the Second Law

The idea traces back to one of physics' most famous thought experiments. In 1867, James Clerk Maxwell imagined a mischievous being—a "demon"—who could sort fast and slow gas molecules using a tiny trapdoor between two chambers. By letting only the fast ones through one way and slow ones the other, the demon could create a temperature difference out of randomness, apparently defying the second law of thermodynamics:

$$\Delta S_{\text{total}} = \Delta S_{\text{system}} + \Delta S_{\text{environment}} \geq 0$$

If such a demon existed, it could create useful work for free, making a perpetual-motion machine of the second kind and this was century old unsolved problems.

Szilard's Brilliant Simplification

Half a century later in 1929, the Hungarian physicist Leo Szilard gave the demon a more concrete stage. He devised a *Gedankenexperiment* that distilled Maxwell's paradox to its purest form: a box containing just a single molecule of an ideal gas in contact with a heat reservoir. His "one-molecule engine" proceeds in four conceptual steps:

a) Insert a partition to divide the box into two equal halves of volume $\frac{V}{2}$. The lone molecule lands on one side or the other.

b) Measure which side it's on. That act of observation gives the demon exactly one bit of information.

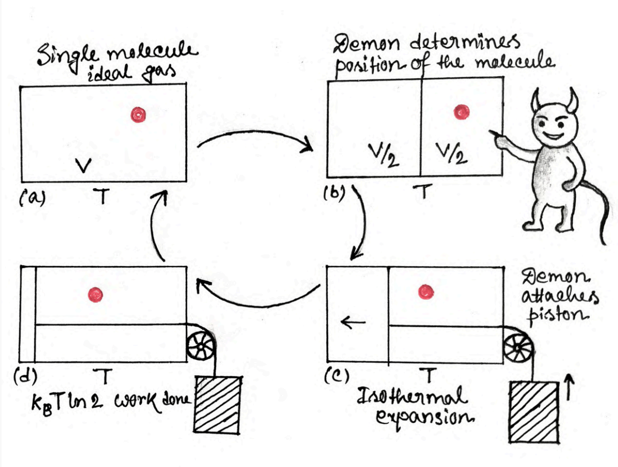


FIG 1 : *Schematic of Szilard's gedanken experiment. The demon inserts a partition, measures the molecule's position, and allows isothermal expansion to extract work $k_BT\ln 2$. To repeat the cycle, the demon must erase its memory, dissipating the same heat*

c) Attach a frictionless piston to the correct side. The molecule pushes the piston outward, expanding isothermally and doing work

$$W_{\text{out}} = k_BT\ln 2$$

a) Remove the partition and reset the system. The demon is ready to start again.

At first glance, Szilard's setup appears to defeat the second law: the demon extracts work from random motion without any apparent cost. The catch lies in the demon's memory. To repeat the cycle, it must erase the record of which side the molecule occupied. According to Landauer, that act of forgetting releases exactly the same energy gained earlier:

$$W_{\text{erase}} = k_BT\ln 2 = W_{\text{out}}$$

Balance restored—the second law follows. The demon can't win, because the universe always collects its entropic cost.

When Bits Meet Atoms

This simple realization changed how scientists view both computation and nature. In Shannon's information theory, uncertainty is measured by the Shannon entropy

$$H = -\sum_i p_i \log_2 p_i$$

while in statistical physics, the Boltzmann entropy reads

$$S = -k_B\sum_i p_i \ln p_i = k_B \ln 2H$$

They are not just mathematically similar—they are the same concept in different units. Every bit of information corresponds to a physical entropy of $k_B\ln 2$.

Whenever a computer deletes or erasure data from its hardware chip, it is not merely rearranging symbols on silicon chip of your computer; it is converting structured information into heat that diffuses into the environment. Or as Landauer famously said, **"Information is physical."**

From Thought Experiment to Real World Technology

For decades, Landauer's limit was a theoretical curiosity. Today, it defines the holy grail of low-power and quantum computing. Modern transistors waste billions of times more energy per operation than this bound, largely because real devices operate far from equilibrium. But as engineers shrink circuits to atomic scales, and physicists manipulate qubits that are easily disturbed by heat, Landauer's principle becomes not just elegant but essential.

Recent experiments have even erased information using **angular momentum** instead of energy, and verified quantum versions of the principle using superconducting

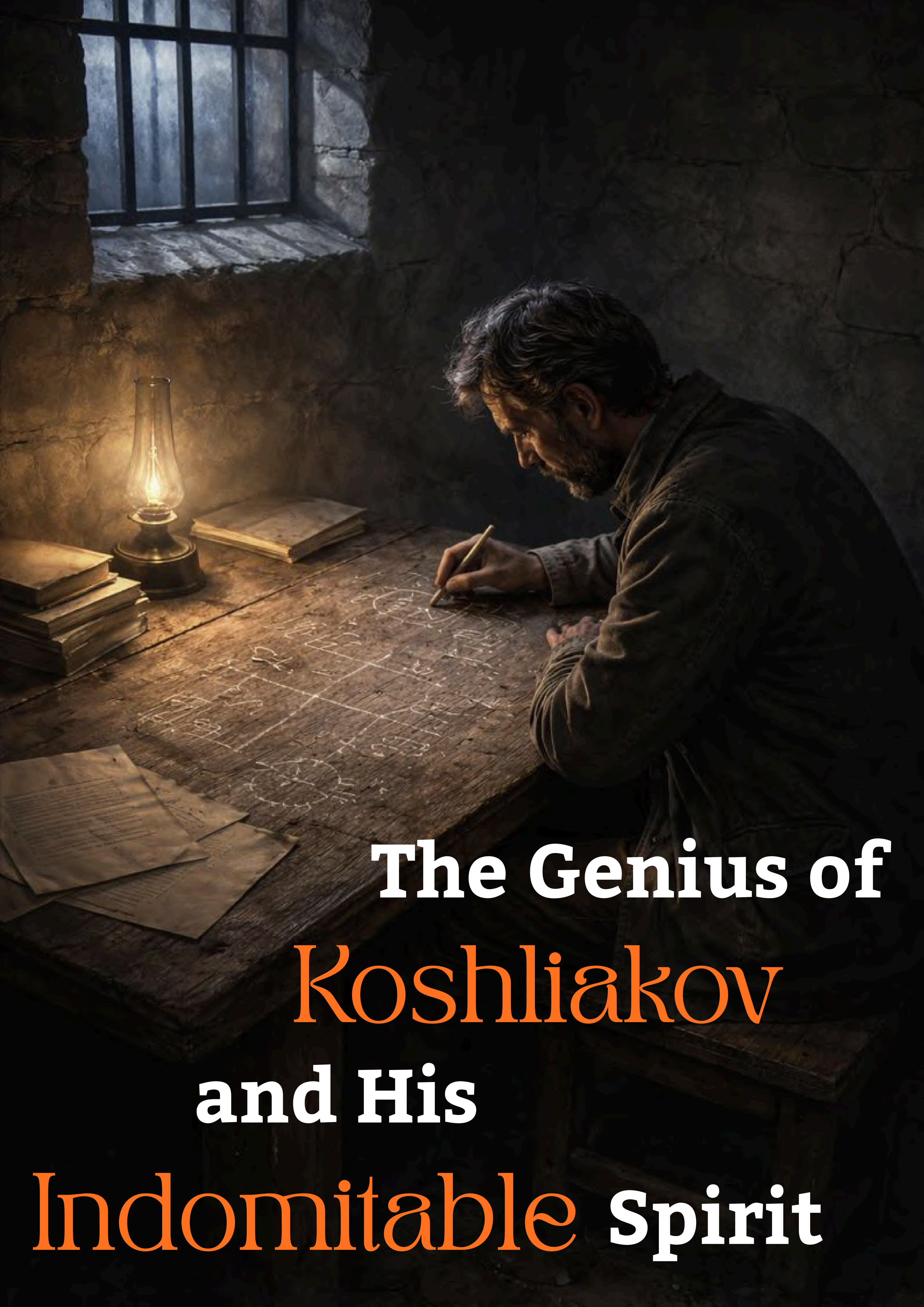
FIG 2 : *In 1867, J C Maxwell imagined a tiny being that could seemingly outwit the second law of thermodynamics. Decades later, Leo Szilard transformed the paradox into a single-molecule engine, showing that information and energy were inseparably linked. In 1961, Rolf Landauer closed the loop, proving that erasing information carries a fundamental thermodynamic cost.*

qubits. Each test confirms the same conclusion: there is always a thermodynamic price for forgetting.

The Universe Keeps its Books

From Maxwell's demon to Landauer's principle, the message is clear: there is no free lunch, not even for information. Every act of learning creates order; every act of forgetting restores disorder. The heat from your laptop, the power consumed by data centers, and the entropy of black holes are all governed by the same equation.

In a sense, we are all demons—tiny processors in a vast cosmic engine. And as we compute, think, and erase, the universe quietly tallies our debts in units of heat. To know is to order. To forget is to warm the world, ever so slightly.



The Genius of Koshliakov and His Indomitable Spirit

The Genius of Koshliakov and His Indomitable Spirit

Atul Dixit *Department of Mathematics, Indian Institute of Technology Gandhinagar*

📅 *Dec 22, 2025*

From a Soviet labor camp, Nikolai Koshliakov developed a striking generalization of the Riemann zeta function under conditions that defy imagination. This article traces the origins of his work on transcendental functions arising from a generalized Riemann equation. Along the way, it reveals how profound mathematics can emerge even in the most hostile environments.

Atul Dixit is a Professor of Mathematics at IIT Gandhinagar and holds the N Rama Rao Chair position at the institute. Atul's research interests are in Analytic Number Theory, Special Functions, Theory of Partitions, q-series and Modular Forms. He also likes to work in the areas of mathematics developed by Srinivasa Ramanujan.

In memory of Nikolai Sergeevich Koshliakov

Introduction

The humankind has regularly witnessed the birth of influential personalities who have time and again guided people through difficult situations and have raised their spirits. Adversities or ordeals could not crush them, and instead, they emerged victorious through their heroic deeds.

One such role model that we will see in this article is the Russian mathematician Nikolai Sergeevich Koshliakov[1]. Koshliakov was born on 11th July 1891 in St. Petersburg, Russia. After finishing his gymnasium (high school and college), Koshliakov entered the Department of Physics and Mathematics at St. Petersburg University, graduating in 1914 with a diploma securing a first class. Before being accepted at St. Petersburg, Koshliakov had mastered differential and integral calculus on his own [1] (see also [10]). At the university, he was taught by excellent mathematicians such as Markov, Steklov, Uspenskii etc. He became interested in analytic number theory, heavily influenced by the work of G. F. Voronoï. After graduation, he remained at St. Petersburg for his Masters. Throughout his life, Koshliakov held several eminent positions at various universities. He was an excellent teacher, his lectures being precise and comprehensible. His textbook on differential equations [6] became greatly popular among students, the outgrowth of which is [9].

Koshliakov was a researcher par excellence who mainly worked in analytic number theory and differential equations. He published more than 65 papers ranging from summation formulas to problems in applied mathematics. His slick proof of the Voronoï summation formula [4] is, according to the present author, the shortest proof known so far and full of ingenuity!

The subject of this note is concerned with one manuscript written in Russian by Koshliakov [7], whose title translates to 'A study of a class of transcendental functions defined by the generalized Riemann equation'. But before we delve into it, it is important to understand the political situation in Soviet Union and the conditions in which Koshliakov wrote it.

Political situation in the Soviet Union during World War II, Koshliakov's arrest, and mathematics from jail

NKVD was the Soviet Union's secret police organization from 1934 to 1946. During the World War II, Axis powers undertook the "Siege of Leningrad", a military blockade, from 1941 to 1944. In [1], the authors write

> *The repressions of the thirties which affected scholars in Leningrad continued even after the outbreak of the Second World War. In the winter of 1942 at the height of the blockade of Leningrad, Koshlyakov along with a group ... was arrested on fabricated ... dossiers and condemned to 10 years of correctional hard labour. After the verdict he was exiled to one of the camps in the Urals. ... On the grounds of complete exhaustion and complicated pellagra, Koshlyakov was classified in the camp as an invalid and was not sent to do any of the usual jobs. ... very serious shortage of paper. He was forced to carry out calculations on a piece of plywood, periodically scraping off what he had*

[1] His last name is spelled in several different ways, the second most common being *Koshlyakov*.

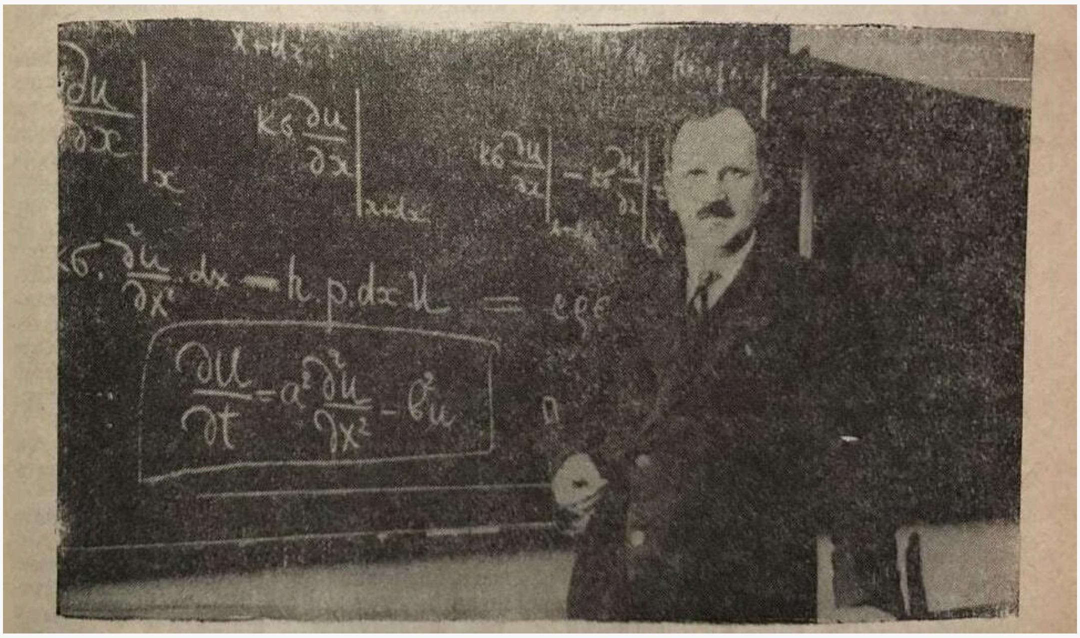


FIG 1 : *Nikolai Sergeevich Koshliakov (Picture courtesy: V. N. Koshlyakov, O. A. Ladyzhenskaya and D. R. Merkin and M. M. Smirnov, Vestnik Leningrad Univ. Mat. Mekh. Astronom. (1991) No. 4, 81–83.)*

> *written with a piece of glass. Nevertheless, between 1943 and 1944 Koshlyakov wrote two long memoirs* Issledovanie nekotorykh voprosov analyticheskoi teorii rational'nogo i kvadratichnogo polya *(A study of some questions in the analytic theory of rational and quadratic fields)*[2] *and* Issledovanie odnogo klassa transtsendentnykh funktsii, opredelyaemykh obobshchennym yravneniem Rimana *(A study of a class of transcendental functions defined by the generalized Riemann equation).*

Further details are given in [11, p 211–213], where the author says that the main purpose of the NKVD was to obtain signed "confessions"[3] from the accused as proofs of their guilt (of supporting the Axis powers). Koshliakov wasn't the only one. In fact, he was one among 13 scientists and mathematicians who were considered as the accused. Lorentz [11, p. 212] says,

> *By April 1942, after seven hungry months, the accused were suffering from acute starvation; many of them had lost 1/3 of their normal weight and were close to death. It is humanly understandable that an offer of a bowl of soup was sufficient to force them to sign a "confession", an ultimate proof of guilt. Forced to stand for hours was another form of torture. No wonder that Koshlyakov signed:"I intended to establish relations with the German commandant... I would like to atone for my guilt, be it in a small measure, by participating in our working front.... In particular, would be very happy to complete my work on summation formulas which I have been conducting for 30 years...*

It is not our intention to delve a lot into politics but rather to put forth before everyone (especially students), how, in the extreme predicament that Koshliakov was going through, he could maintain his scientific fervour and produce magnificent research!

My "discovery" of Koshliakov's second manuscript written from jail: A personal story

The second manuscript which Koshliakov wrote from jail under his patronymic name N. S. Sergeev, namely, [7], although published, can still be considered as "lost" since nobody (except for a passing reference to it in the thesis of A. G. Kisunko [3, p. 4]) studied its contents for 70 years! I had the good fortune of "discovering" it in 2010 while I was a fourth year PhD student in Mathematics at the University of Illinois at Urbana-Champaign. Since this episode might be interesting to some of you, let me take some liberty to explain how it unfolded. I happened to come across the article [1] written on the centenary of Koshliakov's birth, where I first learned of his second manuscript [7]. The authors of [1] had discussed in it some of the contents of [7]. I was taken aback to see an integral involving the Riemann Ξ-function considered there which generalized an integral considered by Ramanujan in his published paper [12].

I was happy and anxious, at the same time, to see the manuscript [7], and decided to get hold of it, and also everything else that Koshliakov had published. This is because I, myself, was working on a generalization of that very same integral of Ramanujan, and so I wanted to make sure that I am not replicating what Koshliakov did years ago! The manuscript was available at the Center for Research Libraries (CRL) in Chicago. I asked the UIUC Math librarian Tim Cole if we could get it for a few days via inter-library loan. I was pleasantly surprise to find that the CRL had scanned the 150-page manuscript and had emailed it to me! To my solace, Koshliakov had not done

[2]It is believed that this manuscript was lost in transit from jail to Steklov Institute of Mathematics, however, Koshliakov resurrected it in the form of three papers[8] in 1954.

[3]This word in quotes, of course, means *fabricated confessions*.

FIG 2 : *Koshliakov graduated from the Faculty of Physics and Mathematics of the University of St. Petersburg in 1914.*

anything I was working on. I found the manuscript to be very interesting though.

However, it wasn't until ten more years that I decided to seriously study this manuscript along with my PhD student Rajat Gupta. It was then that we found out what a gem this manuscript is! We made two modest contributions to the theory [2].

Contents of the manuscript

To describe the main idea, let us first define the Riemann zeta function, one of the most important functions of mathematics. For $\mathrm{Re}(s) > 1$, it is defined by the absolutely and uniformly convergent series $\zeta(s) := \sum_{n=1}^{\infty} n^{-s}$. It can be analytically continued to the entire complex plane except for a simple pole at $s = 1$. Koshliakov's theory stems from a problem in Physics on heat conduction. We refer the reader to [5] and [6, p. 488-489] for a description of this problem.

The equation $p\sin(\pi\lambda) + \lambda\cos(\pi\lambda) = 0$, where $p > 0$, forms the crux of Koshliakov's theory. It is the characteristic equation of the generalized heat equation encountered by Koshliakov in his problem on heat conduction. As $p \to \infty$, the positive roots λ_n of the characteristic equation are $\lambda_n = n$ (being the roots of the resulting equation $\sin(\pi\lambda) = 0$). Thus, in this special case, the series $\sum_{n=1}^{\infty} \lambda_n^{-s}$ is nothing but the Riemann zeta function $\zeta(s)$. Moreover, when $p \to 0$ and $\lambda \neq 0$, we get $\cos(\pi\lambda) = 0$, which implies that the positive roots are $\lambda_n = n - \frac{1}{2}$. Thus, one can study the series

$$\sum_{n=1}^{\infty} \left(n - \tfrac{1}{2}\right)^{-s} = (2^s - 1)\zeta(s).$$

For any $p > 0$, one may then construct a general zeta function $\sum_{n=1}^{\infty} \lambda_n^{-s}$ for $\mathrm{Re}(s) > 1$. In fact, Koshliakov considers a normalized version of this series, namely,

$$\zeta_{p(s)} := \sum_{j=1}^{\infty} \frac{p^2+\lambda_j^2}{p\left(p+\frac{1}{\pi}\right)+\lambda_j^2} \cdot \frac{1}{\lambda_j^s}.$$

This is one of the two *Koshliakov zeta functions*. With this foundation, Koshliakov shows unmatched brilliance in developing the theory of these zeta functions and the functions associated to them. For details, the reader is referred to [7] and [2].

Concluding remarks

Koshliakov died of a brain haemorrhage on 23rd September 1958. While mortal remains put an end to a person's physical presence, the ideas he/she comes up with live forever. Koshliakov's legacy and his indomitable spirit will continue to inspire everyone as long his mathematics is studied!

Acknowledgements

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FIG 3 : ***Rajat Gupta*** *was then a PhD student under Atul Dixit when they studied Koshliakov's second manuscript in more detail and even managed to extend his theory.*

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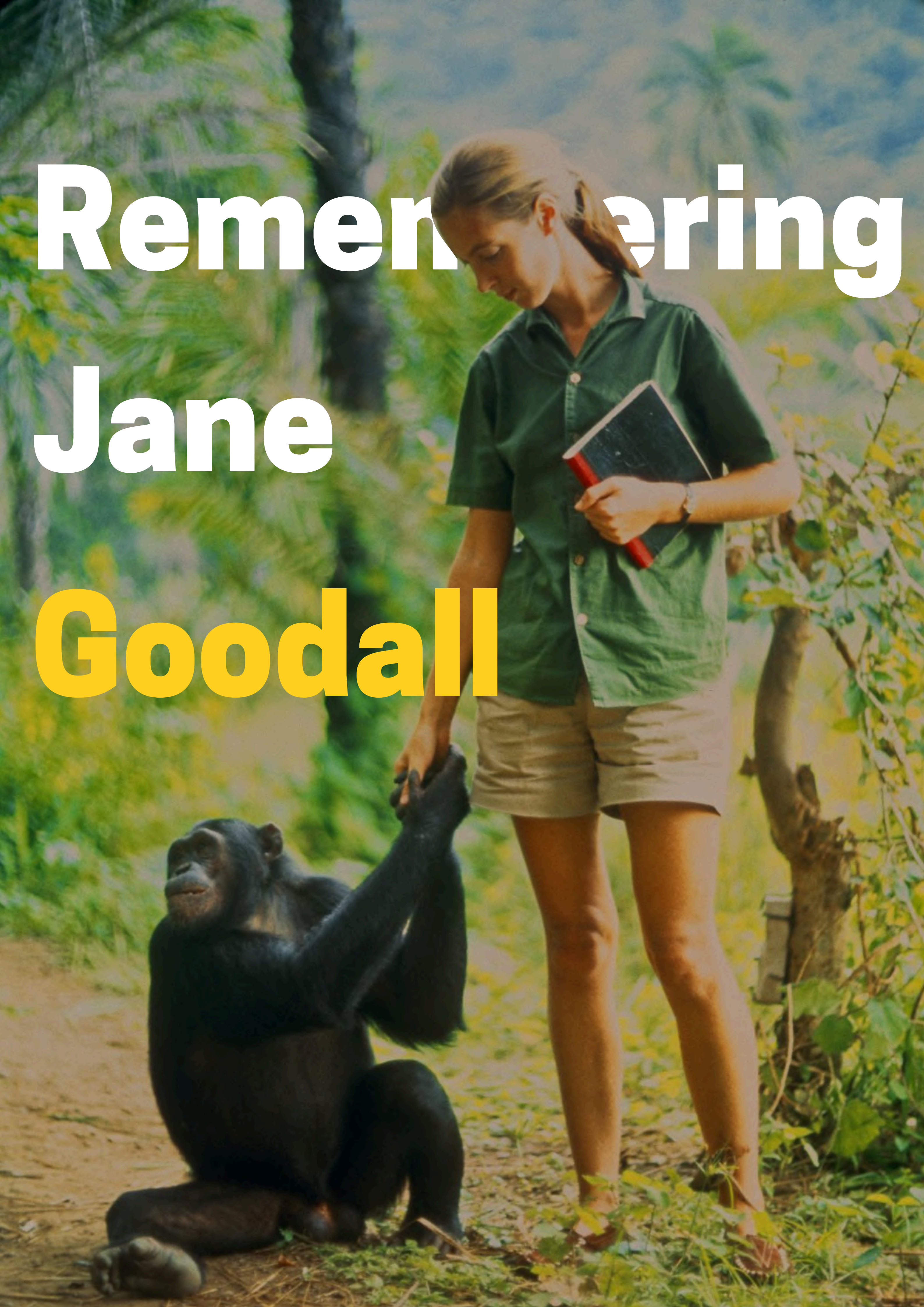
Remembering Jane Goodall



Remembering Jane Goodall: In the Forest and Beyond

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Reviewed By: Ishita Bardhan

📅 *Jan 27, 2026*

FIG 1: *A photo of Jane Goodall and infant chimp Flint reaching out to each other, captured by her husband Hugo van Lawick in 1964. Long after that, the image continues to influence our perception of chimpanzees. "**When I saw it, though I did not realise it would become iconic, it did make me think of Michelangelo's painting of God reaching out to Man.**" – Goodall*

Dishari traces how Jane Goodall, a young woman with no formal scientific training, walked into Gombe with a notebook and binoculars and ended up overturning one of humanity's most cherished assumptions – that tool-making, complex social life, and culture belonged to us alone.

Dishari Dasgupta, currently a PMRF scholar at the Dog Lab, works under the joint supervision of Prof. Anindita Bhadra and Dr. Manabi Paul. Her research focuses on the urban adaptation of free-ranging langurs and their interaction dynamics with free-ranging dogs and humans.

The iconic image of a blonde-haired lady in khaki shorts stretching out her hand towards a baby chimpanzee, and the chimpanzee too stretching out its hand towards the lady in the forest, is still fresh in my mind from when I first saw it back in college. Out of curiosity, I had tried to find out more about her and got to know her name was Jane Goodall, an iconic primatologist who changed the world's perception about our non-human primate cousins – the chimpanzees of Gombe. That is also when I realized there is more to life science than the usual cancer-virus-DNA sequences. Cut to 2025, almost a decade after coming across this image, Jane Goodall breathed her last on 1st October at the age of 91. The internet was flooded with obituaries. After all, a legend had died.

Early Life and Inspiration

To know who she was, it helps to begin before the forest, before the chimpanzees, when she was a little girl named Valerie Jane Morris-Goodall. She was born in London in 1934. Her first encounter with chimpanzees came in childhood through a stuffed toy named Jubilee. Her father left early, and she was raised largely by her mother in a household shaped by strong women. Although she did well in school, university was financially out of reach. In 1953, at nineteen, she enrolled at London's Queens Secretarial College and went on to hold a series of clerical jobs. Amidst all this, she nurtured within her an ambitious dream: a dream to visit Africa. In 1955, a former school friend invited her to stay on her family's farm in Kenya. Determined to seize the opportunity, Jane worked as a waitress to save the fare. In 1957, she finally travelled to Africa.

She took an office job in Nairobi, where she met Louis Leakey, a paleoanthropologist studying human evolution. Though he was an academic, he believed that formal training could sometimes limit a person's capacity for observation, binding them to pre-conceived theories. Jane's lack of a degree, which would later become one of the strongest criticisms against her, was an advantage to him. Leakey trained her in basic research

FIG 2 : *Jane Goodall with David Graybeard. In Gombe, the first chimp to lose their fear of Jane was Greybeard. This gave Jane the opportunity to study the complex world of chimpanzee life. [National Geographic / Jane Goodall Institute]*

methods and entrusted her with a task to study wild chimpanzees in what would later become Gombe Stream National Park.

Work at Gombe Stream National Park

Armed with a notebook and binoculars, Jane arrived at the National Park in the 1960s in her 20s. Authorities did not permit solo women in the forest, so her mother agreed to accompany her. There were no sightings of the wild chimps for the first few months. Eventually, the chimps appeared. And once they did, everything changed.

She documented chimpanzees deliberately choosing grass stems or twigs, stripping leaves from them, and altering their length before inserting them into termite mounds. The termites clung to the probe, which the chimpanzees then withdrew and consumed. This work, published in Nature (1964), demonstrated that tool use occurred in the wild and that these tools were made for a specific purpose. This finding was revolutionary because it challenged the long-held definition of humans as "the toolmaker." By showing that chimpanzees could not only use but also modify objects for a specific task, Goodall provided the first clear evidence that the capacity for purposeful tool-making was not unique to our species, fundamentally altering the understanding of this boundary between humans and other animals. Louis Leakey responded with a line that became legendary: "Now we must redefine tool, redefine man, or accept chimpanzees as humans." The findings reframed chimpanzees as cognitive agents capable of planning, learning, and problem-solving, laying the foundation for modern primate cognition research (Goodall, 1986; McGrew, 2010). Her subsequent research in the following decades further revealed that these free-living chimps of Gombe had social hierarchies, alliances, maternal bonds, territorial fights, male infanticide, and cannibalism. The world reacted to her findings with both appreciation and criticism. She named her chimpanzees instead of numbering them, a practice critics dismissed as anthropomorphism. Many pointed out her lack of formal scientific training and statistical rigour in the early years. Goodall responded to part of this criticism by earning a PhD from Cambridge under the mentorship of Robert Hinde, becoming one of the few people admitted to a PhD programme without an undergraduate degree.

Her visibility grew when she met her first husband, Hugo van Lawick. His photographs and films for National Geographic carried Gombe into living-room televisions across the world. One of those images, the same one that I mentioned in the beginning, came to define her in the public imagination. Leakey's institutional backing, paired with van Lawick's captured imagery, helped secure the grants that kept the research project running.

Criticisms and Scientific Debate

But the spotlight created a simplified story of Jane Goodall alone in the forest, quietly erasing the native Tanzanian field assistants whose knowledge and labour sustained the research. This omission has since become a central point in broader critiques of how scientific fieldwork, particularly in colonial and post-colonial contexts, has historically overlooked the contributions of local collaborators. Their absence from authorship and intellectual credit is now recognized as part of a larger pattern of structural bias in early primatology.

In 1975, the Gombe project was shaken when four young researchers linked to Jane Goodall were kidnapped

FIG 3 : *The Jane Goodall Institute is a global organization founded by Dr. Jane Goodall in 1977. It works in 6 African countries and supports the rehabilitation of chimpanzees, alongside conservation projects. [Jane Goodall Institute]*

at night by rebels associated with Laurent Kabila. In her memoirs, Goodall mentions the incident briefly, framing it as one of many dangers of working in a politically unstable region and focusing on the relief of the researchers' eventual release. However, contemporary media accounts were far less restrained in their reporting. They detailed the beatings, the weeks of captivity, and the ransom, eventually raised by the families, while questioning why neither institutions nor senior leadership took a more visible public stand. This crisis left a haunting question for everyone, one that extends beyond Gombe: when science crosses borders and goes to the field, who is responsible for the safety of the people who make it possible?

Conservation and Advocacy

By the 1980s and 1990s, she gradually shifted from daily field research and moved towards advocacy. She founded the Jane Goodall Institute and redirected her efforts to community-based conservation, education, and livelihoods. This transition into advocacy came to define the latter half of her life. She became a global voice on conservation ethics, fearlessly advocating for policies that protect the environment. Her commentary often extended to world leaders, whom she consistently urged to prioritize science and environmental health over short-sighted political or economic gains.

Legacy

Jane Goodall – a celebrity scientist, a global advocate, an icon. But to understand her legacy, we must focus on her journey and not just the outcome. The journey of a woman who ventured out with a notebook and binoculars to explore the world of free-living chimpanzees. She quietly redefined what it meant to be a field-based researcher in academia. Demonstrated that the previously known boundaries differentiating between human and ape were not rigid.

Her story also reminds us that science is a method that can be used by people, who were not formally trained in their 'formative' years, to go on to do great work in future, given the right mentorship, generous funding agency, great visual storytelling, and timing.

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In Conversation
With
Shyama
Narendranath

In Conversation with ISRO Scientist Shyama Narendranath

interview by
Swarnendu Saha *IISER Kolkata*
Suman Halder *DPS, IISER Kolkata*

📅 *November 08, 2024*

"Often, our work is viewed as something exotic, while in reality, science is fundamental to our daily lives", **Shyama Narendranath** remarks on the perception of research in India. She is a scientist at U R Rao Satellite Centre, ISRO. She is a part of Chandrayaan-2 and other Indian planetary programs. She has been awarded the Zubin Kembhavi award by the Astronomical Society of India.

Prof. Shyama Narendranath is an academic researcher from Indian Space Research Organisation. She primarily works on solar system research with expertise in spectroscopic techniques and instrumentation. She is actively involved in the current and future ISRO's chandrayaan missions in various roles.

SS: Good afternoon, ma'am. So, to start off, can you tell us about your background? Starting from when you were a student, how did you eventually reach the place you're in now after all these years?

SN: I can't say that I started out thinking I wanted to be a scientist. I come from Palakkad, a small town in Kerala. Back then, things were very different. The mobile phone, for instance, came into my life during my MSc. So, your generation can't even imagine a time without the internet or such technology. Exposure to the outside world was quite low.

Academically, I was a good student, but I was really interested in dance. I trained in classical dance, and most of my school days were focused on dancing. In Kerala, school youth festivals are taken very seriously, and every school participates. So, I was always involved in that.

SS: Oh, have you been trained in Kathakali, or was it another form of classical dance?

SN: Actually, I started with Bharatanatyam, and have been training in Odissi for the past 15 years. I'm still passionate about dance, and I continue to perform. So, initially, I wanted to be a dancer. I even had a short story published when I was in the 6th grade. At that time, I thought maybe I'd become a writer. But becoming a scientist was never something I considered when I was young. Probably, my interest in science began during my post-graduation. I had excellent teachers who really made the subject interesting. For young children, it's so important to have good teachers. If you love the subject, it's often because you had an amazing teacher.

I always had good English teachers, so I loved English, even though I was pursuing a degree in Physics. In fact, during my undergraduate years, I looked forward to my English classes more than my Physics ones. But things

FIG 1 : *SN completed her PhD from the Indian Institute of Science, Bangalore.*

changed during my MSc when I had some excellent professors in Physics. They made me understand what I was doing. That's when I had a turning point.

SH: So, did you realize that you wanted to pursue research during your MSc?

SN: Yes, it was during a small summer project that I first thought research might be an option. I had the opportunity to visit Bangalore and stay there alone for the first time. I met many PhD scholars, and that's when I realized research could be something I'd like to pursue. Before that, I never considered it seriously.

SH: And did you think about teaching as a career?

SN: Yes, like many girls of my time, the plan was to finish MSc, do a B.Ed., and then teach. That's the path I was following. Teaching was seen as a suitable career for women. In my MSc Physics class, there were actually more girls than boys. But when I did my short summer project, I realized there was more I could do, and I became really interested in research.

SS: But at that time, societal expectations must have been a challenge, especially for women pursuing PhDs.

SN: Absolutely. There was definitely pressure. I got married soon after my MSc and moved to Bangalore. Fortunately, I continued my studies. I taught as a guest lecturer at a college for six months, even though I didn't have a B.Ed. at the time. Then, I joined as a Junior Research Fellow (JRF). But within a few months, I was pregnant, so I had to take a break. After my daughter was born, I resumed when she was three and half months old.

SS: Wow, that must have been quite a challenge - balancing motherhood and studies.

SN: Yes, it was. I did my coursework for the PhD while working as a JRF in the Astronomy Program at the Indian Institute of Science (IISc), and I was able to complete it with the support of my family, especially my mother. I also had an excellent PhD supervisor, which is very important for a successful PhD journey.

SH: You mentioned working with international space agencies. Can you tell us about that?

SN: Yes, I was fortunate to be part of India's first lunar mission, Chandrayaan-1. I worked on an instrument that was developed in collaboration with the European Space Agency. It was built at the Rutherford Appleton Laboratory in the UK, so I got the opportunity to go and work. It was a difficult period because I had to leave my daughter behind, but with the support of my family, I managed. It was a new experience, and it gave me significant exposure. Working on Chandrayaan-1 was a turning point in my career. That project really helped shape my future work in space missions.

SH: You've spent a lot of time as a student and as a scientist at major space agencies like NASA, the European Space Agency, and JAXA. How do their approaches compare to ours? Especially with the perception that ISRO achieves a lot with significantly less funding.

SN: There's no debate—NASA is far ahead in terms of technology. They landed the first humans on the moon in 1969, and we haven't sent humans to space yet. Their technological advancement is evident. However, in India, we are conditioned to work with limited resources. It's not just in space research—across sectors, there's always a resource crunch. Our approach is more about optimizing what we have. In many cases, we spend more time on things and make up for the lack of resources with extra effort. In NASA, industries take on parts of the

FIG 2 : *SN performing the Indu Sairisiri at Udupi krishna temple in Karnataka.*

FIG 3 : *PSLV C11 carrying Chandrayaan-1. SN was involved in developing the Chandrayaan-1 X-ray spectrometer, in collaboration with the Rutherford Appleton Laboratory in the UK.*

technology development. Here, we still rely heavily on academic institutions and agencies like ISRO to develop technology in-house. But India is in a phase of transition. Over the next 10-20 years, I believe we'll see more involvement of private industries in space missions.

SS: There's a lot of pride in India about the Mars mission, Mangalyaan. It was achieved on a limited budget, but how does it compare to missions from NASA?

FIG 4 : *Aerial view of Rutherford Appleton Laboratory, where SN worked towards Chandrayaan-1.*

SN: Yes, Mangalyaan was a great achievement in terms of engineering. However, from a scientific perspective, it's not on the same scale as NASA's Maven mission to Mars. The amount of science that came out of Maven is much greater. The Indian mission was more about demonstrating that we could navigate a spacecraft to Mars and make it work within our constraints.

SH: Could you talk a bit about Chandrayaan-3 and how that mission was planned?

SN: I think Chandrayaan-3 was very critical for ISRO and India's planetary program. After Chandrayaan-2's near-success, we needed Chandrayaan-3 to work to ensure the continuation of our planetary missions. The success of Chandrayaan-3 proved that we could achieve a soft landing on the moon, and now we are well-positioned to plan future lunar missions.

SH: When it comes to research funding in India, especially in space research, how do you feel about the current budget allocations?

SN: Without adequate funding, research progress is slow. In order to innovate, we need new funding. There is a push from the government to involve academic institutions more, which is a positive development. We need to focus on core research, while industries can undertake more of the technology development. This transition will take time, but it's necessary for the future.

SS: What about the Chandrayaan-3 mission's scientific studies? What have we learned from it?

SN: The mission included several instruments, bothon the lander and the rover. The rover analyzed the composition of the surface, and it seemed to be a fairly homogeneous area. The lander carried a Langmuir probe to measure the electron density in the moon's exosphere, and a seismometer to measure moonquakes, though the data we collected over 10.5 days did not record any significant seismic activity. The mission was a great success overall, contributing valuable data for future lunar exploration.

SS: And the Aditya L1 mission? How is that going?

SN: Aditya L1 launched in September, and it's doing well so far. The spacecraft is in a halo orbit around the Lagrange point L1. The payloads are still being calibrated, but the mission is on track, and we expect some significant scientific findings from it soon.

SS: When you look back at your journey, from a student to a scientist, and the progress of ISRO, how do you feel about the way society views scientists in India?

SN: I think there is still a gap, but missions like the Chandrayaan and Mangalyaan are making people more aware of ISRO and the work we do. That being said, I believe there's still a need for better science communication. People should know the time and effort it takes to make scientific progress. Often, our work is viewed as something exotic, while in reality, science—especially physics—is fundamental to our daily lives.

SH: Do you think the current system supports students interested in pursuing research careers?

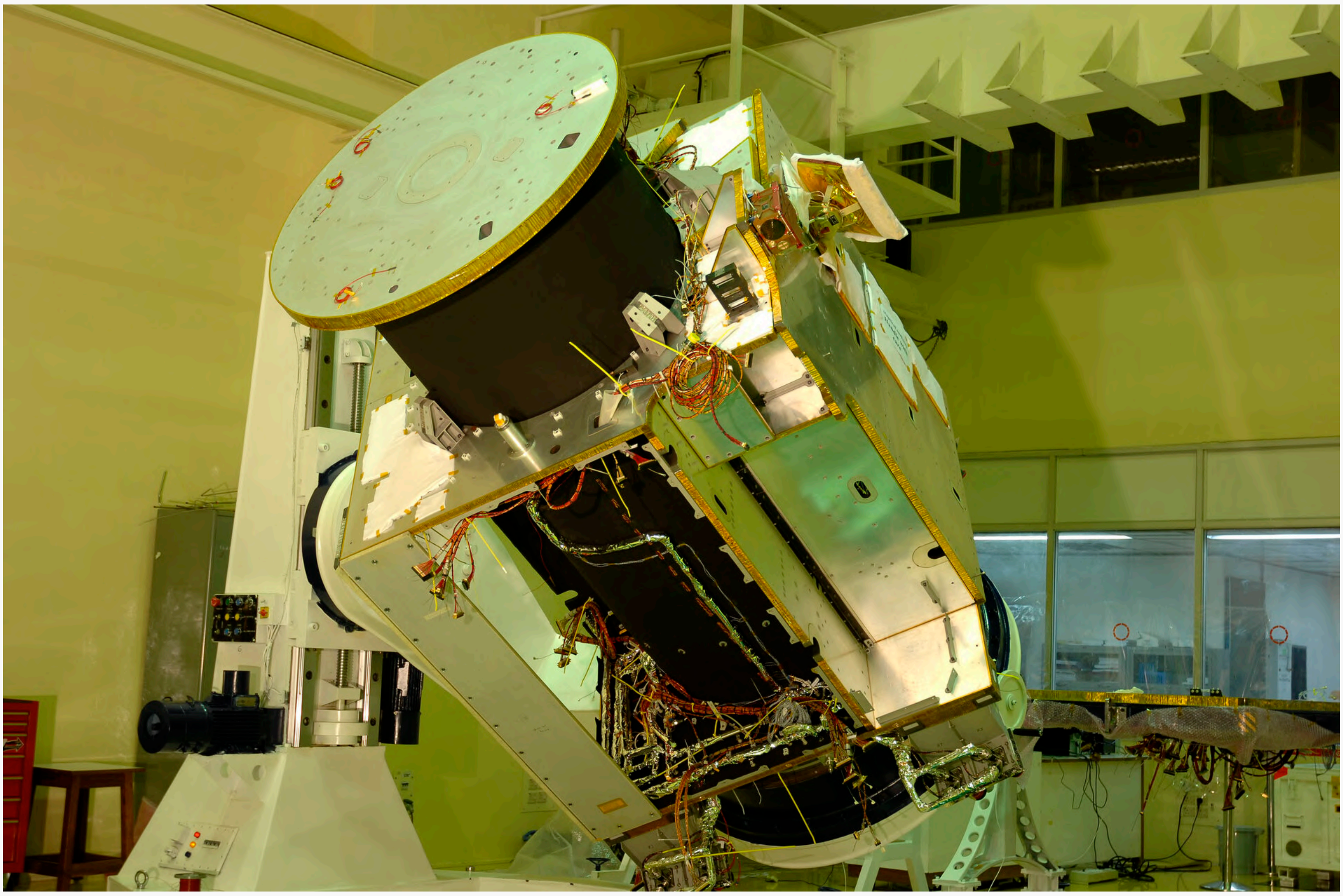


FIG 5 : *European Lunar X-Ray Camera, employed on Chandrayaan 1. SN was the Instrument Operations Scientist at ISRO at that time.*

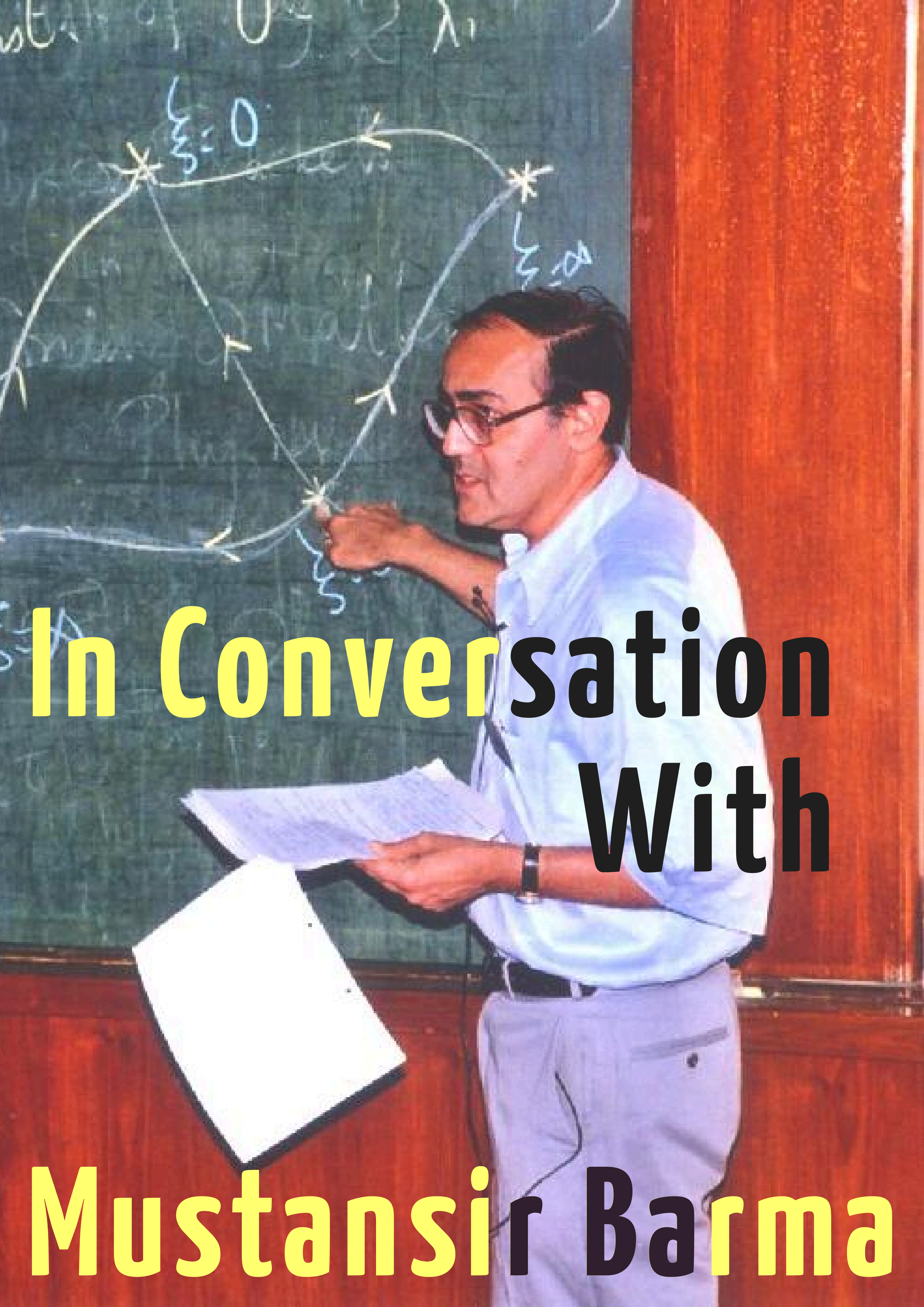
SN: There are challenges. Many bright students are discouraged from pursuing research because of financial insecurity. The stipends are often not enough, and delays in funding can make life difficult for students. I've seen students struggle just to pay rent while pursuing their passion for research. This situation can dissuade many from continuing in science, and it's something that needs attention.

SH: Do you think the research ecosystem in India needs improvement, especially in terms of job opportunities?

SN: Yes, definitely. Many of our postdocs don't return to India because there aren't enough job opportunities here. We need to create more positions and ensure that talented researchers have a place to contribute. Other countries, like China, have programs where they send postdocs abroad with the requirement that they return and work for their space agencies. We could benefit from similarinitiatives in India.

SS: As we conclude, do you have any final thoughts or advice for the next generation of scientists?

SN: I would encourage students to be patient and persistent. Success in science doesn't come quickly. It requires time, effort, and the willingness to face failures along the way. But the satisfaction of contributing to knowledge and discovery is worth it. Focus on the long-term impact of your work, not just the number of papers you publish. At the end of the day, it's about making a meaningful contribution to the field.



In Conversation With Mustansir Barma

In Conversation with Prof. Mustansir Barma

interview by
Swarnendu Saha *IISER Kolkata*

📅 *November 08, 2024*

What sparks a lifelong passion for physics—and what does it take to lead one of India's premier scientific institutions? In this rich and wide-ranging conversation, Prof. Mustansir Barma opens up about his journey from a curious schoolboy writing letters to textbook authors to becoming a celebrated physicist and the founding director of TIFR Hyderabad. He reflects on the essence of randomness, the beauty of phase transitions, the art of asking questions, and the quiet power of effective leadership.

Prof. Barma is an Indian scientist specializing in statistical physics. He was former director of the Tata Institute of Fundamental Research[1] from 2007 to 2014 and currently Professor Emeritus at Tata Institute of Fundamental Research, Hyderabad DAE - Homi Bhabha Chair Professor. He is the recepient of several awards including the Shanti Swarup Bhatnagar Prize for the Physical Sciences awarded by the CSIR (1995) and Padma Shri Award (2013).

SS: Good morning sir. I am Swarnandu Saha from InScight. First things first, are you from Bombay?

MB: Yeah, I was born in Bombay. For the last 9 years or so, I have been at TIFR Hyderabad.

SS: You studied at St. Xavier's College, Mumbai, if I am not wrong, after which you went to the United States.

MB: Yeah, I went to the State University of New York at Stony Brook.

SS: I would like to know how you reached the position you are today, in the academic sphere. Were you inspired by your family, or was it more of an accident?

MB: Yeah, so it's like this. I had an interest in physics. I want to tell you about my school days because I will tell you about an incident from my school days.

What happened is that we had a textbook on light and there was a statement there that if you have two parallel mirrors and a candle in between, you will get an infinite number of images. Now, I sort of found that not quite right in that light has a finite speed of propagation. So, if we put the candle there, there would be reflection from one mirror to the other and soon.

So, the number of images will keep increasing in time but in a very short time, there will be no image because the light has not gone and come back. I wrote to the author. At that time we were in the 1950s, this was an English book. So, this person was in England. I wrote to him and he wrote back a nice letter saying that he is glad that I read my books and think about what is written and he sort of agreed with me that in a finite time, you won't have an infinite number of images.

So, that incident sort of sparked my confidence and then there were many other things in school and college. So, I really wanted to take up physics. Now, when I told this to my parents, my father was actually quite supportive for various reasons. When he was young, he had done engineering but he was asked to step into the family business because his father passed away. So, he had a sympathy for people who wanted to do academics. So, that is how I have done it.

SS: Now, coming to science, you work in statistical physics. When I as a layperson hear the word random, I do have some idea of what that means. But to a practising physicist such as you, what does randomness really mean?

MB: Randomness means to me the same thing that it means to everybody else. Something that is not predictable because it could be this way or that way. There are options and there might be different probabilities or different options so that you cannot be sure which one will happen.

So, that is what I would say is the characteristic of randomness. You are not sure of what will happen in time.

Randomness in space, we all have an intuitive idea - things are scattered without any pattern or arrangement, you know. So, my idea of randomness is the same as anybody else's, I think.

SS: So, if we could find out a mechanism to determine which one is going to be picked, then do you think this concept of randomness will become redundant?

MB: Not in such a sweeping sense but it is also true. See, there could be some things that are intrinsically random like nuclear decay which involves beta particle emission - from one emission to the next, it is truly random. There are other things which are effectively so random that you, I mean, well, which are effectively very well described as random.

For instance, when you toss a coin, you know it will end up as heads or tails and the question is why do we think of it as equally probable? Well, that is because actually as we know the laws of physics including, I mean, involving classical mechanics should determine exactly what the outcome would be - either heads or tails. But it is complicated enough that effectively indeed it is a random process.

So, what I am trying to say is that things that are complicated though intrinsically described by deterministic equations will effectively be random. People should use effective descriptions and the reason is very simple - because they are simpler. Any description that is simpler is good and useful and certainly, effective randomness is an example.

SS: I understand. My next question relates to how we traditionally learn about phase transitions in school. We are taught that given a temperature and pressure, ice changes to water, and water changes to vapor as temperature increases. However, we often overlook the role of pressure. While temperature is the primary factor we focus on, a slight change in pressure near the triple point —even while keeping the temperature constant —can prevent a phase transition from occurring. The fundamental idea remains that once a certain boundary is crossed, a phase transition takes place.

MB: That's an interesting point. When we talk about phase boundaries, particularly the transition between liquid and vapor, we see that this boundary terminates at a critical point. However, the solid-liquid boundary behaves differently—it does not end at a critical point but rather continues indefinitely. The reason lies in symmetry considerations.

Liquid and vapor phases share the same symmetry—both are homogeneous and isotropic. This allows for the existence of a critical point where the phase boundary terminates. However, the solid phase has a fundamentally different symmetry. In a solid, atoms are arranged in a structured manner, meaning it breaks continuous translational symmetry. This broken symmetry prevents the solid-liquid transition from terminating at a critical point because, if it did, one could theoretically move around the phase diagram and bypass the phase transition entirely, which is not physically possible.

A particularly fascinating case is water under high pressure. Unlike many other substances, water exhibits multiple solid phases, meaning that at very high

FIG 1 : *Mustansir Barma accepting the INSA (Indian National Science Academy) medal for Young Scientists in 1980. [Source TIFR H]*

pressures, the phase diagram becomes highly complex, with over 10–11 different solid phases discovered so far. Each phase is separated by its own phase boundary, creating a web of phase transitions rather than a simple linear boundary.

This concept of symmetry-driven phase behavior is fundamental in statistical physics and quantum mechanics, and it was originally formulated by Lev Landau. His argument explains why phase boundaries can terminate at a critical point only if the phases involved share the same symmetry—as seen in the liquid-vapor transition. However, for solid-liquid transitions, where symmetry fundamentally differs, such a termination is not possible.

SS: Let me try to understand this from a different angle. You mentioned earlier that in theory, for a very short time interval after I place the candle, there is no image of it on the mirror. In the same way, if I consider the system over a very short time interval, there will be a region where the phase is morphing. Can you please explain or help me visualize what exactly is happening there?

MB: Well, the first thing is that you must understand what is meant by this temperature, pressure phase diagram and what it is referring to is phases which have reached equilibrium. So, the diagram with pressure and temperature and so on applies only to equilibrium phases of matter. Now, equilibrium is a state which is reached in principle if you wait very very long - you have to wait really long for a system to reach equilibrium and for example, if you change the temperature, it takes some time for the system to equilibrate.

So, the diagram, that phase diagram applies only to phases and systems which are actually in equilibrium. The moment you say that you do something and for a time, short or you know finite time, the system may or may not have reached equilibrium in that time, it probably would not, I mean it is a very short time and so this diagram on its own will not apply, but the fact is that as time goes by, you will indeed transit to the other phase. So, the question you ask is actually very interesting and a matter of current research. How do you accomplish a phase transition, how does one phase change to another in time? The answers are also very nice and finally, very simple.

So, there are regions with phase 1 and regions of phase 2 and these are small if the time is low. As time passes, these regions grow, they are still not very very large, but they are bigger than they were and you can define if you like a typical droplet size. So, as time passes, that size increases.

When that size reaches the size of a container, you actually will finally reach equilibrium. So, that is the way one can imagine it.

SS: Thank you. My next question is about administration. You have served as the Director of Tata Institute of Fundamental Research (TIFR). How do you see the difference between a non-scientist administrative role with regular responsibilities and the role of a director, in a scientific institution?

MB: These two roles are very different, yet they are interconnected. As a director, my responsibilities extended across various aspects of the institute.

First and foremost, there is a responsibility towards the faculty, as well as the entire staff—administrative personnel, technical teams, gardening staff, and so on.

FIG 2 : *The then Prime Minister of India, Dr. Manmohan Singh, unveiled the foundation stone of the new TIFR Hyderabad campus in October 2010. [Credit: Mohd. Yousuf, The Hindu]*

The director oversees the well-being of everyone in the institute. Even small but meaningful changes, such as installing an air conditioner in a driver's cabin, can make a difference in creating a better working environment.

While these are administrative tasks, the director plays a crucial role in academics. The responsibility is not to dictate but to help define the direction the institute should take in research and education.

Personally, I found that the biggest support in this role came from two sources, i.e.,The Faculty – They are central to the institution, and their collaboration is crucial for the institute's growth and The Council of the Institute – In the case of TIFR, the council was chaired by Ratan Tata (which, though incidental, is notable). The council played a key role in providing critical oversight and guidance. It met four times a year and functioned similarly to a Board of Governors (BOG) in other institutions.

The director also has an external-facing role—securing funding and engaging with government bodies. Since TIFR operates under the Department of Atomic Energy, I had many interactions with government officials and funding agencies.

This is very different from the role of a researcher. As a researcher, I would be happy to teach, mentor a small group of students, and work on problems at a blackboard with chalk in hand. That is where my personal comfort lies. But a director's job is different.

One of the biggest challenges in leading an academic institution is managing highly talented, independent-minded individuals. Academics are known for their strong opinions, and everyone believes they are right—and often, they are, in different ways. The challenge for a director is to bring these different viewpoints together to shape a collective vision for the institution.

So yes, being a director is a very different experience, but fortunately, it is also a fulfilling one.

SS: How do you evaluate the present condition of academia in various countries - for science in general and research in particular? I don't have a more specific question regarding this, so I would just like to hear your thoughts on this. MB: To assess the current situation, we must compare it with the past. So, I'll share my perspective by comparing today's scenario with the time when I returned to India from the United States.

I came back in 1976 and joined TIFR, first as a postdoc and later as a permanent faculty member. If I focus on physics, particularly condensed matter physics, the research environment back then was very different from what it is today. At that time, there were very few active research groups in India. It is difficult to imagine today, but back then, you could count all the major groups on your fingers—probably no more than ten. It was a challenging time, but also exciting in its own way. The DAE Solid State Physics Meeting was one of the very few academic gatherings in the country. Since there weren't many conferences, this meeting became the central hub where almost everyone working in condensed matter physics in India would come together. Travel was very different too. There were no frequent flights, so we relied on trains for travel. I remember collaborating with a researcher in Roorkee while I was in Bombay—and every interaction required significant logistical effort.

SS: Do you mean IIT Roorkee?

FIG 3 : *STATPHYS – Kolkata IX (2016): Abhishek Dhar, Sanjib Sabhapandit, Mustansir Barma, Sakuntala Chatterjee, Shamik Gupta. [Source TIFR H]*

MB: There was no IIT in those days—it was the University of Roorkee. But yes, the same place.

Back then, travel was very different. To visit Roorkee, I would take the Dehradun Express, which slowly made its way through Delhi and reached Roorkee in about 36 hours. Today, that seems unimaginable—there were no direct flights, no quick alternatives, but we managed. We took trains all over the country, and that was just how things were.

Of course, that's not the main point. The real point is how different the academic landscape was. There were very few researchers, but it was still very enjoyable. We communicated by letters—no email, no instant messaging. And in some ways, that was actually a good thing. When you wrote a letter, you had time to think before responding. Today, emails create an expectation of immediate replies—within a couple of hours at most. But back then, you could take a week to reply, reflect on ideas, and engage more deeply. Compared to those days, things today are much faster and more interconnected. Collaborations are no longer limited by geography—they happen online, across institutions, and even across continents.

If I focus on my field, statistical physics, the transformation has been incredible. Today, India has one of the largest statistical physics communities in the world. That didn't happen overnight—it took years of meetings, training, holding schools, and community-building efforts. One of the best examples of this is the Annual Community Meeting, organized by the International Centre for Theoretical Sciences (ICTS) in Bangalore. It is a completely open forum, where everyone—no matter how senior or junior—gets just 10 minutes to speak. The idea is to foster inclusivity and ensure that everyone contributes.

Another major initiative by ICTS is the Annual Summer School, where they bring in top international speakers. Around 80–90 students participate each year, getting exposure to some of the best minds in the field. It's not just about learning from experts—it's also about impressing them with the quality of Indian research. There's no doubt that the research scenario in India has evolved dramatically. Opportunities have multiplied, and the landscape is far richer than before.

I once wrote about this in an article titled "An Evolving Landscape" for the Indian Association of Physics Teachers magazine. But that's beside the point—I'm happy to share these thoughts again because the transformation of science in India is something worth celebrating.

SS: What do you make of the present scenario regarding research funds in India?

MB: Research funding has its challenges. Due to the budget cycle, sometimes funds are not released exactly on time, but such delays have not been severe enough to disrupt the entire system. It is not as though salaries are suddenly cut in half or research is completely halted.

The government has been generally supportive of science—sometimes more, sometimes less. All institutions have aspirations: they want to grow, expand into new

FIG 4 : *Mustansir Barma delivering an invited talk at the International Institute of Physics, Brazil, on "Entropy, Order and Fluctuations", in January of 2020. [Source IIP]*

areas, and accommodate more students. However, it is not always possible for the government to support everything at the desired scale.

That said, if I compare today with the 1970s, the situation has greatly improved. Back then, traveling abroad to attend conferences was not possible frequently—perhaps once in a few years, not every year as it is for many researchers today.

Research funding today is better than in the past, but a judicious allocation of resources across institutions and researchers would have a huge impact. In the grand scheme, the amount allocated to fundamental science is still minuscule, but it does not mean that simply increasing the budget is the solution.

If we can ensure that financial support is given in an effective and strategic manner, India can progress by leaps and bounds.

SS: Should we question everything, or should we only ask the right questions?

MB: Question everything. There is no such thing as questioning rightly or wrongly. How do you even know if a question is right or wrong until you define it and explore the answer?

In science, answers are not the main thing. The question is paramount. The true essence of science lies in asking the right questions, pushing boundaries, and challenging assumptions.

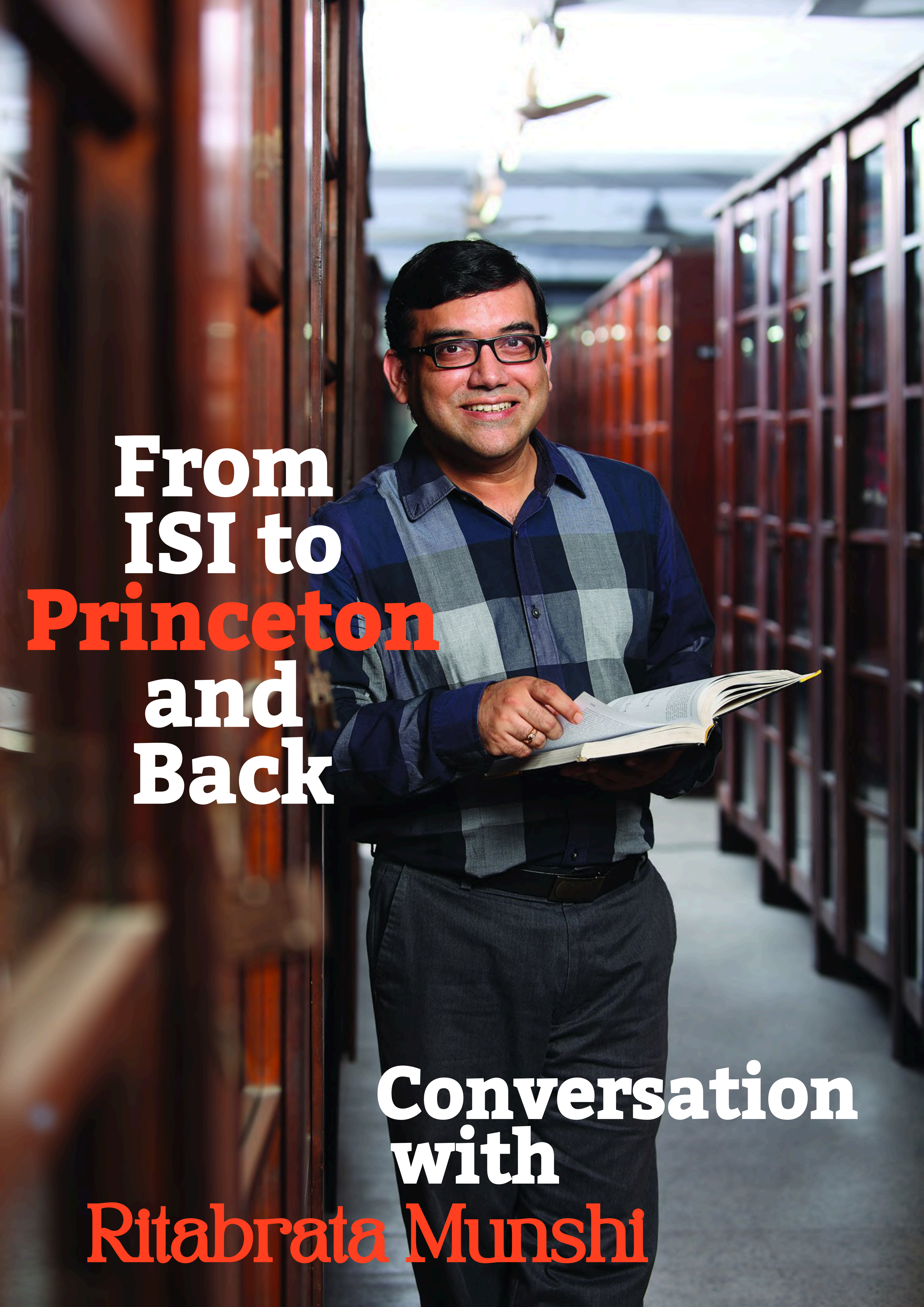
SS: Having completed a major portion of your academic life and having become an Emeritus Professor, what do you consider to be your biggest contribution to science, TIFR, and the students?

MB: One of my most significant contributions as a Director of TIFR was initiating and playing a key role in the formulation and partial execution of the new TIFR campus in Hyderabad. It is a very large campus, seven times the area of the TIFR campus in Mumbai. It holds enormous potential, and if it reaches its full realization, it will be a game changer—not just for TIFR, but for the entire country.

Progress is happening, though not at the speed we initially envisioned. Time has inflated, as is often the case with large-scale projects. But in the long run, this does not matter, because we hope that this institution will last for hundreds of years. Seeing the plans I helped initiate now being executed is a source of immense satisfaction and pride for me.

SS: Thank you, sir. It was a pleasure speaking with you.

MB: Thank you very much.



From ISI to Princeton and Back

Conversation with Ritabrata Munshi

From ISI to Princeton and Back: Conversation with Ritabrata Munshi

interview by

Swarnendu Saha *IISER Kolkata*

📅 *December 10, 2025*

In this wide-ranging conversation, Prof. Munshi reflects on a life shaped by mathematics–from early fascination with symbols to research at Princeton and a return to ISI Kolkata as faculty. He discusses number theory as an artistic pursuit, the changing philosophy of academic institutions, and why mathematics survives when fashionable disciplines fade. The interview offers rare insight into mathematics as both a personal vocation and a centuries-old human enterprise.

Prof. Munshi is a mathematician specialising in number theory. He was awarded the Shanti Swarup Bhatnagar Prize for Science and Technology for the year 2015 in mathematical science category. On 8 November 2018 he was awarded the ICTP Ramanujan Prize in a ceremony held at the Budinich Lecture Hall, ICTP. He is affiliated to Tata Institute of Fundamental Research, Mumbai, and the Indian Statistical Institute, Kolkata

SS: Hello sir, I am Swarnendu Saha from Team InScight, and it is an honour to have you with us today.

RM: Thank you. It's a pleasure to be here.

SS: To begin with, could you take us through your journey of becoming a mathematician? Perhaps a brief overview of your academic path.

RM: Yes. It has always been my dream to be a mathematician. Even when I was very young, during my school days, I wanted to become either a mathematician or a theoretical physicist. When I was in high school, I used to read my father's journals. My father was an engineer and received journals from the Institution of Engineers. I was fascinated by the symbols—especially the mathematical symbols—that appeared in those journals. I loved looking at them and trying to understand what was actually going on. That curiosity gradually turned into a passion. Even in classes seven and eight, I started maintaining a diary in which I would write down mathematical ideas and thoughts.

After finishing school, I faced an important decision—whether to pursue engineering, possibly through the IITs, or to study mathematics. For me, it was a clear-cut choice. There was no confusion. I chose mathematics. At ISI, I received excellent training in mathematics. In my view, it was—and still is—the best place to study mathematics. From there, my journey truly began. I later went to Princeton and worked under Andrew Wiles, which was a dream come true.

SS: At that point in time, since your father was an engineer, was there pressure on you to pursue engineering? Do you think it would have been an easier route, given the familiarity?

RM: No, actually, I think my parents realized quite early on that I was not really interested in anything apart from mathematics. I also used to draw and paint a lot, so those were the only two passions I had—mathematics and painting. So, for me, the choice was quite easy.

SS: So, you were a student at ISI?

RM: Yes, I was a student at ISI. I did B. Stat. and M. Stat.. There was no B. Math or M. Math back then. I did my B. Stat at ISI Kolkata—that was the only option at the time. For M. Stat, I completed the first year in Kolkata. The second year I did in Bangalore, because it depended on the specialization one chose. Since I was more interested in mathematics than statistics, I opted for advanced probability. For that specialization, I had to go to Bangalore.

SS: Today, you are a faculty member at ISI Kolkata, and you were once a student at ISI. Having experienced the same institute from two very different perspectives, how do you see it now?

RM: First of all, ISI has changed quite a bit. When I was a student—from 1996 to 2000—I was at ISI Kolkata. I returned as a faculty member in 2015. So, there is almost a 15-year gap between the two phases. A lot has changed. When I was a student, ISI was a very small place. There were very few students and very few faculty members. The focus was entirely on performance, education, and knowledge—nothing else. Now, there are many more students, and I think the diversity and variation among

FIG 1 : *Prof. Ritabrata Munshi at his dorm room in New Graduate College, Princeton, Aug 2001*

students have also increased. For instance, when I was a student, my batch had only 13 students.

SS: Thirteen. You mean, one and three ?

RM: Yes—thirteen. One and three. Now there are around fifty students. So you can imagine the increase in variation.

SS: So, roughly four times the size.

RM: Yes. Our batch was different—quite exceptional. In fact, one of my classmates is here today; he is now at the University of Georgia. I am meeting him after almost twenty years. It was a very small group, and we were very closely knit. We helped each other with studies and almost everything else. We all lived in the hostel back then. Now, most students stay outside campus. I think the atmosphere has changed. I find it difficult to precisely articulate what has changed, but something certainly has.

SS: Would you say the change has been for the better or for the worse—both from a student's and a faculty member's perspective?

RM: If you ask me personally, I would say that I would rather be a student in the 1990s than now. But this is a different generation, and their priorities are probably different. Back then, interaction between faculty and students was much stronger. Our professors were always very welcoming.

SS: And how is it currently? When I joined in 2020 at IISER Kolkata for my BSMS, my batch had around 200 students. When my juniors joined, it increased to around 230. In that context, you are saying that 50 students in ISI is a large number. But in many institutes, a single department has more than that many students majoring in mathematics. So why do you think 50 students at ISI is a huge number?

RM: I think the key point is how ISI was originally designed. ISI was built to function with small groups. It is not like an IIT or an IISER. The philosophy behind ISI was fundamentally different.

SS: How is it different? What was that philosophy?

RM: The idea was to have a very small, carefully selected group of students, and teachers who would devote a significant amount of time to training them. With larger numbers, that becomes difficult. You simply cannot have one-to-one interaction with everyone. Earlier, that level of interaction was possible.

SS: What is the current teacher-to-student ratio?

RM: I don't know the exact numbers, but—

SS: I'm asking because if there are about 50 students, one would expect at least 20–30 faculty members.

RM: It's about 50 students per batch in B.Stat. Then there is M.Stat and M.Math. So roughly, you are looking at around 150 B.Stat students, about 100 M.Stat students, and around 70–80 M.Math students. And then there are PhD students as well. I personally supervise seven PhD students.

SS: So altogether, it would be around 250 students or more.

RM: Yes, altogether. But another important point is that not all faculty members at ISI are involved in core teaching. For example, in the Statistics and Mathematics Unit, all professors teach at least one course every semester and are deeply involved. However, that is not the case in all departments, simply because it is not always feasible.

SS: When ISI was founded, as far as I understand, its primary focus was mathematics and statistics, right?

FIG 2 : *Prof. Ritabrata Munshi at Beside Carnegie Lake in Princeton, Aug 2001*

RM: When ISI was built, the main focus was statistics—and anything closely connected to statistics.

SS: Yet, interestingly, one of the few preserved dinosaur fossils in the Kolkata region is housed on the ISI campus. It's quite old, and if I am not mistaken, it comes from the Tungabhadra Basin, discovered around the time of Tagore's centenary.

So ISI does not seem to be limited strictly to mathematics and statistics in the way we often perceive it. From both a student's and a teacher's perspective, how do you connect this broader academic presence? I'm trying to understand the background.

RM: Yes, ISI does have a Geology unit. In general, any discipline that has a strong connection with statistics finds a place at ISI.

SS: So how is geology connected to statistics?

RM: You can apply statistics to geology, anthropology, or almost any discipline. Wherever there are measurements, data collection, and the study of data and numerical distributions, statistics becomes relevant.

That is why, when Mahalanobis founded ISI, he had all of this in mind. His idea was that wherever statistics could be applied, that discipline should have a place at ISI.

There is also a unit of computer vision and pattern recognition. You need computers to perform statistical analysis, which is why there is a Computer Science Department. You need mathematics to develop the theoretical foundations of statistics, which is why there is a Theoretical Statistics and Mathematics Unit.

Statistics can be applied to quantitative economics—hence the Economics Department. It can be applied to the study of language—hence Linguistics. It can be applied to biology—so there are Biostatistics and Genetics units. In that sense, everything is connected.

SS: Were these developments already in place when you were a student, or did they come up later?

RM: They were already there. These ideas have existed since Mahalanobis's time.

SS: So over the years, how do you see the growth and expansion of ISI in terms of education and academic research?

RM: Today, the primary focus is on four core subjects—Statistics, Mathematics, Economics, and Computer Science. These are the subjects for which ISI offers degrees.

However, when ISI was founded, the degree was only in Statistics. Mathematics was treated as applied statistics at that time. Over the years, other units have, in my opinion, lost some of their earlier significance. They were more central when Mahalanobis himself was around.

SS: So would you say there has been a decline in diversity at ISI?

RM: In a sense, yes—at least in terms of relative importance. Take mathematics, for example. Mathematics has become more important because it is now formally taught as a subject. For B.Stat and M.Stat, mathematics is essential, since it is a core component.

And now we also have B.Math and M.Math programmes. This has attracted more students who are specifically interested in mathematics. As a result, the Mathematics department has gained prominence.

SS: What is your primary field of research?

RM: Number Theory. Number theory is essentially the study of numbers—primarily integers. But the interesting part is not the numbers themselves; it is the structure they carry. Numbers have an additive structure—you can add them. They also have a multiplicative structure—you can multiply them. And number theorists are interested in understanding how numbers behave as you move along the number line—say along the positive integers—with respect to this multiplicative structure.

For example, consider divisibility. The number 1 has no divisors other than itself. The number 2 has no divisors other than 1 and 2. The same is true for 3. These are called prime numbers. But 4 is 2×2, so it has a non-trivial factor. Five is prime. Six is composite. Seven is prime. So primes appear irregularly, but they are fundamental. Prime numbers are the multiplicative building blocks of integers. Every integer can be written as a product of primes. What we are really interested in is understanding the interplay between the additive structure and the multiplicative structure of integers.

SS: What do you mean by "interplay"?

RM: As you move along the integer axis, you are progressing additively—you keep adding one. But at the same time, the multiplicative properties of numbers—such as primality and factorization—change in complex and fascinating ways.

Understanding this relationship is at the heart of number theory. Every step is essentially adding one. And what we want to understand is what happens to the multiplicative structure at each step—whether the number you reach is prime or composite.

SS: So in that sense, subtraction would just be adding minus one.

RM: Exactly—adding minus one. That also comes under the additive structure. However, when studying multiplicative structure, it is not very important to look at negative numbers. One can restrict attention

FIG 3 : *Prof. Ritabrata Munshi at Ramanujan Prize Ceremony in International Centre for Theoretical Physics, 9th November 2018. [source: ictp.it]*

to positive integers, and the questions remain just as interesting. So, for example, you can ask: how many prime numbers are there? If you go up to a large number —say 10,000—how many primes are there below it? More generally, how many primes are there up to a number ?

We would like to have a formula for that. Gauss came up with a conjectural formula for this around 1796. He suggested that the number of primes less than or equal to x, is denoted by $\pi(x)$, is approximately $x/\log x$. This became a central problem in number theory, and mathematicians spent nearly 100 years trying to prove it. Finally, between 1796 and 1896, the problem was completely resolved.

What is remarkable is that, in the process of trying to prove this single statement about the distribution of prime numbers, mathematicians developed entirely new areas of mathematics. Complex analysis was developed, new applications of Fourier analysis emerged, and combinatorics and real analysis advanced significantly. In mathematics, we often say that the most interesting problems are those that generate more mathematics. This problem—understanding the distribution of prime numbers—did exactly that. It led to deep developments across multiple fields.

That is why prime numbers remain such an active area of research even today. As you can see, this conference itself is titled "Primes, Patterns and Propagation." We are still deeply invested in understanding primes.

SS: When you started your career, as far as I remember, you wrote a proof of the Jordan Curve Theorem. In that regard, I have two questions. First, were you interested in number theory at that time, or did your interest develop later? Second, in the introduction to your work, it is mentioned that you were not very interested in computers at that time—has that opinion changed?

RM: Yes, I wrote a proof of the Jordan Curve Theorem during my first year of B.Stat. At that time, I was quite interested in topology.

However, my interest in number theory began even earlier. I remember that when I was in Class 10, while preparing for my board examinations, we went to the book fair and bought David Burton's Introduction to Number Theory. That book fascinated me. It is written in a way that even school students can read and appreciate it, and it provides remarks and notes that connect naturally to higher mathematics.

FIG 4 : *Prof. Ritabrata Munshi delivering his talk on number theory at Ramanujan Prize Ceremony in International Centre for Theoretical Physics, 9th November 2018. [source: ictp.it]*

That is really how my interest in number theory developed. Even before that, of course, I had read about Ramanujan—which is a fairly standard Indian student story. You read about Ramanujan when you are ten, you try to become Ramanujan, and by the time you are sixteen, you realize that you cannot become Ramanujan.

Regarding computers—yes, at that time I was not very interested in them. Back then, computers felt rather boring. Things have changed since then, and of course I have also aged over the last 25 years. But even today, if you give me a computer and a mathematics book or a mathematical problem, I will choose mathematics any day.

SS: Currently, ISI Kolkata is facing certain challenges. As a former student and now a faculty member, how do you see these changes? How might changes in the institutional structure affect research and academics, given that the community and resources largely remain the same?

RM: I sincerely hope that the new structure will not affect the academic functioning of ISI. Academically, ISI is doing very well, and it does not need changes in that direction.

Of course, we always need more resources to grow and develop. But my main concern with the proposed bill was the restructuring of the governing council and, more importantly, the academic council. The academic council is central to maintaining academic autonomy. Fortunately, in the revised or modified version of the bill, that particular aspect has been addressed, so I am more comfortable with it now. As for the governing council, some changes were expected—I had been hearing about such possibilities for some time. What impact these changes will ultimately have on ISI remains to be seen. It could turn out to be beneficial, or it could bring challenges. But my firm view is this: as long as the academic structure is left untouched, ISI will continue to function well.

SS: As we approach the end—perhaps the last five minutes—I want to ask you something specific. You completed your undergraduate and master's education in India at ISI, arguably the best place for mathematics in the country, and then went to the United States for your PhD.

How do you compare the study, training, and thinking in mathematical research between India and the West?

RM: Overall, the training in mathematics in India is quite good. In fact, if you compare an average Indian student with an average American student, I would say the average Indian is better placed mathematically.

SS: By "average Indian," do you mean someone who has completed their bachelor's and master's from a public university?

RM: Yes. If you compare them with an average American who has done a major or minor in mathematics—especially if you include community colleges and exclude the very top universities—then I think the average Indian student stands higher.

However, the big difference lies in flexibility and freedom. In the US, if you are a promising student, you are strongly encouraged and given access to opportunities. From a very young age, students have access to resources, mentorship, and even university-level courses. You can talk to professors, attend college classes, and sometimes even fast-track your education.

You might start college-level mathematics at the age of 15. Mathematics is largely a subject for young minds—much like chess. When you are young, your mind is fresh, and that freshness is crucial for mathematics. So it is very important to identify talent early and guide it properly.

SS: One of my final questions—and you may disagree with me, or even get angry—is this. Many of us chose science over engineering or medicine and faced questions about that choice, given the current situation in the country. Now, after studying science, I want to ask you—someone who has devoted his life to mathematics—how do you see the subject today? Do you see it flourishing? Do you see students choosing it out of genuine interest, or merely as a degree?

And more broadly, many people say that science—and especially mathematics—is a "dead" subject. What is your take on that?

RM: People say many things. That does not mean they make sense.

SS: It is our responsibility to explain what is correct.

RM: Exactly. Mathematics is one of the oldest human intellectual pursuits. You can trace it back to ancient civilizations—the Vedic period, the Babylonians, the Greeks. Mathematics has existed for thousands of years.

What is remarkable is that even after 2,000–3,000 years, it is still alive and thriving. People continue to work in mathematics and discover new results. How many other subjects can claim that kind of longevity?

Take artificial intelligence, for example. Do you think AI will survive for 2,000 years?

SS: It may evolve or transform.

RM: I don't think it will survive in the same way. When I was deciding between engineering and mathematics, computer science, electronics, and information technology were "in fashion."

SS: But those fields still exist, right?

RM: They exist, but not in the way they once did. The excitement, the structure, the focus—it has changed. Mathematics, on the other hand, has endured, although its prominence has not been uniform throughout history.

SS: By "not uniform," do you mean temporally or subject-wise?

RM: Temporarily. If you look at ancient Greek mathematics—Euclid, Pythagoras, Archimedes—it was a golden era. Then there were periods with relatively little visible activity. Later, from around the 12th century onward, algebra and new mathematical ideas emerged. Again, there were quieter periods, followed by renewed bursts of activity.

SS: Why do you think this pattern exists? The need for mathematics—whether practical or intellectual—should always be present, shouldn't it?

RM: I think before the Industrial Revolution, mathematics had limited application in everyday human life. After the Industrial Revolution, people realized how mathematics could be used to optimize systems, solve practical problems, and drive technological progress. But the Greeks were not doing mathematics because it was useful. Mathematics was, in a sense, a "useless" pursuit back then—or perhaps a better word is art. At its highest level, mathematics is art, not science.

SS: And that still holds—that higher mathematics is a beautiful but "useless" art?

RM: Yes, absolutely. So it remains. At the highest level, mathematics is purely art. There is no science in it—it is pure imagination. At the same time, mathematics is also the unifying language. It is the language we need to understand underlying reality.

FIG 5: *Prof. Ritabrata Munshi invited as a speaker at International Congress of Mathematics 2018 in Rio de Janeiro. [source: Rio ICM2018]*

SS: By reality, you mean—

RM: The universe, physics, and all of science. Mathematics is the correct language to describe them.

That is why mathematics has survived for thousands of years. I do not think it has lost any of its charm. In fact, I doubt whether many of the subjects that are fashionable today will survive even a hundred years. Things will change so much that people may forget them altogether.

SS: One final question. As an experienced mathematician, what would you like to say to younger students—those who have already taken up mathematics, those who are thinking of taking it up—and also to the general public?

RM: To students who are choosing mathematics, I would say this: you are making an excellent choice. But be prepared for a lot of frustration. Doing research in mathematics—especially at a high level—is like trying to move a wall. And when it moves, you are lifted to a completely different level. But most of the time, it does not move. So mathematics is, in some sense, 99% frustration and 1% success.

SS: So we have to enjoy the journey through that frustration?

RM: Exactly. The real joy of mathematics lies in the attempt itself—in trying to move the wall. That is where the fun is. When the wall finally moves, you feel immense satisfaction—but there is also a strange sadness, because the struggle that defined the journey has ended.

FIG 6 : *Prof. Ritabrata Munshi with his classmates of St Thomas Primary School, Chandannagar, West Bengal (front row, fourth from right). [source: Department of Science and Technology, India]*

Science Games

Crossword This issue's crossword explores the science of time, from relativity and radioactive decay to biological clocks.

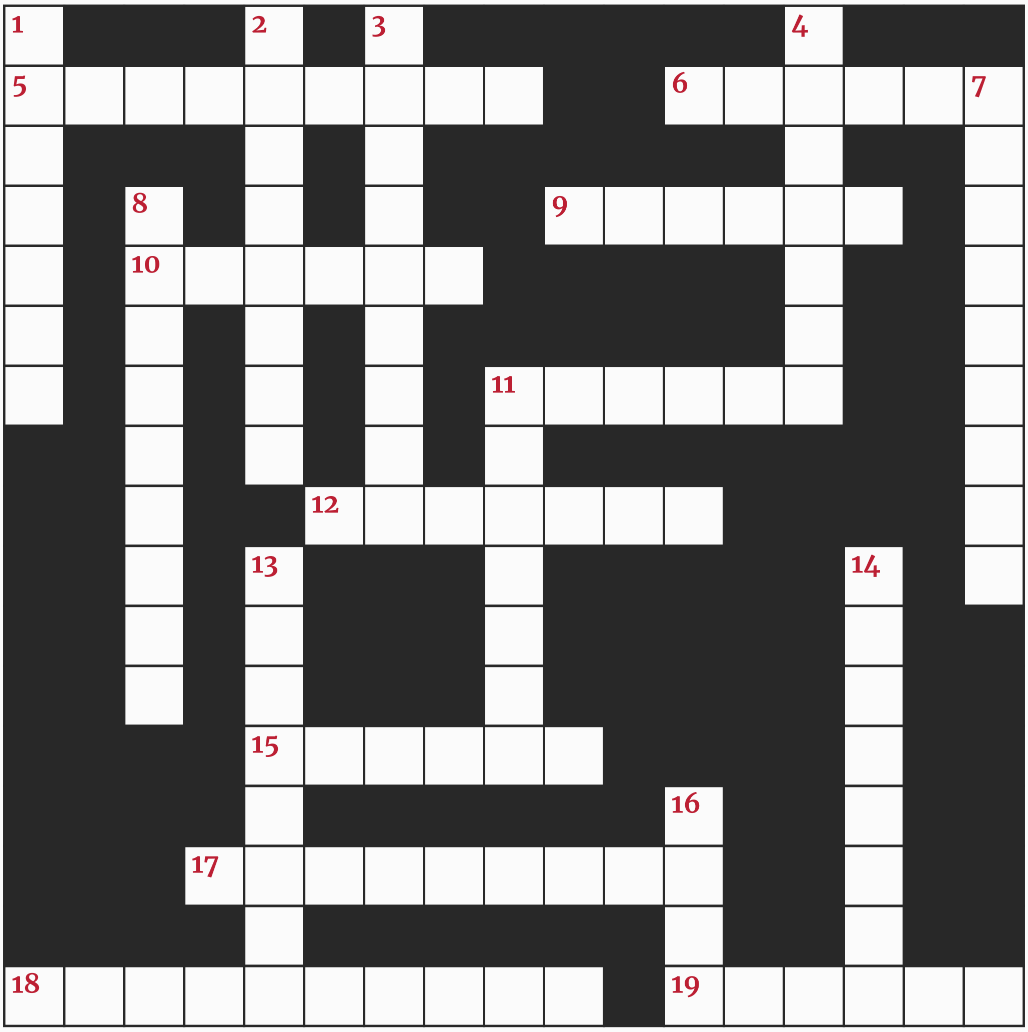
Quiz How well do you know the women who helped shape Indian science?

Linked List Guess the words to complete the word chain.

Themed Crossword — Time

This issue's crossword explores the science of time, from relativity and radioactive decay to biological clocks.

***Abhirup Mukherjee** [DPS, IISER Kolkata]*



Across

5. An extraordinarily rapid expansion of the very early universe, occurring a tiny fraction of a second after the Big Bang. (9)
6. Type of clock whose oscillations provide the world's most precise timekeeping. (6)
9. A record of the distant past preserved in rock. (6)
10. A rapidly rotating neutron star whose regular pulses can act as remarkably precise cosmic clocks. (6)
11. The element whose radioactive isotope is commonly used to date once-living materials. (6)
12. The thermodynamic quantity whose increase gives us one of physics' most famous arrows of time. (7)
15. The SI base unit of time, now defined using a particular transition in caesium-133. (6)
17. (relativity) boundary separating events that can from those that cannot causally influence an observer. (9)
18. Einstein's theory tells us that time is not the same for all observers. (10)
19. _____ time: a tiny unit formed from fundamental constants, often regarded as the smallest meaningful scale in some approaches to quantum gravity. (6)

Down

1. The event or era marking the beginning of the hot, dense early universe—and, in the standard picture, our cosmic clock. (7)
2. The time required for half the nuclei in a radioactive sample to decay. (8)
3. Biological rhythm that roughly follows a 24-hour cycle. (9)
4. Cross this boundary around a black hole and returning to the outside universe becomes impossible. (7)
7. The principle that cause precedes effect. (9)
8. The four-dimensional stage on which relativity describes the universe. (9)
11. A hypothetical discrete unit of time proposed in some theories. (7)
13. A phenomenon that can reveal how quickly distant galaxies are receding from us—and hence something about cosmic history. (8)
14. What happens to a moving clock, according to special relativity. (8)
16. The kind of second occasionally added to UTC to keep it aligned with Earth's rotation. (4)

*Solution can be found at the end of the issue. For an interactive version of the crossword, check out our **website**.*

Science Quiz: Indian Women Scientists

How well do you know the women who helped shape Indian science?

Swarnendu Saha *[IIT Bombay]*

Q1. Which Indian botanist was one of the first Indian women to obtain a PhD in a scientific field abroad and is particularly known for her work on plant cytogenetics, chromosome studies, and sugarcane breeding?

I. Anna Mani
II. E. K. Janaki Ammal
III. Asima Chatterjee
IV. Kamal Ranadive

Q2. Asima Chatterjee made major contributions to Indian medicinal chemistry. Her research included the chemistry of alkaloids and compounds derived from which natural sources?

I. Plants
II. Marine organisms
III. Meteorites
IV. Fossil fuels

Q3. Anna Mani is particularly associated with the development and standardisation of meteorological instruments in India. Which of the following was also a major area of her scientific work?

I. Atmospheric ozone
II. Nuclear fission
III. Quantum computing
IV. Molecular genetics

Q4. Kamal Ranadive is remembered particularly for her pioneering research into:

I. Cancer and the relationship between cancer and viruses
II. Gravitational waves
III. Indian monsoon dynamics
IV. Semiconductor physics

Q5. Which Indian woman physicist is particularly known for her contributions to particle physics, including work related to the Higgs boson and physics beyond the Standard Model?

I. Rohini Godbole
II. Tessy Thomas
III. Rajeshwari Chatterjee
IV. Anna Mani

Q6. Tessy Thomas is popularly associated with which area of Indian scientific and technological development?

I. Missile technology
II. Vaccine development
III. Space telescope design
IV. Agricultural genetics

Q7. Rajeshwari Chatterjee was a pioneer in which field, becoming one of India's earliest women engineers to work extensively in it?

I. Microwave engineering
II. Biochemical engineering
III. Nuclear medicine
IV. Agricultural engineering

Q8. Which scientist's work involved polyploidy and chromosome studies in plants, and whose research contributed to the development of improved varieties of crops such as sugarcane?

I. Kamal Ranadive
II. Janaki Ammal
III. Rohini Godbole
IV. Anna Mani

Q9. Which scientist among the following is most directly associated with the study and measurement of atmospheric ozone and the development of precision meteorological instruments, rather than with biology, chemistry, or particle physics?

I. Rohini Godbole
II. Anna Mani
III. Kamal Ranadive
IV. Asima Chatterjee

Q10. Who am I? I worked in a field where women were relatively uncommon when I began my career. My research involved plant-derived compounds, particularly alkaloids, and I investigated their potential medicinal applications. I became one of India's most prominent women organic chemists.

I. Janaki Ammal
II. Asima Chatterjee
III. Anna Mani
IV. Kamal Ranadive

*Answers can be found at the end of the issue. For an interactive version of the quiz, check out our **website***

Linked List — General Science Edition

Guess the words to complete the word chain.

Swarnendu Saha *[IIT Bombay]*

Linked List is a general science-based word game. The rules are straightforward:

1. The goal is to guess eleven words that have been drawn from science.
2. The first word (the seed) will be provided to you, and hints and number of letters will be provided for the remaining words.
3. You are also informed that the first letter of any word is the last letter of the previous word. So the first letter of the second word will be the last letter of the seed word, the first letter of the third word is the last letter of the second word, and so on.
4. This property goes all the way, so that the last letter of the last (eleventh) word is also the first letter of the seed word.

Find all the words!

Today's seed: **CELL**

1. A molecule that binds specifically to another molecule, often a protein or receptor. (6)

L					

2. The molecule that carries genetic information in almost all living organisms. (3)

3. The smallest unit of an element that retains its chemical identity. (4)

4. The process by which a eukaryotic cell divides to produce two genetically similar daughter cells. (7)

5. The distribution of a quantity according to wavelength, frequency, energy, or another variable. (8)

6. A group of atoms held together by chemical bonds and behaving as a unit. (8)

7. A biological catalyst that accelerates a chemical reaction without being consumed. (6)

8. A negatively charged subatomic particle found outside the atomic nucleus. (8)

9. A hypothetical or nearly massless particle that interacts only very weakly with matter. (8)

10. Relating to compounds containing carbon, especially those associated with living systems. (7)

						C

Solution can be found at the end of the issue. For an interactive version of this game, check out our ***website****.*

Solutions

Crossword

1 B				2 H		3 C							4 H			
5 I	N	F	L	A	T	I	O	N			6 A	T	O	M	I	7 C
G				L		R							R			A
B		8 S		F		C			9 F	O	S	S	I	L		U
A		10 P	U	L	S	A	R						Z			S
N		A		I		D							O			A
G		C		F		I		11 C	A	R	B	O	N			L
		E		E		A		H								I
		T			12 E	N	T	R	O	P	Y					T
		I		13 R				O						14 D		Y
		M		E				N						I		
		E		D				O						L		
				15 S	E	C	O	N	D					A		
				H							16 L			T		
			17 L	I	G	H	T	C	O	N	E			I		
				F							A			O		
18 R	E	L	A	T	I	V	I	T	Y		19 P	L	A	N	C	K

Quiz

1. Which Indian botanist was one of the first Indian women to obtain a PhD in a scientific field abroad and is particularly known for her work on plant cytogenetics, chromosome studies, and sugarcane breeding?: **E. K. Janaki Ammal**

2. Asima Chatterjee made major contributions to Indian medicinal chemistry. Her research included the chemistry of alkaloids and compounds derived from which natural sources?: **Plants**

3. Anna Mani is particularly associated with the development and standardisation of meteorological instruments in India. Which of the following was also a major area of her scientific work?: **Atmospheric ozone**

4. Kamal Ranadive is remembered particularly for her pioneering research into:: **Cancer and the relationship between cancer and viruses**

5. Which Indian woman physicist is particularly known for her contributions to particle physics, including work related to the Higgs boson and physics beyond the Standard Model?: **Rohini Godbole**

6. Tessy Thomas is popularly associated with which area of Indian scientific and technological development?: **Missile technology**

7. Rajeshwari Chatterjee was a pioneer in which field, becoming one of India's earliest women engineers to work extensively in it?: **Microwave engineering**

8. Which scientist's work involved polyploidy and chromosome studies in plants, and whose research contributed to the development of improved varieties of crops such as sugarcane?: **Janaki Ammal**

9. Which scientist among the following is most directly associated with the study and measurement of atmospheric ozone and the development of precision meteorological instruments, rather than with biology, chemistry, or particle physics?: **Anna Mani**

10. Who am I? I worked in a field where women were relatively uncommon when I began my career. My research involved plant-derived compounds, particularly alkaloids, and I investigated their potential medicinal applications. I became one of India's most prominent women organic chemists.: **Asima Chatterjee**

Linked List

L	I	G	A	N	D		
D	N	A					
A	T	O	M				
M	I	T	O	S	I	S	
S	P	E	C	T	R	U	M
M	O	L	E	C	U	L	E
E	N	Z	Y	M	E		
E	L	E	C	T	R	O	N
N	E	U	T	R	I	N	O
O	R	G	A	N	I	C	

You made it to the end! While we cook up the next issue, here's a random photo dump.

This Is Freedom!

Celebrating 80 Years of India's Independence at IISER Kolkata. On the eve of India's 80th Independence Day, IISER Kolkata shines in saffron, white and green.

Credit: IISER Kolkata

The One and Only SB1

As the Indian team secured gold medals at the 58th International Chemistry Olympiad, IISER Kolkata is proud that Prof. Subhajit Bandyopadhyay served as the Head Mentor of Team Indian.

In the Footsteps of Bibha Chowdhuri

5th Bibha Chowdhuri Lecture at the Department of Physical Sciences at IISER Kolkata. This year's lecture was delivered by Prof. Sudeshna Sinha. She spoke about "Leveraging Chaos for Logic"!