CONNECT

WITH THE INDIAN INSTITUTE OF SCIENCE

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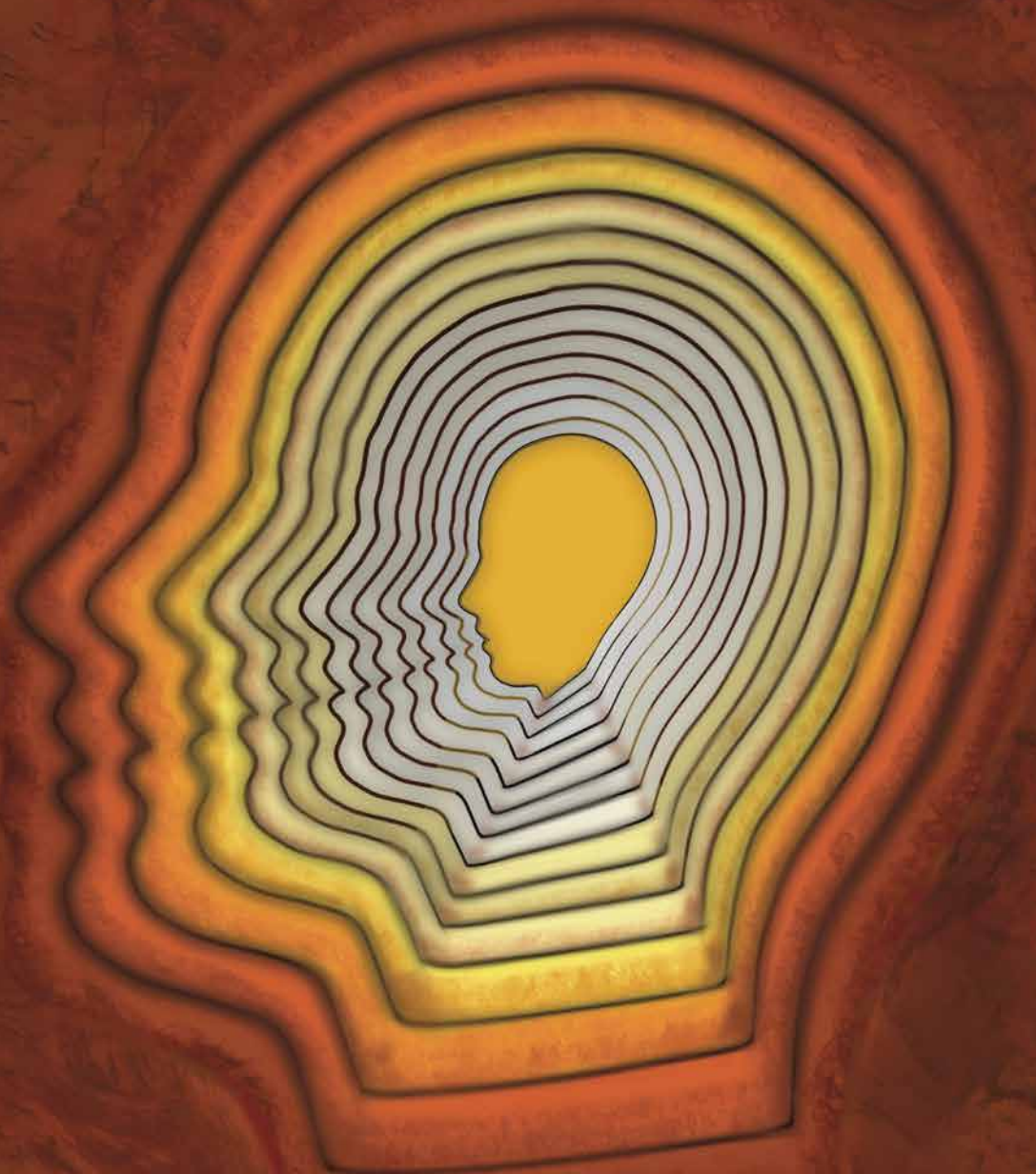
Lifetime at IISc
A chat with Y Narahari

Consciousness Conundrum
Decoding the enigma

Gallium Nitride
Potential and pitfalls



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IN THIS ISSUE

EDITORIAL

What is "consciousness"? Does it arise from neural circuits and pathways, or something else entirely? In this issue of *CONNECT*, we dive into the neuroscience of human consciousness and speak to scientists seeking answers to these age-old questions.

In other features, we highlight the growth of gallium nitride technology and look back at 100 years of quantum mechanics and how IISc scientists have contributed to the field. We feature stories on how human bias can influence animal studies, and the impact of scientific research on the environment. Researchers also share the joys and frustrations of using NMR, an indispensable tool for molecular studies.

On the campus front, students reminisce about their internship experiences abroad, while others tell us about their New Year resolutions in *CONNECT* Asks. We also spent a day with campus security officer K Jayaraj and had a candid interview with a campus favourite: Yadati Narahari. Finally, we chronicled the tenacious life of nonagenarian immunologist GP Talwar, who visited IISc recently.

Happy reading!

Team Connect

Abinaya Kalyanasundaram (Coordinator), Ananthapathmanabhan MS, Bitasta Das, Pratibha Gopalakrishna, Ranjini Raghunath, Rohini Subrahmanyam, Sandeep Menon

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Email: connect.ooc@iisc.ac.in
Phone: 91-80-2293 2066
Address: Office of Communications, Indian Institute of Science, Bangalore 560 012
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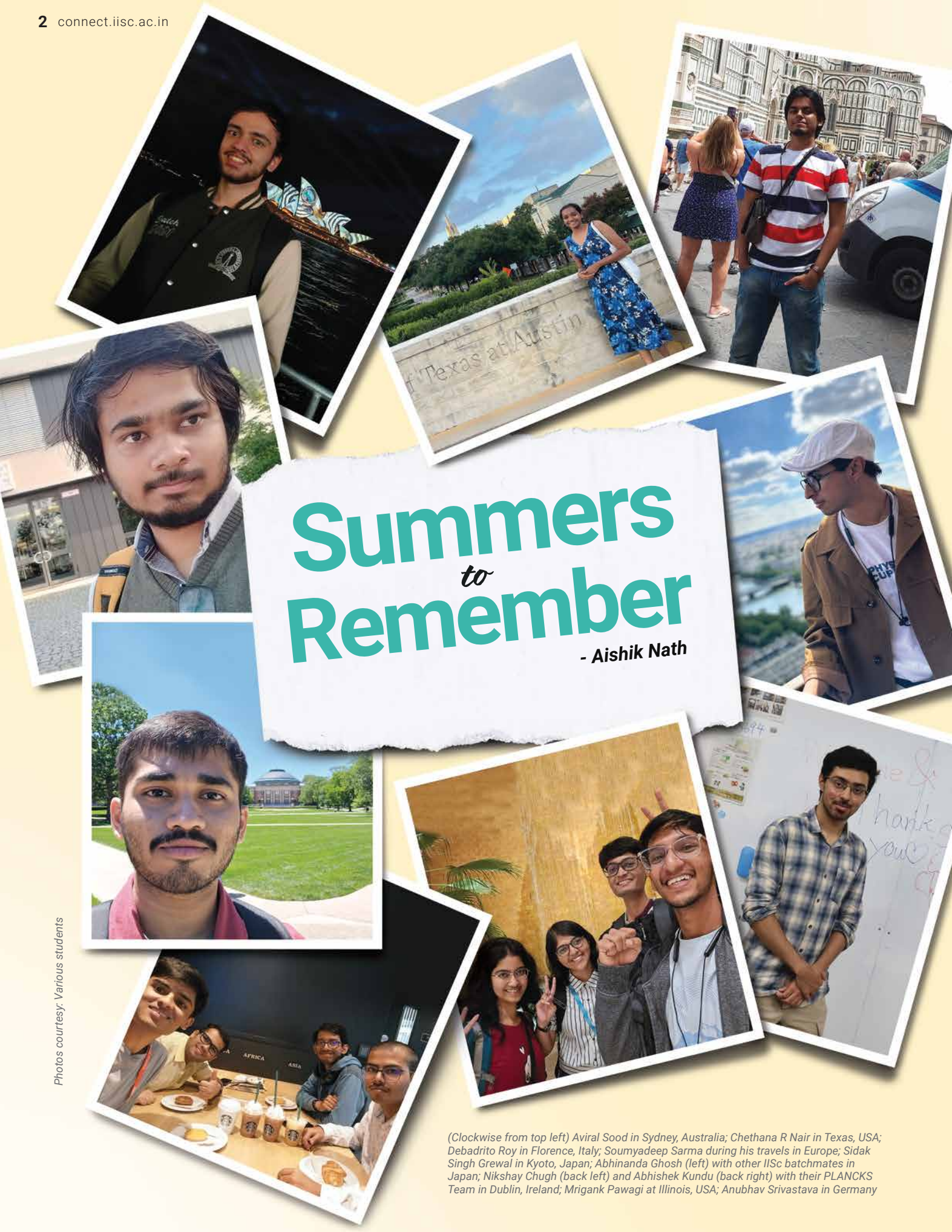
Summers *to* Remember

- Aishik Nath



Photos courtesy: Various students

(Clockwise from top left) Aviral Sood in Sydney, Australia; Chethana R Nair in Texas, USA; Debadrito Roy in Florence, Italy; Soumyadeep Sarma during his travels in Europe; Sidak Singh Grewal in Kyoto, Japan; Abhinanda Ghosh (left) with other IISc batchmates in Japan; Nikshay Chugh (back left) and Abhishek Kundu (back right) with their PLANCKS Team in Dublin, Ireland; Mrigank Pawagi at Illinois, USA; Anubhav Srivastava in Germany

Students share life lessons from internships abroad

When Mrigank Pawagi set foot outside the Chicago airport in May 2024, he didn't anticipate the ordeal ahead. A second-year BTech in Math and Computing student at IISc, Mrigank was in the USA for his summer internship at the University of Illinois Urbana-Champaign (UIUC). Tired from his long transit, he had a fresh quandary when he reached campus. His accommodation plans had fallen through.

"It seemed sorted before I went," he recalls. However, once he reached the States, Mrigank and the hosts could not find a middle ground regarding some terms in the agreement. He was stranded. Ultimately, he had to call upon a 2017 IISc alumnus at UIUC for a temporary housing arrangement. It took him a week of constant searching to eventually find an empty apartment.

Mrigank is one of the many undergraduate students who travelled to foreign lands for the summer as part of internship programmes. Staying in an alien environment and away from their comfort zone where things don't always go as planned, they are left to use their guile and nous to navigate the challenges that come their way.

But, many students say, it is a quest worth taking. The learning and experience are invaluable. "It broadened my horizon," admits Aviral Sood, a third-year BSc (Research) student, who went to Australia for his internship this year. "I became less anxious about my academic future."

Bed and Butter

The first and most important challenge is to find a space to stay for the duration of the internship – a place to call home. Mrigank's struggle is not unique. His batchmates experienced the same in their travels too. Mid-layover in Dubai, Nikshay Chugh and his friends were notified that their hotel booking in Dublin was cancelled. If the Irish immigration authorities were to find out, the students wouldn't have been allowed to enter the country without accommodation. When they stepped off the plane, they were quite scared. Thankfully, the authorities had not been updated, and they cleared immigration. Now, they had to dip into their limited funds to find a place to sleep.

Finding food is yet another challenge.

"In Germany, you have your non-vegetarian food, and then you have vegan food," explains Debadrito Roy, a third-year BSc (Research) student at IISc. "Vegetarian options are definitely available, but they are limited," adds Anubhav Srivastava, his batchmate.

> ***'[Summer internship] broadened my horizon. I became less anxious about my academic future'***

Interestingly, while searching for local culinary delights, they learned that very little of Germany's cuisine is original and borrows heavily from other cultures. Soumyadeep Sarma, Debadrito's batchmate who was doing his internship at the Max Planck Institute for Solid State Research, Stuttgart, couldn't find anything other than brot, doner kebabs, and schnitzel. Groceries bamboozled him, made worse by the exchange rates. Eventually, he resigned himself to eating dal-roti for dinner every day.

Finding the right food was harder in Japan where Abhinanda Ghosh, a first-year BSc (Research) student, was left to depend on Google Translate to read and understand food labels. Most food items, she swiftly realised, had elements alien to her taste buds. It was an exciting discovery that set her on a path to explore Japan's culinary delights. However, being on a budget, the adventure proved challenging as the tastes were as novel as they were expensive.

The challenge was harder for her vegetarian and vegan companions at Niigata University's Field Training programme. They had to search for food that was free from bonito flakes or any kind of non-vegetarian ingredients. "The vegetarians had a lot of onigiri (Japanese rice balls wrapped in seaweed)." They soon found the choices to be more varied than they thought. "For me, it was the co-op bakery food. If you find nothing else, you stock it up and eat it. Since it was in the university, it was quite economical," she adds.

Brückentag, and other surprises

Internships and visits abroad also allow students to learn about a different culture. One Friday, Debadrito went to his host university, the University of Regensburg, only to find the entire floor empty. After a few hours, concerned that no one was showing up, he called his colleagues. "This day is between two holidays, why would we be coming in?" his coworker asked quizzically.

It was Brückentag, an off day taken between two holidays or a holiday and a weekend to make it an extended break. That Thursday was a state holiday and everyone had *brückentag'd* on Friday. It was very common in Germany, Debadrito learned. He also learned to never disturb Germans on holiday. "They focus a lot on work-life balance and having breaks between work. It made working more enjoyable," he explains. "On Sundays, everything is closed. If you forget to stock up on groceries beforehand, you might be left with nothing."

The German transport system threw up some surprises as well. While returning to Regensburg after visiting Soumyadeep at Stuttgart, Debadrito booked tickets for the 6 pm train. But the train was cancelled. "An entire part of the train line got burned down," he recalls. That was the last train to Regensburg, so Debadrito changed his plans and decided to head to Munich

Photo courtesy: Sidak Singh Grewal

Sidak Singh Grewal enjoyed local delicacies such as Tengo Ramen during his internship at Kyoto University in Japan

instead and spend the night with his friend there. The train to Munich was also delayed by four hours. “Sometimes they delay the train because there is a cat on the train line and nobody is equipped to handle a cat, apparently,” he says, with a shrug.

> ***‘The Germans focus a lot on work-life balance and having breaks between work. It made working more enjoyable’***

There was also an instance when the train app notified him that a bomb had been found on the track. “These are bombs from World War II lying dormant in random parts of the city. Sometimes, these bombs end up on the train line,” he explains. “Professionals then come at their convenience to decide if they should defuse it or not. This is normal in Germany.”

What adds to the difficulty of navigating these challenges is the language barrier. “It's quite difficult, especially in some parts of Bavaria, where they speak German exclusively,” Debadrito says. However, in major cities and universities, not knowing the language wouldn’t be a barrier, Anubhav and Soumyadeep clarify.

In Japan too, language was a major stumbling block. “We had to communicate with the local people at the marketplaces and convenience stores or read the signs. Since English is not a very popular language there, and since we did not have any idea of Japanese, communication was an issue,” Abhinanda explains. “It was a lot of dependence on Google Translate to understand what the road signs meant, what the product labels meant, and so on.”

There were also more nuanced and systematic challenges. Chethana R Nair, a third-year BSc (Research) student, was spending her summer at the University of Texas, Austin in the USA. The people were kind and friendly but she found it hard to wrap her mind around the tipping culture in restaurants. “They expect a tip of around 10-20% of the price,” she exclaims.

Across the Pacific, Aviral was taken aback by the generosity of people in Australia. “If a car sees that you might even want to cross the road, they’ll stop. And it creates a lot of awkward standoffs where you are looking at the driver and the driver is looking at you and you’re deciding whether you want to cross the road or not,” Aviral says, laughing.

Aviral also found their banter, particularly against Indian cricket, endearing. “Each time you have a meeting, the programme administrator would drop one joke about Australia winning against India,” Aviral says. “But we won the T20 World Cup while I was there.” It was 4.30 am in Canberra when India won the World Cup and Aviral and his Indian friends were celebrating in their apartments. “That was our moment of victory,” he chuckles.

New horizons

Like most experiences, a summer internship abroad comes with both perils and perks. “There is a tradeoff between doing internships at your university and abroad. In local internships, you can continue your work and publish some papers. But foreign internships give you strong letters of recommendation,” explains Sidak Singh Grewal, a second-year undergraduate who went to Kyoto University for his biophysics summer internship. “An internship abroad really adds to your CV,” Chethana adds.

> ***From coding to using robotics in biophysics projects to researching evolution and searching for fossils, the experiences were rich with learning and stories***

For third-year students, scholarships helped put their minds at ease. The trio in Germany got the DAAD-WISE Scholarship. Chethana was honoured with the Khorana Programme for Scholars Scholarship while Aviral received Australian National University’s FRT Award. However, it was a struggle for the second-year students. Neither the Dublin crew nor Mrigank or Sidak received any formal scholarship, but they received funding from their host universities or IISc.

The students also got to work on many interesting projects during their internships. Mrigank was part of a project translating whole computer programs from one programming language into another. He worked on developing a framework to validate the translations. All three undergraduates in Germany tackled various problems in condensed matter physics. Chethana focused on understanding the contribution of Neanderthals in the human genome. Aviral worked on understanding the properties of a geometric evolution equation on closed curves called the Curve Shortening Flow.

Sidak had his hands full with his biophysics project, his skills in robotics helping him explore underutilised machinery in the lab. “I was given full access from day one, to do whatever I wanted to. They said: ‘All the equipment is yours,’” he recalls. He tinkered with the equipment, trying to automate lab processes. He even built a fully autonomous system with a robotic arm and computer vision algorithms that prepared and studied microtubule samples.

Photo courtesy: Abhinanda Ghosh

Abhinanda Ghosh looking for fossils in Site 3 of a sedimentary basin outcrop in Niigata, Japan

Nikshay and his friends represented India at the theoretical physics competition PLANCKS, hosted by Trinity College, Dublin. They were a group of eight students in two teams. The seven-day programme was filled with lectures, talks, and presentations. “The second day featured talks from leading faculty members across the world and three Nobel laureates,” explains Abhishek Kundu, Nikshay’s teammate. The two teams finished in the 7th and 11th places.

Photo courtesy: Sidak Singh Grewal

Aerial view of Nijo Castle in Kyoto

Abhinanda’s work was more explorative. “A large part of it involved studying sedimentary basins of Niigata,” she elaborates. From searching for fossils to climbing up the Yake-Yama volcano, it felt like an adventure, with “lots of amazing experiences,” she says. “I never thought that I would find a fossil myself and hold one [in my hands].”

N.B. The educational qualifications of the students mentioned in the story are reported as of summer 2024.

Aishik Nath is a second-year Bachelors in Science [Research] student at IISc and a science writing intern at the Office of Communications.

The Feeling of Being

- Rohini Subrahmanyam

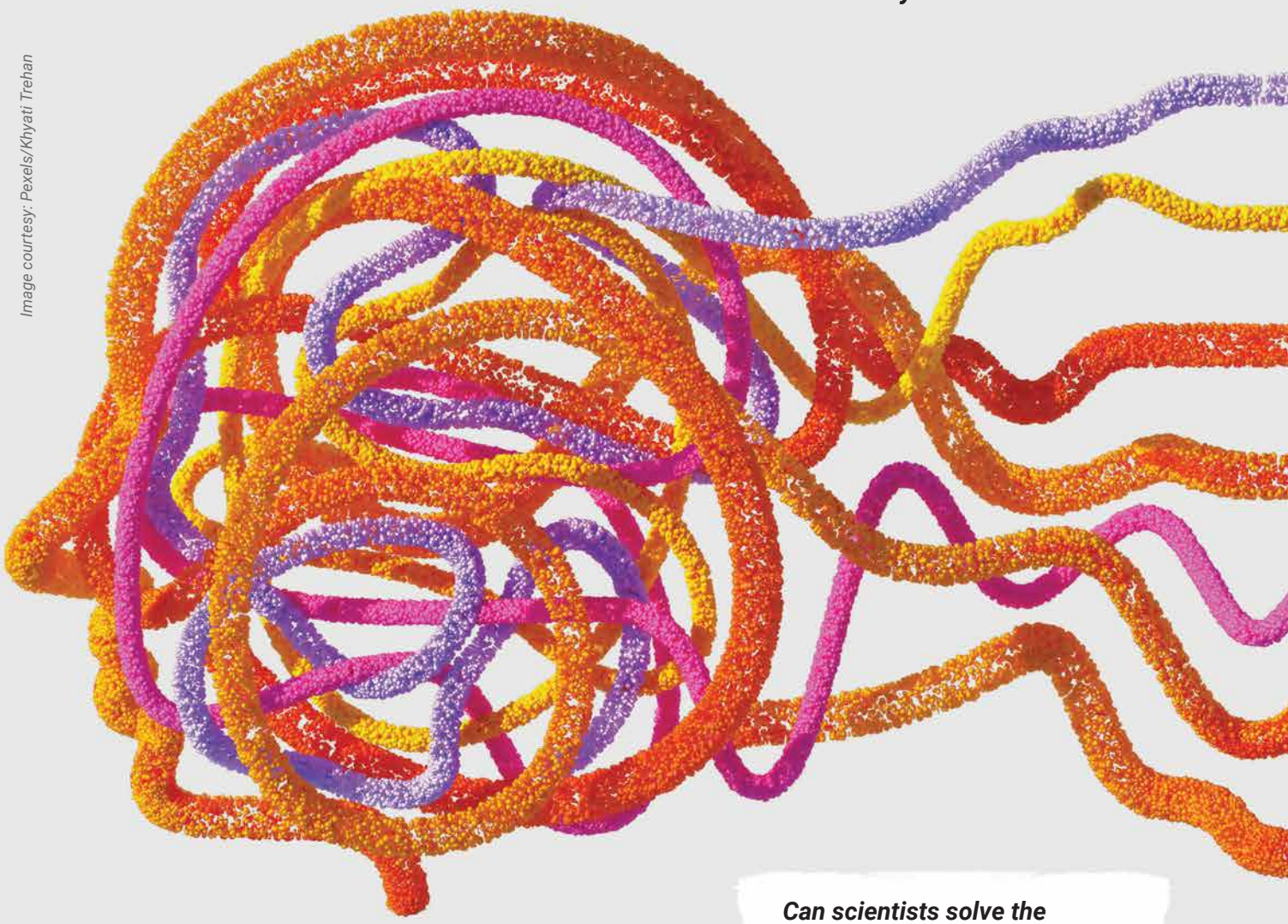


Image courtesy: Pexels/Khyati Trehan

Can scientists solve the conundrum of consciousness?

Sometime in the late 1980s, two Oxford scientists examined PS, a patient who had suffered damage to the right side of her brain. The damage left her unable to notice things to her left. Even when she drew objects, she would draw their right sides perfectly but completely leave out the left. She didn't even realise that the drawing was incomplete – it was like the left side of objects just didn't exist for her.

The scientists then showed her pictures of two houses, with the left side of one of the houses on fire. PS could not see any difference between the two houses. When asked which house she would choose to live in, however, she pointed to the house that was not on fire – not just once, but almost every time. Her brain seemed to be processing information about the burning left side of the house; she just seemed unaware of it.

This inherent yet inexplicable awareness is a major part of a phenomenon that we all experience – consciousness.

"Consciousness is like … the feeling of being. The feeling of being present, of being aware of a thought, perception, sensation," says Nithin Nagaraj, mathematician and Professor at the Consciousness Studies Programme at the National Institute of Advanced Studies (NIAS), Bangalore. We all inherently experience it, he adds, but it is very hard to define conceptually.

Being conscious is an experience that is intricately tied to all our lives, but we still struggle to wrap our heads around it. One possible definition for consciousness would be the feeling of "what it is like to be us" – the experience of existing inside our heads and being aware of everything around us. We are conscious of external sensations, along with our thoughts, our emotions, and our pain. We are conscious when we are awake, but dreams and hallucinations also feel like conscious experiences. It is like an immersive "inner movie" that runs in our minds and around us, where each of us is the main character.

But how exactly our brain generates this inner movie or "makes" us conscious has eluded scientists for decades, mainly because it is such an irrefutably "first-person" experience.

"The simple fact is, I know I'm conscious. I don't know if you, or anybody else, is conscious," points out SP Arun, Professor and Chair of the Center for Neuroscience (CNS) at IISc. "You sort of assume that everybody else is conscious as you're interacting. [But] I can't think of an objective way to test whether you are conscious."

> ***'Consciousness is like … the feeling of being. The feeling of being present, of being aware of a thought, perception, sensation'***

Aditya Murthy, Professor at CNS, agrees; he thinks that objectively recording brain activity may not be enough to explain how a subjective, qualitative event seen from the inside arises.

"Consciousness is about our experiences from a first-person perspective, but when you see the brain from the outside, like neurons firing and dopamine getting released, even [manifestations of] behaviour, these are all third-person phenomena," explains Aditya. "Throwing out the first-person subjectivity has proved to be very successful for science in areas like physics, or physiology, but when it comes to neuroscience [of consciousness], an explanatory gap seems to remain. Perhaps by correlating neural activity with first-person reports, this explanatory gap can be reduced," he adds.

Bridging these objective-subjective and third-person-first-person gaps has been the root of all problems in consciousness research.

But this hasn't stopped scientists from trying. In the 1990s, prominent neuroscientist Christof Koch, now a Meritorious Investigator at the Allen Institute of Brain Sciences in Seattle, was young, enthusiastic, and highly confident in the advancements in brain-imaging and brain-recording techniques at the time.

In 1998, amidst a few jovial drinks in a bar in Germany, Christof famously struck a bet with philosopher David Chalmers. The wager was that in 25 years, scientists would have solved at least one major challenge: nailing down the "neural correlates of consciousness (NCCs)" – specific features of neurons that could explain any given conscious experience.

David, currently the co-director of New York University's Center for Mind, Brain and Consciousness, was mildly sceptical. As he explains in an older *Scientific American* article and a recent World Science Festival discussion – he believes that conscious experiences are just too intensely personal; if he and Christof were to see a rose, the red that he sees may not even be the same red that Christof sees. The solution of subjective experience lying within objective data recorded from our brains? Unlikely, he thought.

David's hunch was right. Christof conceded defeat to David in 2023, publicly giving him a case of fine wine (those were the terms of losing the bet) – scientists have still not figured out the biological basis of conscious experiences.

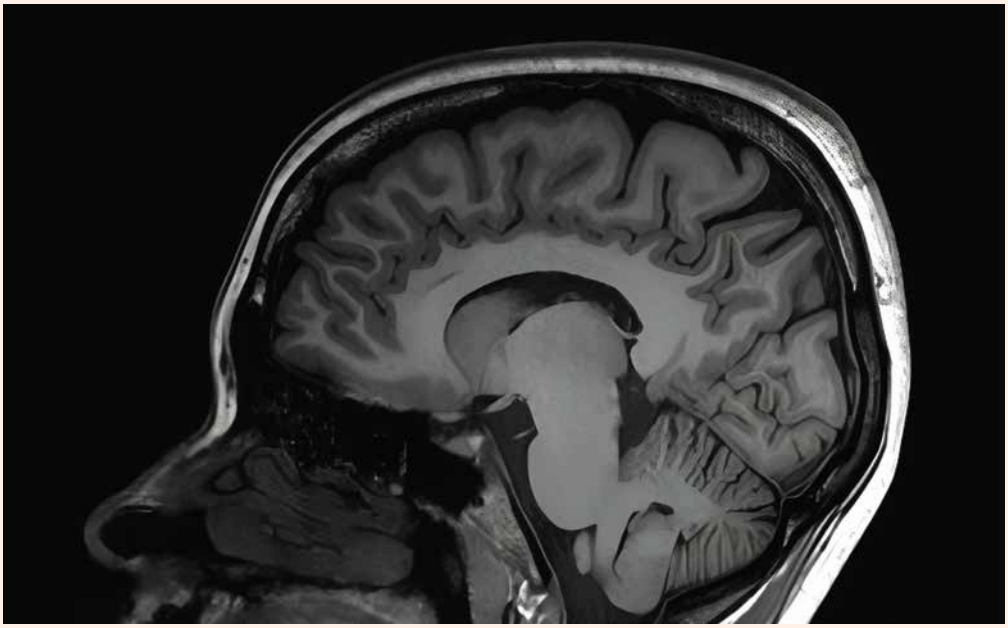


Image courtesy: Swagata Halder, Cognition Lab, CNS, IISc

Scientists sometimes use Magnetic Resonance Imaging (MRI) scans to look into the brain's structures and functions to understand different aspects of consciousness

"How to construct a theory that tells us which physical systems are conscious … is one of the deepest, most fascinating problems in all of science," writes computer scientist Scott Aaronson, Professor at the University of Texas at Austin, in his blog. "I don't know of any philosophical reason why [it] should be inherently unsolvable … but humans seem nowhere close to solving it."

Christof is, however, still keen on solving the consciousness problem. He challenged David to another "double-or-nothing" bet – by 2048 they should have a brain marker for consciousness.

> ***'I can't think of an objective way to test whether you are conscious'***

Apart from the near certainty that both of them will be a bit too old for wine, what will happen in another 24 years is hard to say. As of now, the battle for the best theory of consciousness is ongoing – a battle that Christof himself was instrumental in starting more than 30 years ago.

One theory to rule them all

At first, neuroscientists just avoided the consciousness problem. For most of the 20th century, a subjective awareness of ourselves and the world around us seemed too vague a topic to be studied using science.

Then, in 1990, Francis Crick, known for his role in solving the mystery of DNA structure, decided to enter the fray. He co-wrote a paper with Christof titled "Towards a Neurobiological Theory of Consciousness", which brought the much-avoided "C" word – something only philosophers and psychologists pondered about – back into the minds of neuroscientists. The paper claimed that the essence of consciousness has to lie within the circuitry of our brains; it was just a matter of finding these "neural correlates".

Spurred, scientists around the world began examining different regions or neural signatures in the brain that could be linked to consciousness. Others tried to unify scientific observations into elegant theories that could neatly explain our subjective sense of being.

One such theory, championed by cognitive scientist Stanislas Dahaene at the Collège de France in Paris, is the global workspace theory (GWT).

According to GWT, our brains end up receiving all kinds of information, but only some information passes through a "bottleneck" to reach a "global workspace". This is how we become "conscious" of some information, which is then integrated and broadcast to other parts of the brain for further decision-making. Based on brain-imaging studies, this process most likely occurs within a network of neurons in the front of the brain – a region called the prefrontal cortex (but it also includes other parts of the brain).

Christof, however, was not convinced. He teamed up with neuroscientist Giulio Tononi at the University of Wisconsin-Madison, who proposed a competing theory called Integrated Information Theory (IIT). Giulio believed that consciousness is an intrinsic property that arises from a network that has a "cause-and-effect" power – the network can change its own state in some way (cause) and it can also affect its future states (effect). The neural structure that best fits this description, according to IIT theorists, is a grid-like arrangement of neurons somewhere in the posterior cortex, or the back of the brain – a region they called the "hot zone".

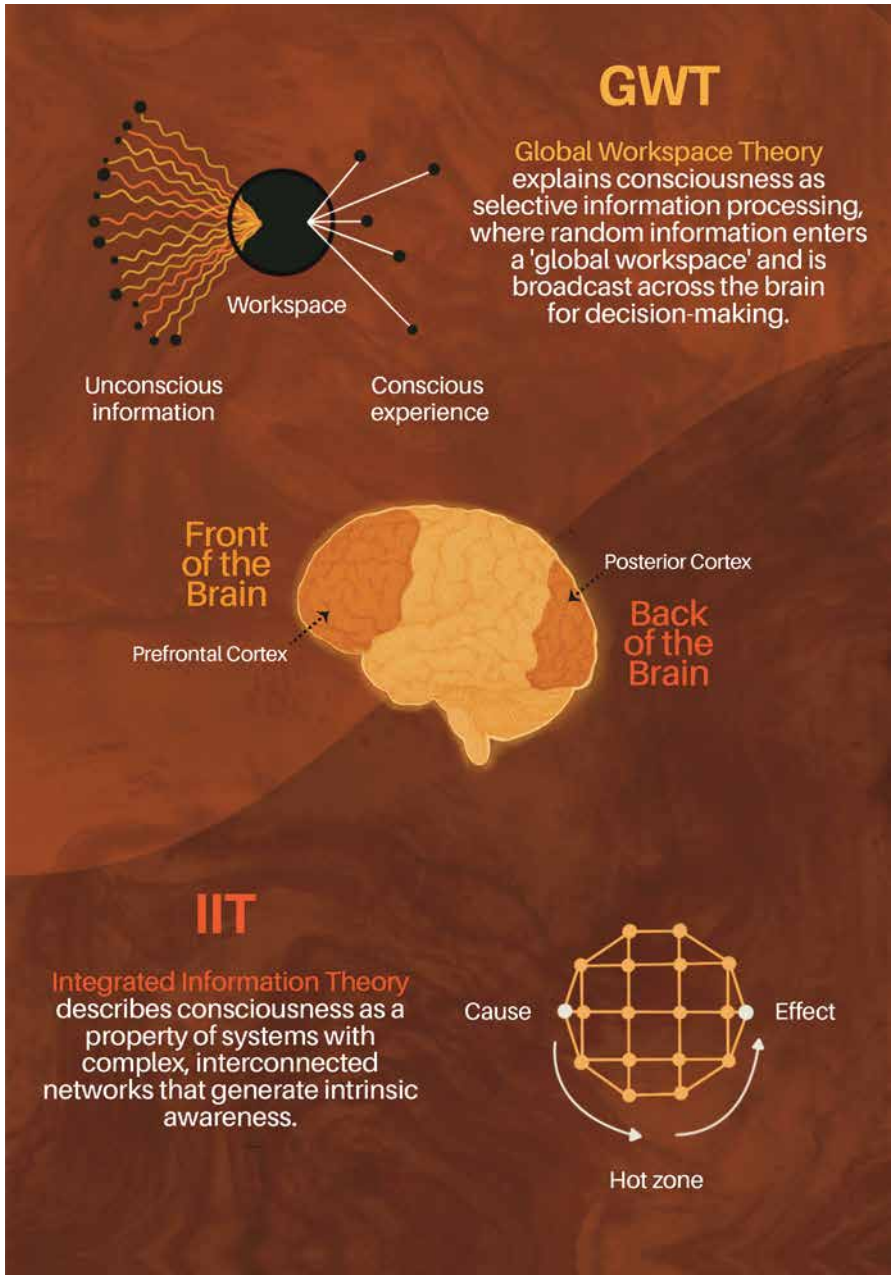
These two leading theories of consciousness went head-to-head in an "adversarial collaboration", in which scientists worked together, designed different experiments, and tested predictions about consciousness to see which theory fits better.

But when the results were unveiled last year, no clear winner emerged. Neither theory was a perfect fit.

Even before the highly publicised contest, scientists had started picking out flaws in both theories. For example, people with epilepsy have had surgery to remove portions from the front of their brain, yet they seem perfectly conscious – countering the predictions of GWT. And IIT, in its simplest sense, suggests that any system with the right wiring to integrate information can potentially be somewhat conscious. This implies that to some extent, however small, even our phones and laptops could have inner senses of being – a philosophical idea called panpsychism that has some scientists shaking their heads in sheer disbelief.

Besides these two theories on consciousness, there are at least

Illustration: Harsh Kapoor



A visual representation of the two leading consciousness theories proposed by neuroscientists

twenty others, ranging from "higher-order" theories to quantum mechanics being at the core of consciousness.

> ***The essence of consciousness has to lie within the circuitry of our brains; it was just a matter of finding these "neural correlates"***

All these theories describe how consciousness could work, but there is still no clear, convincing answer to how it actually does.

"It's a bit frustrating," says Aditya. "I mean, we're not able to get something that's so obvious to all of us internally. We can record every activity of 100 billion neurons, but unless we understand how this activity enables experience, we risk missing, I think, the essence of what makes us human."

Components of consciousness

Anil Seth, a cognitive neuroscientist at the University of Sussex, suggests another approach in his *Aeon* essay – instead of trying to solve the consciousness problem head-on, we could break it down and address different aspects. He draws a comparison with the study of life – at one time scientists baulked at the idea of simple biochemistry being behind complex processes that keep us alive. But over time, they accepted it and started to think about life in terms of its various functions, like reproduction, growth, and metabolism. We may still not know how exactly biochemical processes give rise to living systems, but chipping away at the parts that make up life has helped us learn more about it.

In 2023, a NeuroConsciousness initiative was started at IISc, with support from KR Sreenivasan, Dean Emeritus of the NYU Tandon School of Engineering and an alumnus of IISc. As part of the initiative, several labs at CNS are studying the neural basis of different features that ostensibly make up our inner being.

Consciousness in the brain

Apart from the front and back of the brain, other regions of the brain have been implicated in different conscious experiences.

1. **Claustrum:** A 2014 case study showed that electrically stimulating this sheet-like structure below the cortex caused a woman to stare ahead blankly, looking almost unconscious. But another patient who had his claustrum destroyed by encephalitis turned out to be perfectly conscious.

2. **Anterior insula:** Nestled deep within the brain, this region has been found to play a role in multiple subjective experiences, mostly by integrating our internal states and emotions with external sensations. It is a strong candidate for being the seat of "sentience", a place in our brain which regulates our sense of self.

3. **Thalamus:** In some comatose patients, stimulating the thalamus – a major hub that is connected to multiple parts of the brain – using ultrasound has been correlated with them recovering from the coma.

Aditya's lab, for example, probes questions about our sense of self – an aspect of consciousness that, in Anil's words, "we cling to most tightly." They are looking at how our brain connects with our sense of agency, and how that helps us think or introspect about our decisions and predict the consequences of our movements.

"For example, when you move your eyes voluntarily, you know that stuff in the world will move on your retina. But as your brain is monitoring your eye movements – you can infer that the movement on the retina is caused by your own action, and not by an external movement," says Aditya. "In other words, you can distinguish the stuff that's changing out there versus the stuff that's changing as a consequence of what you are doing. In principle, such a computation may be the kernel of agency."

There's a theory that patients with disorders of agency, like schizophrenia, are not able to distinguish their inner world from external changes. They start hearing voices in their head, but to them, they appear as hallucinations of external people directing them to act.

"This concept of agency is linked very strongly to our will to act on things. The idea that you are an agent itself is quite profound, right? That you have control over your actions," says Aditya. "So that might be the first shell of basic consciousness – you are aware of your body and aware that you can actually control parts of your body."

> ***'This concept of agency is linked very strongly to our will to act on things… that might be the first shell of basic consciousness'***

Arun, also part of the initiative, is trying to understand another aspect of consciousness: visual perception. He studies how the brain transforms objects we see into things we perceive.

"In a certain general sense, whatever you see is already there in the image that comes into your eyes, right? But then the brain is spending almost 50% of its real estate to actually process the image, to figure out what is there," explains Arun. "So, the brain is converting the information present in the image into some complex format. A lot of our research is aimed at understanding that format."

"The way I see it, perception, decision making, attention – all of these are basic building blocks of cognition, and in a way, consciousness," he adds.

Supratim Ray, Professor, CNS who is also part of the initiative, is particularly interested in the meditative state – a slightly altered state of heightened consciousness that some people achieve through practice.

"The fact that over thousands of years, so many traditions have been developed to control your mind and not let it wander, and be in a state where you are calmer, is a great neuroscience question in its own right," says Supratim.

He is keen on seeing what happens in the brain during meditation, specifically looking at gamma waves – a kind of brain wave generated when neurons fire in synchrony at around 40Hz. Gamma waves are known to be modulated by high-level cognitive behaviours, like paying attention to a particular task. These waves were an early contender for driving consciousness as well, until people found them even in unconscious, anaesthetised animals.

"We [want to] learn about the brain and the effect of meditation on the brain. Meditative practices could have a neuroprotective role potentially, and those are all beneficial things, as neuroscientists for us to study," Supratim says.

Studying different aspects of consciousness can also help untangle our complex web of emotions and teach more about phobias and psychiatric disorders. Conflicts between conscious and unconscious pathways in our brain could be leading to conditions like anxiety and depression, scientists think. We might even learn how to treat patients in a coma, or patients with brain injuries who slip into a "wakeful unawareness" – where they seem to be awake but unable to respond to stimuli. Such patients in a vegetative state may even be conscious, but with their ability to respond completely destroyed – figuring out their level of consciousness can help us know if they are 'still them' inside, to some extent.

But many aspects of consciousness remain shrouded in mystery. As David explains in his 2014 TED talk, questions like "how do we decide when to move" and "how we perceive objects" are immensely valuable and interesting, but still come under the "easy" problems of consciousness. Given enough time and money, experts will eventually get to them.

A few years before his bet with Christof, in a 1994 conference in Arizona, he became famous for outlining the "Hard Problem of consciousness". And that is: Even as we sense, perceive, and respond to stimuli, why do these different processes in the brain actually lead to us feeling and experiencing things? And how does our brain manage to generate this ineffable feeling of experience inside of us? Talking to journalist Oliver Burkeman at *The Guardian*, he invokes the logical possibility of a philosophical zombie with no conscious feelings or experiences. Not the snarling, flesh-eating kind, but a "creature" that looks and behaves exactly the way we do – except it is completely empty inside. Evolution could have resulted in such robot-like creatures, but it didn't; it resulted in us. And not only are we conscious of the world, but we are also conscious of ourselves, sometimes to a fault.

A planned movement

Scientists suggest that when the brain plans a movement, a motor command goes down to the muscles, but a part of that command also goes back into the brain in the form of an "efference copy". The brain can actually use this to anticipate the sensory consequences of the action, something that other researchers have also shown in the case of eye movements. They found that after an action, a signal from the muscle goes back into the brain and correlates with participants moving their eyes accordingly – thus tracking the effects of their own movement. Aditya and his team intend to use the idea of motor efference to test its role in agency, in humans.

Even if we do study different aspects of consciousness, solving the "hard problem" scientifically seems nearly impossible. So, some researchers are wondering if science alone will help us understand it.

Beyond the brain

Apart from neuroscientific studies, Sreenivasan sees value in exploring the diverse views of consciousness via IISc's NeuroConsciousness initiative. The initiative also organises an annual workshop, to foster discussions between various consciousness experts who may have differing views.

Some of these views include the ancient Upanishadic and Buddhist traditions, such as consciousness being a fundamental entity like space or time.

A scenario to think about this, according to Nithin, would be to imagine consciousness to be this all-encompassing entity, and that our brains just transmit this feeling of being – they don't create it.

"Think of the brain as a trans-receiver," says Nithin. "Let's say I have a radio, right? There is a base station that is transmitting the song, but I cannot listen to the song unless I am tuned to the song. The radio is required, but the radio does not generate the song."

To many scientists, the idea that consciousness can exist beyond the brain seems impossible to test rigorously with current scientific methods. But some scientists, psychologists, and physicians think lucid near-death experiences (NDEs) are a form of evidence. These are conscious, other-worldly, out-of-body experiences that have been reported by some cardiac patients who had flatlined and then been resuscitated. If one can have a conscious experience when there is no blood flow to the brain, the scientists say, then perhaps consciousness can linger on, even without the buzz of neurons.

> ***Some researchers are wondering if science alone will help us understand the "hard problem" of consciousness***

But other scientists are pushing back, saying that the brain doesn't die immediately after the heart stops; it is a slow process and not a sudden switch-off. According to them, NDEs are usually accompanied by huge surges of brain activity – indicating that any conscious experiences that accompany them must be caused by the brain. They theorise that it is a desperate survival tactic, the brain's last-ditch attempt to revive itself before dying.

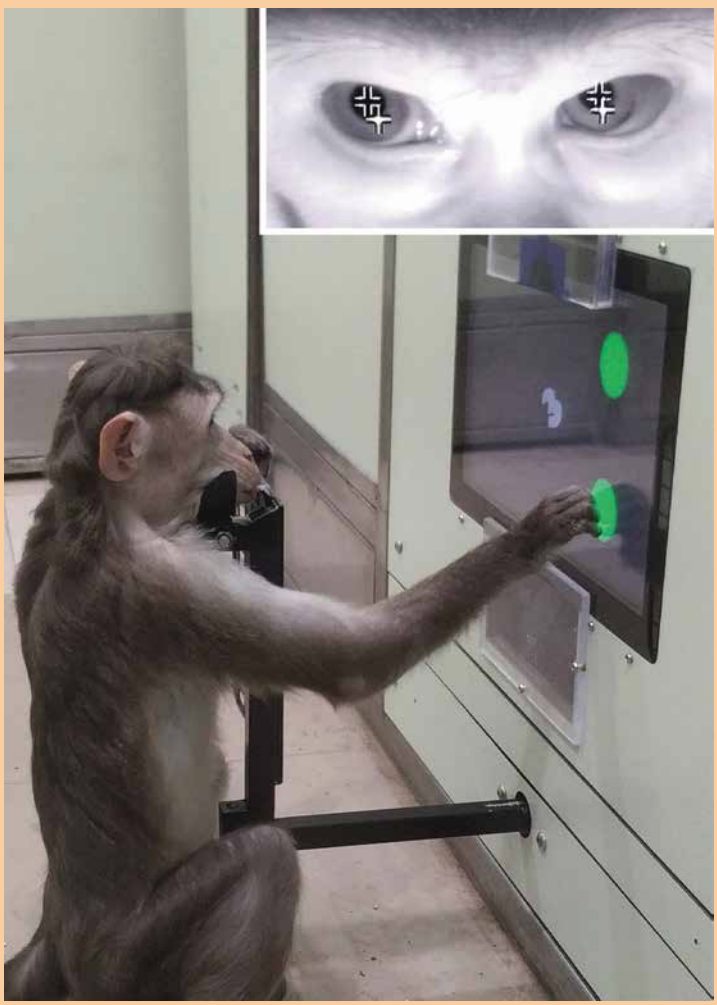


Image courtesy: Vision Lab, IISc

Perplexed by mirrors

Sometimes the brain gets confused by its own processing, like in the case of mirror images. One of Arun's lab's projects is understanding why young children get confused by alphabets that mirror each other and end up innocently interchanging their b's and d's.

"That's a confusion that doesn't come from the image itself, it's a processing feature of your brain," says Arun.

Our brain learns (either during childhood or through evolution) that two images that mirror each other are really the same object, seen from different viewpoints. Young children learning to write English initially get confused because of this adaptive learning; they think alphabets that mirror each other are the same. It is something we unlearn as we grow older and read more.

According to Arun, adult humans also tend to get confused while processing mirror images, especially if they are mirrored along the vertical access (left-right mirroring). We do better with horizontal axis (top-bottom) mirroring. But monkeys process mirror images quite differently, getting equally confused with both kinds of mirror images. Arun's group is trying to understand the neural basis of this difference.

Can artificial intelligence (AI) ever become conscious?

Some scientists are concerned AI could become sentient in the future, or may already be exhibiting signs of conscious intelligence. But others feel we don't need to worry yet.

No matter how good AI gets at processing, says Nithin, it cannot yet "understand" the way we do. "If you tell an AI a joke, it won't laugh. It's just processing," he says. "Understanding is a conscious experience."

Aditya believes AI can not really evolve consciousness unless it develops the way humans and other animals do, and having agency of its own body (if it were to have it) might be necessary first.

Instead of consciousness, Arun thinks we should be asking whether AI can have the same kind of cognition we do. According to him, the answer is no. Not yet, at least. "There's no danger that AI is suddenly becoming more intelligent than humans because currently, they just don't see, they don't understand speech, and they can't interact in the world the way we do," he adds. "It's like asking if calculators will take over the world!"

Scientists are debating whether large language models (like the ones driving ChatGPT) have some form of understanding – even if it is not human. Broadening the definition of what "intelligence" could mean for machines, scientists think, could help us better understand diverse forms of cognition.

"One view is that [consciousness] is an emergent phenomenon that can be explained by understanding the complexity of the human system, particularly the brain. And the other is that it is an irreducible entity," says Sreenivasan. "I don't know where the truth lies, and I thought that something that will attempt to understand each of these two views in relation to the other would be very helpful."

A central mystery of life

"Some problems in science are so hard, we don't really know what meaningful questions to ask about them – or whether they are even truly solvable by science," wonders science writer Philip Ball in *Quanta*.

> ***'We are hoping, because of the NeuroConsciousness initiative, that we can educate the public about the difficulty of the problem'***

For now, scientists are sticking to chipping away at the aspects of consciousness that seem most penetrable by science – the "easier" problems – even as other aspects continue to fuel countless scientific, philosophical, psychological, and even spiritual debates.

"We are hoping, because of the initiative that we have taken on, that we can educate the public about the difficulty of the problem," says Arun.

There is a distinct possibility that scientists may never fully crack the code of consciousness. But there is a silver lining. Amidst all the intense discourse and intriguing uncertainty, we get to learn a lot about the brain and ourselves. "This sparring has a lot of value," says Supratim. "I think this is what keeps up the intellectual rigour and, in some ways, it shouldn't die out."

He jokingly asks what we will do if we have an answer to consciousness. "Then, you know, there's nothing else to do!"

Photo courtesy: Ankan Biswas

Scientists in Supratim's lab using an electroencephalogram (EEG) cap to record brain activity and study the effects of meditation on the brain

A Century of Quantum Mechanics

- Aniket Majumdar

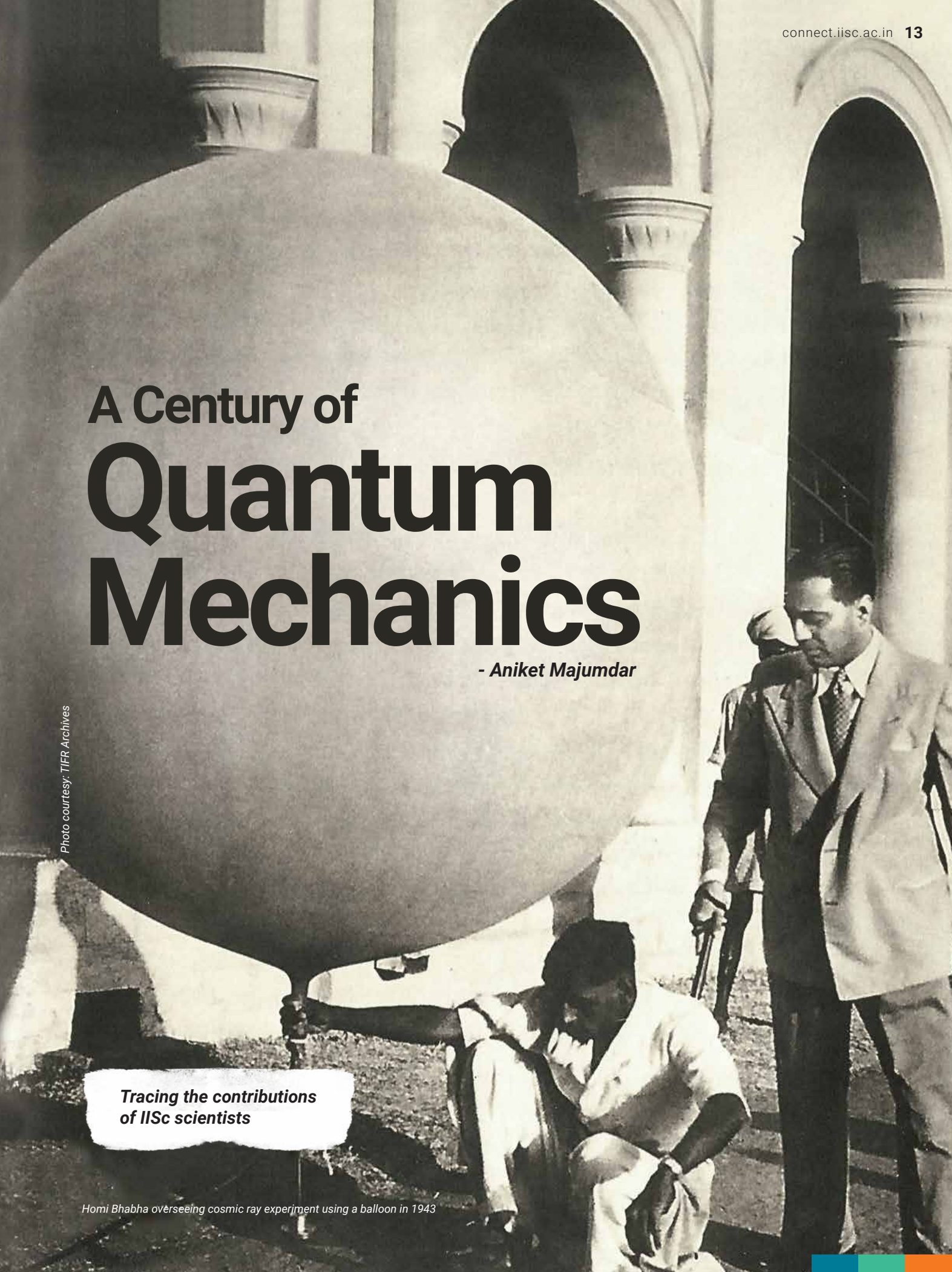


Photo courtesy: TIFR Archives

Tracing the contributions of IISc scientists

Homi Bhabha overseeing cosmic ray experiment using a balloon in 1943

Danish physicist Niels Bohr once had a visitor at his country cottage at Tisvilde. Seeing a horseshoe nailed above the front door, the visitor was amused and asked Bohr if he believed in the superstition that it brought luck. Bohr apparently replied: "No, I certainly do not believe in this superstition. But they say that it does bring luck even if you don't believe in it!"

This tongue-in-cheek comment is a perfect analogy for quantum mechanics, a relatively new field of study born in the early 1900s. A central tenet of this field is that events at the quantum level can occur whether or not you can observe them directly, but if you observe them, they may not happen.

In contrast to the classical understanding of physics, quantum mechanics introduced two revolutionary concepts. The first one, proposed by German scientist Max Planck, was relatively easier to imagine: the amount of energy associated with any form of electromagnetic radiation is "quantised" – it is present in the form of small, discrete and countable packets called photons.

The second idea, introduced by French physicist Louis de Broglie, was that every object in the universe has a "dual nature" – it can behave like a particle sometimes and like a wave in other situations. This is why a highly energetic electron can behave like a billiard ball and collide with other electrons, producing X-rays, but it can also create diffraction patterns like a wave, a property used in electron microscopes to spot even tiny bacteria.

Over the past century, this concept of wave-particle duality, although controversial and fantastical, enabled a better understanding of how atoms work, led to the advent of technology – computers, mobile phones, television and so on – and inspired innovations in other areas like chemistry and biology.

Indian scientists, too, have made their fair share of contributions to quantum mechanics and its applications. They not only solved fundamental problems in the field, but also helped build infrastructure and create an ecosystem conducive to its growth. Research institutions like TIFR, RRI, and others emerged out of these efforts. Scientists at these institutes led many key advances in the field. The first of these happened exactly 100 years ago and involved the usual suspect – light.

> ***Indian scientists solved fundamental problems in quantum mechanics, helped build infrastructure and created an ecosystem conducive to its growth***

First light

In 1924, Satyendra Nath Bose, a Reader at Dhaka University, was studying the nature of photons when he came across something unusual. He investigated the idea that all photons are identical. This was significant because, until then, all known subatomic particles, like electrons, had different labels or "quantum numbers" unique to that particle. However, Bose's calculations concluded that two or more photons can have the same exact set of labels, making them indistinguishable. Later, this turned out to be not just a photon-specific phenomenon but a generic property of a class of subatomic particles called bosons, named after Bose.

Unfortunately, his theory was not accepted by the scientific community until Einstein took notice and vehemently supported it. They jointly published a theoretical report on what they called Bose-Einstein statistics. "Though Bose's ideas were experimentally verified only after 1980, his pioneering contribution was the first (theoretical) effort from an Indian to the development of quantum mechanics," explains B Ananthanarayan, Professor at the Center for High Energy Physics (CHEP) at IISc.

A few years later, in 1928, CV Raman, a scientist at the Indian Association for the Cultivation of Science, Kolkata, showed for the first time that a light beam could scatter off molecules and produce a secondary beam with a wavelength different from the original one. This report, published in *Nature*, was a key experimental demonstration of the particle nature of light, which in turn validated both core concepts of quantum mechanics. Raman would go on to win the Nobel Prize in 1930.

With the Raman effect, India made its foray into the experimental side of quantum mechanics. Bose and Raman continued to lead the early quantum revolution in India well into the 1930s and trained many young researchers in the emerging field. However, the lack of quality research facilities was a constant struggle. The situation changed only in the 1940s when a young man, with a vision for nation building, arrived at IISc.

Cosmic connection

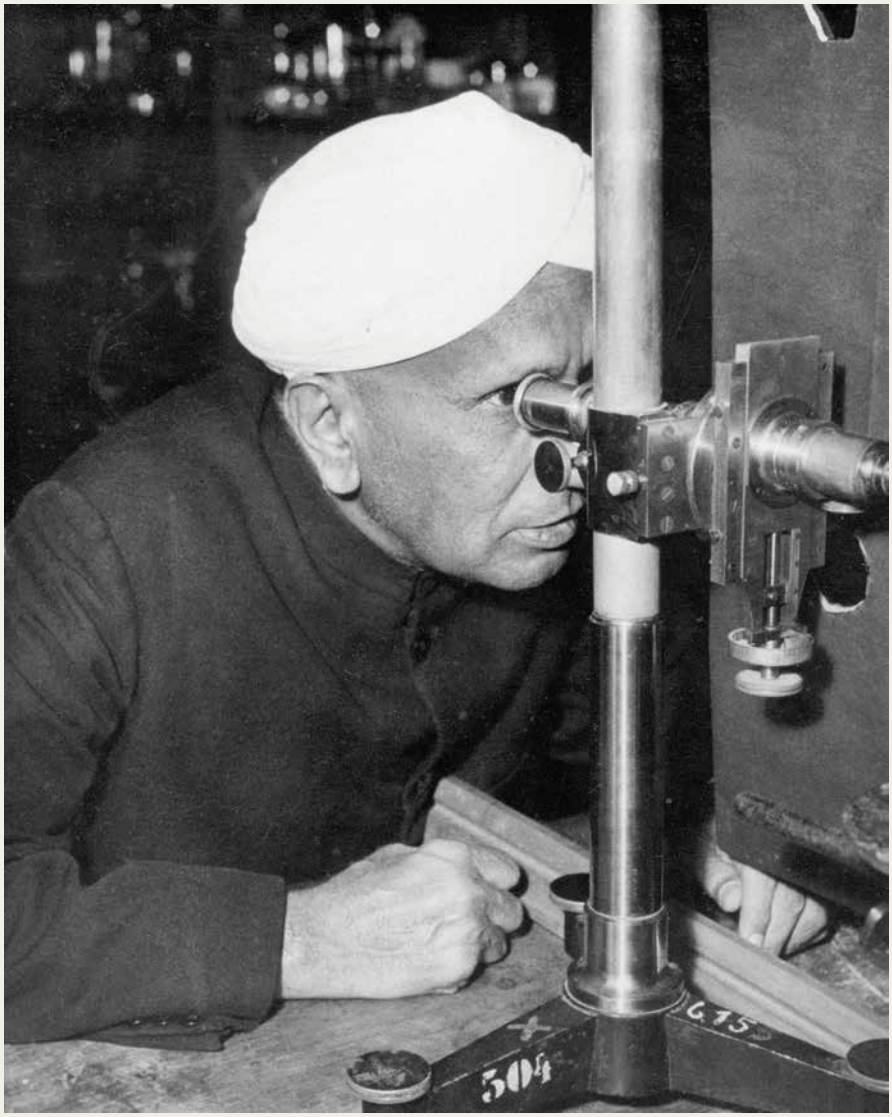
Bose and others soon realised that quantum mechanics was not just a theoretical concept but could explain many phenomena in the real world, from how electrons move to how materials deform.

In the years following his discovery, Raman, who became the Director of IISc in 1934, invited Homi J Bhabha to the Department of Physics. Bhabha joined as a Reader in Theoretical Sciences in 1938. Earlier, during his PhD at Cambridge, he had performed the first quantum mechanical analysis of particle-antiparticle collisions. This process, known as the Bhabha Scattering, is still one of the hallmarks of collider physics experiments.

Soon after joining IISc, Bhabha began experiments on cosmic ray showers – streams of high-energy particles travelling at extremely high speeds throughout the universe. The energies of these particles are large enough to cause particle-antiparticle collisions, just like those seen in particle accelerators at CERN. Bhabha set up a cloud chamber to track the motion of these particles and antiparticles, and a Geiger counter to count the number of particles and antiparticles generated from these collisions. The Cosmic Ray Research Unit in IISc, established by Bhabha, was instrumental in performing the first of such experiments in India.

Bhabha realised that Indian research institutions did not have sufficient infrastructure for advancements in nuclear and high-energy physics. At his request, the Tata Trusts, jointly with the Government of Bombay, funded the establishment of the Tata Institute of Fundamental Research (TIFR) in 1945 within the IISc premises. The Cosmic Ray Research Unit was absorbed into it.

Photo courtesy: Raman Research Institute



CV Raman with a spectroscope

Later that year, TIFR formally shifted to Bombay with Bhabha as its first Director. Within the next decade, TIFR was at the forefront of India's nuclear and atomic programmes, carrying out balloon-based cosmic ray experiments, which resulted in the discovery of particles called K mesons and several cosmic ray isotopes.

Around 1960, for the first time, cosmic ray experiments in India went underground when BV Sreekantan, a student of Bhabha from his IISc days, and his TIFR colleagues conducted the historic Kolar Gold Field cosmic ray muon experiment. They observed the collision of cosmic ray particles with atmospheric neutrinos – mysterious particles that pervade the universe and hold clues to the origins of the universe. "The first atmospheric neutrino event was recorded at the Kolar Gold Fields," says Ananthanarayan. "That is another fundamental discovery that came from India."

> ***Soon after joining IISc, Bhabha began experiments on cosmic ray showers – streams of high-energy particles travelling at extremely high speeds***

While Bhabha was busy building infrastructure for experimental work, theoretical research languished. Some efforts, led by MN Saha, DB Bose and others, were happening at Calcutta University, Allahabad University and Banaras Hindu University. But theoretical quantum physics in India lacked a strong ecosystem – a problem that persisted until 1972.

Building infrastructure

In the late 1960s, Satish Dhawan, the then Director of IISc, invited ECG Sudarshan to spend a few weeks a year at IISc as a visiting researcher. Sudarshan, who had been a student at TIFR, was already famous for his work on quantum field theory (QFT) and particle physics. "Along with his thesis advisor Robert Marshak at the University of Rochester, Sudarshan developed the V-A theory, which was a universal framework for describing the mechanism underlying two fundamental forces of nature – electromagnetic and weak interactions," says Ananthanarayan. Sudarshan also proposed a mathematical framework for the quantum description of light, called the "Sudarshan Representation" – this was crucial for the development of laser physics and quantum optics in the days to come.

In 1972, the Centre for Theoretical Studies (CTS) was established at IISc through the efforts of Sudarshan, DS Kothari and KP Sinha. "With CTS, Sudarshan's idea was to create an environment similar to that at the Institute of Advanced Studies in Princeton, in which talented scholars from different fields would nucleate ideas and engage in interdisciplinary conversations," recalls Ananthanarayan. CTS boasted experts in fields like environmental science, atmospheric sciences, biology, and high energy physics, and employed a rigorous theory programme for visiting researchers. Sudarshan's student and collaborator N Mukunda, along with researchers like R Rajaraman, Romesh Kaul, J Pasupathy, and others, created a unique stronghold for pushing the frontiers of QFT.

CTS was a boost for quantum mechanics in particular. It also set the stage for the next set of advancements in an emerging area called condensed matter physics.

Condensing ideas

Soon after the birth of quantum mechanics, scientists realised that its principles could also be used to understand how assembling clusters of atoms can influence their collective physical, chemical and electrical properties. This field of science eventually came to be known as quantum condensed matter physics – the biggest contributor to modern-day

technologies involving electronics and photonics. The semiconductor and nanotechnology revolutions were spawned by exploring the quantum nature of condensed matter.

Early experiments in this area by Raman's student Krishnan focused on shining light on colloids – mixtures in which tiny particles remain dispersed within a different medium. After 1950, researchers at IISc started experimenting with semiconductors. With CTS, quantum condensed matter theorists also arrived at the scene. "In my opinion, serious, high-level quantum condensed matter theory started in IISc around the early 1970s when KP Sinha and Narendra Kumar joined," says HR Krishnamurthy, Honorary Professor at the Department of Physics, IISc.

Not just quantum condensed matter, Indian physicists also actively participated in establishing the field of soft condensed matter in which proteins, polymers, bacteria and other "soft" materials are put under the microscope. "In India, [research on] soft condensed matter was pioneered in the Liquid Crystals Lab at RRI," says Sriram Ramaswamy, Honorary Professor at the Department of Physics, IISc. "They discovered new phases of liquid crystals." Ramaswamy himself propounded the active matter theory, a framework which deals with micron-size particles attached to self-powered engines. This framework is so diverse that it can be used to understand the swimming motion of bacteria and even the flocking of migratory birds.

Chasing superconductivity

In 1909, Dutch physicist Kamerlingh Onnes discovered superconductivity in mercury – a property that allowed the material to conduct electricity with zero resistance at very low temperature (-269°C). Since then, scientists have been on the hunt for superconductivity in materials at higher and more reasonable temperatures.

> ***After 1950, researchers at IISc started experimenting with semiconductors. With CTS, quantum condensed matter theorists also arrived at the scene***

Sinha was one of the first Indians to begin theoretical research in this area. While at Savitribai Phule Pune University, Sinha, along with N Kumar, showed that shining a pulsed laser on a superconductor can cause it to become superconducting at even higher temperatures. "Following the first experimental demonstration of high-temperature superconductivity by Bednorz and Muller, TV Ramakrishnan and I both became interested in this field," says Krishnamurthy. Ramakrishnan worked on unique theoretical models to get a better understanding of the characteristics of high-temperature superconductivity. Krishnamurthy performed extensive calculations in a bid to understand various theoretical models of high-temperature superconductors.

Ramakrishnan also worked on theories focusing on the effect of adding impurity atoms to materials, including superconductors, leading to a material having small superconducting patches co-existing simultaneously with other non-superconducting patches. "Additionally, Ramakrishnan worked on freezing of classical liquids, and those ideas could be applied to colloidal suspensions too," adds Ramaswamy. "He was one of those people whose range went across classical and quantum systems."

Krishnamurthy, for his part, has also worked on a variety of other problems involving the quantum physics of models and materials with strong inter-particle interactions. These include models of manganite materials which show colossal magneto-resistance, ultra-cold atoms trapped in optical lattices, and so on. His work has also involved developing new theoretical techniques for addressing such problems.

To complement these theoretical advances, scientists like CNR Rao and Ajay K Sood joined IISc in the late 1970s and 1980s respectively, and started working with high-temperature superconductors and other cutting edge quantum materials. Rao made pioneering contributions to the field of materials and popularised the concept of solid-state chemistry, an interdisciplinary field that brings together material science and chemical synthesis, in India.

In 2025, the world will celebrate the International Year of Quantum Science and Technology to mark 100 years of the birth of quantum mechanics. Over this century, Indian scientists have left their mark in almost all branches of quantum mechanics, and continue to contribute to emerging areas like dark matter and dark energy. Quantum computing and quantum communication have captured the public's imagination and attracted significant attention from the Indian research community and policymakers. If there is one thing that these developments have taught us, it is that the unknown often holds great promise, much like Bohr's horseshoe.

Aniket Majumdar is an Integrated PhD student in the Department of Physics, IISc and a former science writing intern at the Office of Communications

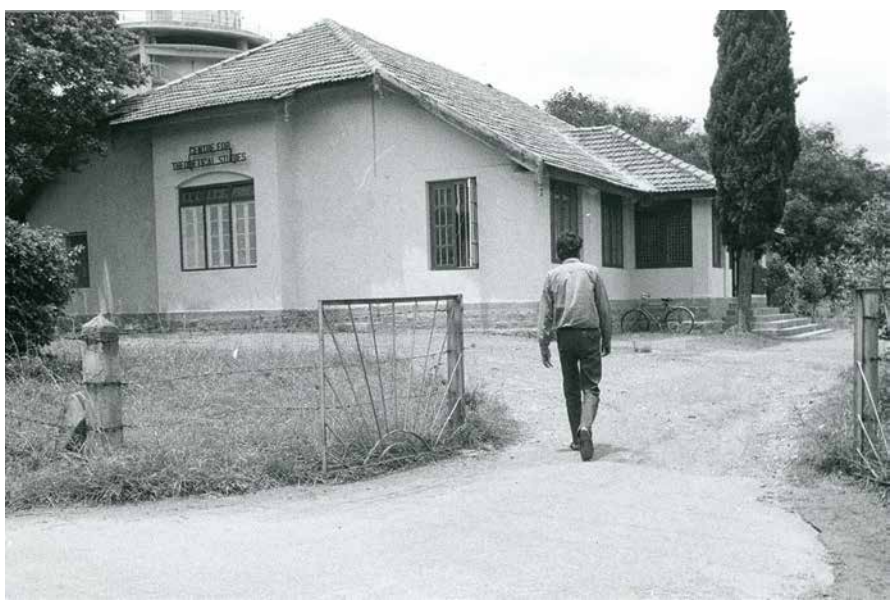


Photo courtesy: Office of Communications

Old CTS building at IISc in the 1970s-1980s

The Hidden Cost of Doing Science

- Yukta Subramanian

Image courtesy: Freepik

Are we harming the world in our pursuit to understand it better?

Around 7 pm on Mondays, Maya can be found in her natural habitat, carefully seeding a culture to be infected the next day or inoculating a batch of bacteria to be genetically transformed. This is where she is on most days, in a brightly-lit biology lab, surrounded by huge freezers, fume hoods, and biosafety hoods. In the background, you can sometimes hear the light buzz of the centrifuge spinning in a corner or spot the oven heating up agarose to help visualise some DNA. As an individual in this research ecosystem, her work has the potential to lead to findings that deepen humanity's understanding of the world and perhaps better our lives.

But aside from this important work, another reality lingers – a quieter, more insidious cost hidden in plain sight. Each pipette tip Maya discards, each sample tube she pushes into the crammed freezers, and each plastic petri dish she tosses into the waste bin, represent a trail of an environmental impact that her work leaves behind.

"The proper use of science is not to conquer nature but to live in it"

– Barry Commoner, American cellular biologist, professor and ecologist

Maya is not alone. According to the Office of Laboratory Safety and Environmental Health (OLSEH), IISc, research activities at the Institute generate 70,000 kg of biowaste annually, which includes 50,000 kg of animal waste. In the last year alone, IISc has generated over 3,000 kg of waste categorised as toxic. A 2014 *Nature* article estimated that the total amount of lab plastic waste generated globally was 5.5 million tonnes.

There is more. According to the National Renewable Energy Laboratory in the US, labs consume at least five to ten times more energy than an office building of equivalent size, and this value can increase by 100 times if there are clean rooms and high-process operations. A major energy guzzler is fume hoods, enclosures that safely contain and ventilate hazardous fumes, vapours, gases and dust generated during chemical processes. Due to safety considerations, fume hoods usually run non-stop in most labs. When open, a single fume hood can consume as much energy as 3.5 homes in 24 hours, and very often, researchers are not aware of how energy-intensive the high-tech equipment they use daily is.

The energy consumption is also stark in fields like computer science and those that involve simulation-based experiments. While the Supercomputer Education and Research Centre (SERC) at IISc has enabled complex studies such as modelling for climate predictions, drug discovery, and aerospace engineering, its energy requirement is vast. Sathish Vadhiyar, Chair of SERC, shares: "The one [supercomputer] in IISc consumes about 500-550 kilowatts. It is at least, on average, 100-300 times slower than the fastest supercomputing machine in the world. If you scale the speed, the power consumption can run up to the rate of 25-30 megawatts. It is believed that this kind of power can provide electricity to an entire village."

These systems run 24/7. Data centres employ transformers, diesel generators, and UPS devices. They also require elaborate cooling infrastructure as these machines generate a lot of heat. Most AI

Photo courtesy: Dipshikha Chakravorty

Tissue culture plates being discarded in separate solid waste containers in the Molecular Pathogenesis Lab, IISc

models work on devices called accelerators which can handle AI workloads with greater speed, efficiency, and cost-effectiveness compared to generic computing hardware. Sumit Mandal, Assistant Professor in the Department of Computation Science and Automation, IISc, reveals: "The daily carbon footprint of ChatGPT is 24 kg [of carbon], which is equivalent to cutting down 406 trees. At IISc, we have about 22,000 trees, and that means it will take less than two months to destroy them if we run ChatGPT. Of course, they're not [actually] cutting down the trees, but those are the statistics."

Big tech companies like Amazon, Microsoft, and Google are now looking toward small-scale nuclear power plants to meet the rising energy needs of their data centres and AI initiatives. Microsoft even plans to reopen the Three Mile Island power plant, despite it being the location of the worst commercial nuclear accident in US history in 1979. The potential for nuclear waste generation, or worse, disasters, is a major concern.

"The greatest threat to our planet is the belief that someone else will save it"

– Robert Swan, British explorer and global environmental activist

Researchers often get caught up in trying to find solutions to the world's problems, including global warming and climate change. However not many are aware or are actively thinking of ways to make their research more sustainable. It begins by realising that this is an issue, and taking stock of the environmental impact.

Image courtesy: OLSEH newsletter

	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24
Rad-Wastes	80	0	35	110	80	0	80	0	40	120	0	120	0
Animal Waste	4011	4097	3743	3150	3145	4716	2725	4474	4311	3873	4430	4283	5839
Waste oil	0	0	0	0	0	0	800	0	0	0	0	100	
Bio	1550	1760	906	1460	1345	2116	1056	1372	1894	1500	1981	1701	2375
Unknown	0	300	0	0	0	60	0	0	0	0	0	0	0
Toxic	0	150	526	155	86	80	625	315	180	216	409	225	335
Solid	0	970	986	535	494	615	687	954	1567	625	645	696	510
Solvent	0	6138	1830	1475	2639	1872	2900	1820	3520	1916	2810	2145	2540

Waste disposal statistics from labs at IISc between October 2023 - October 2024. All units in kg, except oil, solvent, unknown in litres

Photo courtesy: Harish Byndoor

The supercomputer at the Supercomputer Education and Research Centre (SERC), IISc

Minimising waste generation is the first step. Dipshikha Chakravortty, Professor at the Department of Microbiology and Cell Biology, emphasises that every student must "account for each and every piece of material that they are using – every microlitre of enzymes and chemicals."

One can also opt for reusable alternatives to single-use items and design experiments to obtain data robustly and reliably such that experiments aren't repeated unnecessarily. Unavoidable waste produced should be handled in a way that reduces its harmful effects. At IISc, OLSEH collects and segregates waste from the labs into categories such as solid, solvent, biomedical, radioactive, oil, and so on. Waste materials are then handed over to contract-based vendors, who dispose of them based on Karnataka State Pollution Control Board regulations and the Atomic Energy Regulatory Board guidelines (for radioactive waste).

As individuals working in the lab, we can also personally take small steps like switching off appliances when not in use. During a recent "Shut the Sash" contest at the University of Virginia, the Office for Sustainability team reported saving USD 34,000 in energy costs in one month thanks to the efforts of 21 laboratories closing their fume hood sashes when not in use. They concluded that "maintaining these behaviours could result in energy savings of over USD 400,000 annually." More researchers have begun to realise that as their labs get greener, it can relax the strain on their long-term budget significantly.

In data centres, innovative approaches such as using ambient cooling can substantially reduce energy requirements. Ambient cooling systems bring in cold air from outside and drive out hot air from the data centres using heat exchange equipment. This can significantly reduce energy consumption in data centres, when compared to using heavy-duty chillers that consume high energy.

There are other smart solutions. "In certain parts of a [computer] program, you don't need to use very high precision numbers and operations, which will consume storage, generate heat, and consume a lot of power as well. One can be smart while developing such programs by switching to low precision," Sathish suggests. Without compromising on accuracy, machine learning programs can also be made less energy-intensive through techniques such as pruning. Pruning, like in a tree, cuts down or avoids the computation of certain parts of an algorithm that do not affect the results. Sumit's group explores the use of "in-memory computing" to make running programs efficient in speed as well as energy. "With this technology (in-memory computing), we don't need a separate memory and separate computer system like in a GPU (Graphics Processing Unit). If we have a separate memory, then every time memory access happens, it takes a lot of time. It also consumes a lot of energy," he explains.

"Scientists [should] ensure we are not among the last to jump on the sustainability bandwagon"

– Gaia Bistulfi, scientist and author

One of the root causes of increased environmental impact of research is the culture of "fast science" – the relentless push to publish quickly, often at the expense of rigorous methodology and reproducibility. Impact factors drive competition, encouraging more experiments, faster results, and a mountain of waste in the process. This is especially pertinent to well-funded labs at universities. "Because we have a lot of free resources here at IISc, we don't think that this kind of thing may impact others, if not us, right?" Sumit points out. "Everybody should be aware of this kind of negative influence."

A 2014 study estimated that the number of scientific publications doubles every nine years. What does this say about the growing negative impact of research on the environment?

As more and more scientists across the globe recognise this issue, there have been efforts at both university and national levels. In 2005, Harvard University became one of the first educational institutions to commit to what was then called the Green Labs Program. It aims to be fossil fuel-free by 2050 and fossil fuel neutral by 2026.

Climate@MaxPerutzLabs is an Austrian grassroots organisation where employees aim to make research at the institute more climate-friendly. They advocate the incorporation of sustainable practices as an integral feature of research, just like ethical and safety standards. The US-based *My Green Lab* is a non-profit that established the first-ever sustainability criteria for laboratory operations and products in 2013, which have been adopted by a thousand labs across the world. They survey labs and provide recommendations on equipment use, lab practices related to purchasing, chemicals and reagents, and waste disposal.

Back at IISc, Maya has switched to reusable autoclavable plates from the use-and-throw ones, to culture her bacterial colonies, and she operates the autoclave only at full capacity. Baby steps sure, but important nevertheless.

Yukta Subramanian is a BSc (Research) student at IISc and a science writing intern at the Office of Communications

Protect and Serve

- Pratibha Gopalakrishna

A day in the life of Security Officer K Jayaraj

Photo: Pratibha Gopalakrishna

Jayaraj (right) briefing the security guards before their shift

K Jayaraj usually begins his day around 9 am. But this October morning, an unexpected call prompts him to rush out the door an hour earlier. He tells his wife that there is an emergency and that their kids' school is cancelled today. He quickly drives to the Kendra Vidyalaya on the IISc campus and alerts the school staff to evacuate the children from the premises. A team of police headed by Inspector Ajay Sarathi from the Yeshwanthpur police station also reach the school. Jayaraj spends the next few hours managing the situation with due diligence.

It is almost 10 am by the time the situation is settled. Another crisis averted. He finally sets off towards the security office on campus in a Bolero, fielding multiple calls on the way. Once he reaches his office, his usual day begins.

The security office is at the end of Tala Marg on the east side of the campus, right next to the Department of Design and Manufacturing (DM). The Security Control Room operates 24x7 and attends to all emergencies on campus. It has 10 security assistants and around 450 security personnel, including 30 women who work at the women's hostels, a few security supervisors, and CCTV operators. Jayaraj is in charge of all of them.

Born in Tirukoilur and hailing from Villupuram in Tamil Nadu, Jayaraj completed his Bachelor's in computer science from Annamalai University and MBA from Pondicherry University. Following this, he worked in the Central Reserve Police Force (CRPF) for about eight years, travelling across India from Agartala to Ranchi, Hyderabad, Mudkhed, and Neemuch. Recalling his initial days in Agartala, he says that the police department had once procured new computers, and kept them in brand new boxes. "No one dared to touch them as they were all afraid of accidentally breaking them." With his computer science background, Jayaraj helped the commanding officers set up the systems, connect to the internet, and train the staff members.

> ***'Managing the security of an institute like IISc is all about balance'***

After his stint at CRPF, Jayaraj joined the India Tourism Development Corporation (ITDC), overseeing human resources and security at Janpath Hotel in New Delhi. After he was relieved from the Human Resource Management Division at ITDC, he took evening classes at the University of Delhi to get his Bachelor of Laws (LLB). He joined IISc in 2019 as an Assistant Registrar in charge of security and students' hostels.

Photo: Pratibha Gopalakrishna

Jayaraj answers a call in his office

Jayaraj's office is a rectangular room with a barrel roof and multiple windows. There are two desks: one with a small pile of documents and two telephones, and the other with a bookshelf, a cricket trophy, and a few knickknacks. A desktop is in one corner of the room with a rifle hanging on the wall next to it. Once Jayaraj settles in, he answers a few more phone calls and then jots down the morning incident in a logbook.

At any given time, around 100-110 security personnel guard IISc; some are stationed at the entrances, departments, and hostels, while others patrol the campus. Jayaraj uses a walkie-talkie to communicate with the guards throughout their shift. "The shifts and posts keep on changing," Jayaraj explains. Every week, each security guard has two morning, two evening, and two night shifts, with one day off-duty, and their placements also change every 10 days.

Managing the security of an institute like IISc is all about balance, says Jayaraj. Educational institutions are soft targets for threats and attacks. "We have our unique challenges," he says. As an example, he mentions people who look for opportunities to steal laptops or phones during conferences, for which screening at the gate becomes essential. "Irrespective of the complaints we get, we focus on the grey areas where there is scope for improvement." Which is why the security office conducts a mandatory 40-minute briefing session before each shift change.

He pauses to listen for any skirmishes outside. Sometimes, he says, people drop by the security office to complain about being stopped at the gates; as the guard placements are changed every 10 days, the new guard asks anyone entering 'Who are you?' The word people often use to complain about the security guards is 'harassed,' Jayaraj explains. "For doing their basic job. The guards are paid for that."

However, Jayaraj also agrees that the topic is sensitive, and guards at the gates have to be careful while talking to visitors who enter the Institute.

After the logbook entry, Jayaraj signs a few documents for Eresh, the administrative assistant in the security office. Then, he moves to the desktop to check his emails. He also makes sure to charge his phone, as its battery has dwindled down to a mere 13% in less than half the day. "My battery dies very fast because of the continuous usage," he remarks.

The security office often gets calls from residents and students about the behaviour of various dogs, monkeys, snakes, and even the elusive slender loris. "Our Institute believes in inclusive living," Jayaraj says. Some of the security staff are trained to climb trees and return the fallen slender loris to its home atop the branches. Others are trained to identify and catch non-venomous snakes.

> ***Some security staff are trained to climb trees and return the fallen slender loris to its home atop the branches***

The office also handles emergencies and unfortunate deaths. In the case of student deaths, the security office provides full support to the family, coordinating with them every step of the way till they go back home. Jayaraj says that these parents keep in touch and call him to talk about their kids. "It is painful and challenging but it is a part and parcel of this occupation," he says. Since his joining, Jayaraj has attended many such cases and some near misses. It is these near-miss cases, Jayaraj says, that give him strength and energy to continue his work.

On a lighter note, a major complaint the security office often receives is about bicycles, Jayaraj says. The office gets 2-3 calls daily regarding misplaced or stolen bicycles – the calls are so frequent that the students are told to keep their bicycle-related bills and documents handy during orientation. And in an interesting twist, about 99% of them are recovered from within the Institute. "Sometimes, students forget where they parked their bicycles," he comments.

The day gets busy again as Jayaraj gets a call from the Registrar asking for support on a staff matter. Then, two members from IISc's Students Council drop by to ask questions regarding Diwali celebrations on campus. Jayaraj advises them on the protocols that need to be followed to ensure student safety.

It is 1 pm now and Jayaraj walks to the front of the security office where the next batch of security guards are standing in line for their briefing. After they salute, he begins his briefing by telling them that it is almost Diwali and they need to stay vigilant. "Wherever you are posted, be on alert." He tells the guards to check every person entering the Institute and to ask the drivers to go slow. "You are all working at IISc – the number one university in India. You also need to be the best because your job is important. Understood?"

The other officers take attendance as Jayaraj goes to meet the Dean of Administration and Finance. They brief the other guards and the women security guards in charge of the hostels separately, giving them a run-down of the events for the day. The security in charge of hostels and messes are also briefed about taking care when talking to students. One of the security officers tells them, "We might not know what the students are going through. But for them, you are the guardian here. So, talk to them politely."

Jayaraj then drops by his home on campus to have lunch – *rice*, *sambar* and *kuzhambu*. He then goes to check on the hostels and reaches the office around 2.30 pm.

Sometimes he gets reports of student injuries and accidents. In these cases, Jayaraj first calls the Health Centre to understand if any students visited for a checkup.

He recalls the initial days of the COVID-19 lockdown when the entire campus was shut to outsiders and the security office never received any complaints of theft. "The Institute handled COVID-19 very well." As part of the COVID-19 committee, Jayaraj regularly sent bulletins to the IISc community regarding quarantine areas and updated guidelines. The security office arranged meals for over 800 students who stayed on campus. They also got police passes for the essential staff who travelled to the Institute daily. During the second wave, the officers helped set up quarantine rooms for the students who were infected. From mattresses and bed sheets to pillowcases and internet dongles, the security office provided all the amenities to the students.

Photo: Pratibha Gopalakrishna

Jayaraj in discussion with Yeshwanthpur sub-inspector Revanna Siddu Hugar

Cybercrimes are a growing issue about which the security office also receives complaints from campus residents. DIGITS has awareness programmes and sends posters and emails to let the IISc community know about these crimes and what steps to take if anything happens. Jayaraj stresses on how letting the security office know immediately helps in such situations. This also gives the police more time to track down such operations.

> ***'We might not know what the students are going through. But for them, you are the guardian here. So, talk to them politely'***

Another responsibility that the security office handles is securing the campus during a high-profile visit from any ministry or the Prime Minister. There are different categories of security, Jayaraj explains, with the Special Protection Group (SPG) being the highest level of security that protects the PM. Nonetheless, all these agencies have their own protocol that they follow to secure the campus and buildings during a visit.

Around 4 pm, a few security guards along with the guard in charge of the campus football grounds walk into Jayaraj's room. Someone has filed a complaint that outsiders were let into the ground. Jayaraj listens to the story, asks the guard a few questions, and lets him go. After giving it some thought, he tells them to suspend the guard for two days. Jayaraj says that security lapses are taken seriously. "There is no compromising on discipline."

As first responders, Jayaraj believes that security personnel should be prepared for emergencies. One of the security vans is equipped with emergency kits, Jayaraj explains. "We have a chemical spill kit, bodysuits for fire emergencies, and oxygen cylinders."

Jayaraj usually leaves office around 6 pm and goes for another round of security checks before heading home. After reaching home, he doesn't immediately get out of his work clothes. Sometimes, his kids and wife pester him about it. "But, you know, if there is an emergency, this will save my time," he says. "'Be Ready'. That is our motto."

CONNECT ASKS

What are your New Year resolutions for 2025?

I have not thought about it too much, I barely have enough time to keep up with my coursework! I'm not really into New Year resolutions; I prefer to make little resolutions every day. For now, I want to get my hands on the lab instruments and reactors. Currently, my mind is all about PhD work, but maybe I'd like to start exercising and pick up a sport again. I stopped playing after college, and it would be great to get back into it!

Syed Helal
PhD student, Centre for Nano Science and Engineering (CeNSE)

I feel like we should make small goals rather than very big goals. It has been difficult to achieve big goals like "resolutions". For me, I don't think resolutions are a good way to motivate myself to do something for a whole year. It should come from within and in small cycles. A small goal for me right now is to work on my manuscript. I am finishing certain small experiments, writing stuff, and so on.

Prince Singh
Integrated PhD student, Department Of Microbiology and Cell Biology

I often think about focussing on my health and gaining some weight. But it doesn't work out most years; once the New Year passes, I usually forget (*laughs*). When I came to IISc, I thought I would have more time on hand but now I have taken up too many credits. So maybe after my first year, I can focus on that. I'm interested in football and badminton. I tried going in the initial months but stopped due to an injury. I really value the mental health improvements that come with physical activity. I also like to plan for trips with friends. I have planned a trip to go to a Coldplay concert in January and maybe plan a trip to Kashmir. Maybe we would like to go to more concerts!

Munawar M
PhD student, Centre for Nano Science and Engineering (CeNSE)

I'd like to get involved in club activities on campus, and just explore more of life outside academics. I was too involved in academic life for the first three years; it was hectic and stressful. I would like to join the Alankaar club for Kathak dance again. I used to learn it back home in Gujarat before I came here, so I would like to reconnect with my hobbies. Until now, I haven't been able to hold up resolutions though (*laughs*). But I think it is motivating to start a new year with a resolution and try to stick to it at least for some months!

Divija Nanavate
BSc (Research) student

My first resolution is to get my first paper published. The second resolution is I want to work on my health a little bit more and have a better work-life balance. When I first came to IISc, I made a resolution to wake up early every morning, and I have stuck to that for four years. I wake up at 6.30-7 am, have a hot drink, do gardening ... And if I'm ever feeling down, just roaming around the campus lifts me up. I also like visiting the nursery; it is the best place on campus to hear the birds and see lots of insects. I am trying to absorb this place as much as I can before I leave. That is another resolution, I guess!

Shefali Srivastava
Integrated PhD student, Department of Physics

This is not specifically for the new year, but these days, health is something on my mind. Trying to eat healthy, walk more, and all that. I started intermittent fasting, and I've been able to do it for a month so far. That feels like more of an achievement than a paper! I find it a good idea to find and do something you're passionate about outside of PhD work also; it allows me to manage my work better.

Prachi Mishra
PhD student, Department of Electrical Communication Engineering

I want to focus on my academics and not waste time on other activities like scrolling social media or sleeping at odd times. Earlier, I used to have different kinds of resolutions, like waking up early in the morning, but it didn't happen. But, I don't think having resolutions just for the new year is helpful. I find that taking resolutions even mid-year is okay, like I did. After my second semester, around May or June, I completely deleted my Instagram account. I have also improved my attendance.

Kunjan Manoj Kumar
BTech student, Math and Computing

I usually make two to three resolutions every year. This year, I want to start journaling, which I started properly as a resolution right from November 1. I think if you start something pre-new year, then it is easier to continue. I found journaling helpful when I was in Japan for a three-month internship. It was amazing there but I didn't feel a sense of belonging. So, writing what I felt every day gave me a push to keep going. I also want to do more meditation, which I took as a resolution back in my first year and again in 2024, but so far, I could only do it in bits and pieces. In the past four years at IISc, I have learnt a lot because of taking resolutions. Another successful resolution for me has been the practice of manifestation, which I believe helped me get my paper published. I think people underestimate it a lot.

Pragya Mishra
PhD student, Department of Electrical Communication Engineering

‘It’s difficult to get into IISc. It’s also difficult to get out because you fall in love with it’

- Sandeep Menon

Photo: KG Haridasan

Yadati Narahari leans over his desk, turning his computer screen around as he shows an image. It shows a group of people standing side-by-side staring into the camera. It is an image that Narahari holds with great regard, one – he feels – encapsulates his time at IISc. "This is six generations of researchers and scholars," he explains. "This is my guru, his guru, me and the ones that I taught."

Narahari has spent over four decades at the Institute. After joining as a student in the late 1970s, his time at IISc saw him scale heights as high as Dean of his Division, Director of a major centre, and the driving force behind the digitalisation of the Institute, all while producing 29 PhD scholars, powering his laboratory and research work in game theory, mechanism design and AI for social good, and publishing several books and papers, with the help of his wife and 'hidden author', Padmashree.

Narahari sat down with* CONNECT *to talk about his journey in academia and the Institute's evolution, in which he played a major role.

You have spent 45 years in IISc. Can you talk about your journey of getting into the Institute and then continuing on?

The thing is, it's very difficult to get into IISc. It is also very difficult to get out after you're inside because you fall in love with it.

Sometime in 1978, I was in my final year of BSc at AES National College in Gauribidanur, in Chikkaballapur district. I did not even know of the existence of IISc at that time. My dream was to finish my BSc, apply for MSc in mathematics at Central College, Bangalore and then go back and teach at AES National College.

It was my brother's father-in-law, Anant Rao, who suggested that I apply to MSc mathematics at IIT Madras and for the three-year BE programme, which was a post-BSc programme, at the so-called Tata Institute or Indian Institute of Science. I cleared both the exams. That's how I came here in August 1979.

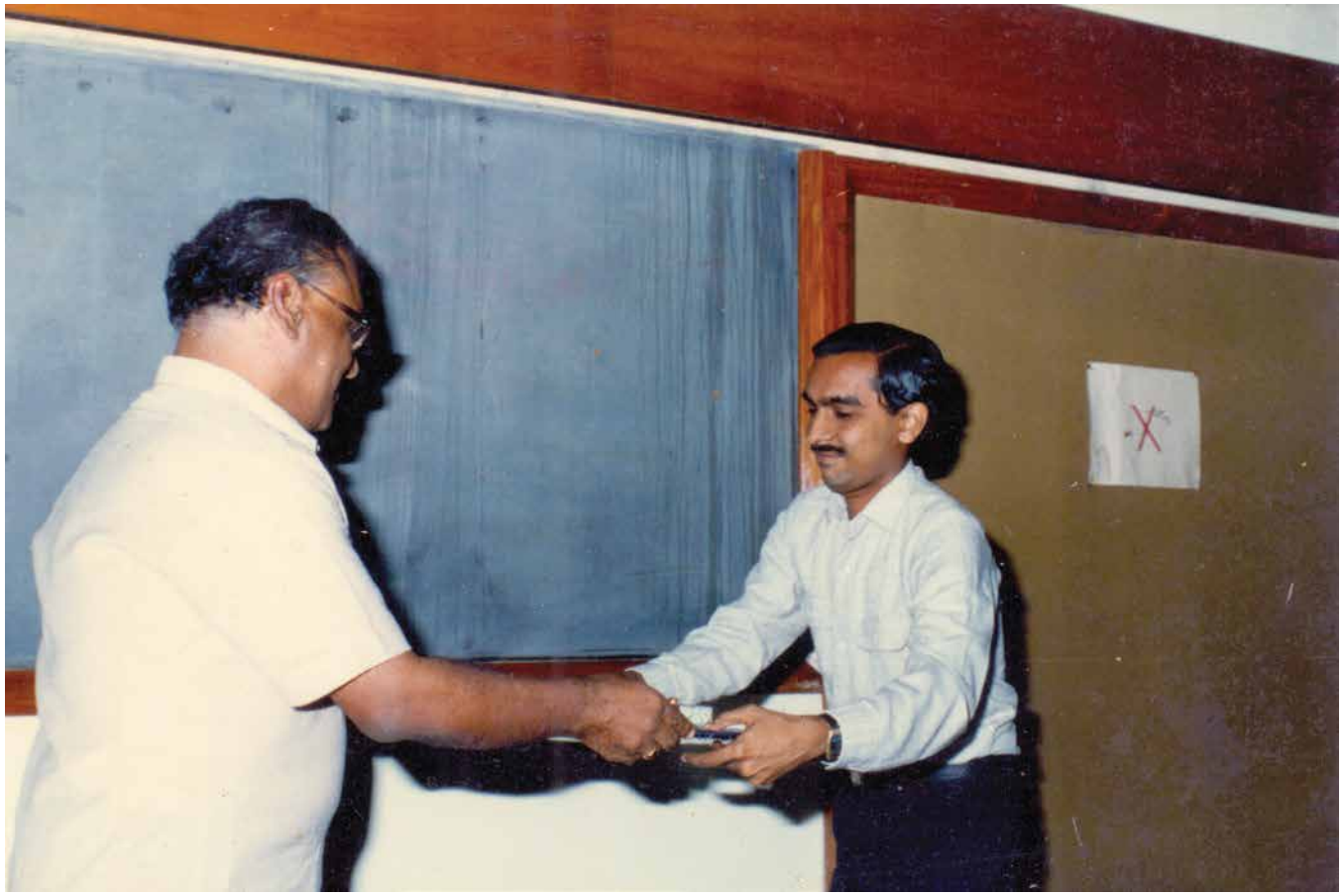
I did my BE here for three years in the ECE Department and enjoyed the course work. There was healthy competition among the 30 students. From 1982-84, I did ME in the Department of Computer Science and Automation (CSA). It was called the School of Automation at that time. Then in 1984-87, I finished my PhD and joined here as a scientific officer, became a lecturer in 1988, an assistant professor in 1989, associate professor in 1995, and full professor in 2001.

In December 2009, I became the Chairman of the Department of CSA. In 2014, I became the Chairman of the

Photo courtesy: Yadati Narahari

Six generations of researchers, including Narahari's gurus and protégées. From right to left: BL Deekshatulu, N Viswanadham, Yadati Narahari, N Hemachandra, Vikas Vikram Singh, and Varagapriya

Photo courtesy: Yadati Narahari



Yadati Narahari receiving the Best PhD Thesis prize from the then director CNR Rao in 1987

Division of Electrical Sciences (subsequently, this became the Division of Electrical, Electronics and Computer Sciences or EECS). I was Dean of EECS till July 2021. During 2022-23, I was officiating as the Director for the Center for Brain Research (CBR). During 2016-21, I was also Chairman of DIGITS. My innings closed on 31 July 2024. I am now an honorary professor until July 2029.

Was there ever a time when you could have left the Institute?

At IISc in general, and in the departments I have worked in, the ecosystem is wonderful. When you are a student, you look for some excitement in the learning process and inspiration from your professors and instructors, and that was very much there. The professors here were very accessible.

At the end of my BE, I got a job at Wipro. In fact, my HR interview was taken by none other than Azim Premji [the former chairman] because it was a small company then. But I wanted to continue here.

Then, I was an ME student for two years here. My dream job was at the Indian Space Research Organisation. So, I applied only to ISRO and got a job where they offered me two increments as well. It was my dream job, but then, the attraction of PhD was there.

How has the Institute evolved during your time here? Not just from an educational perspective but a cultural one as well.

Universities are where the future of science and technology is supposed to be envisioned, where future leaders of the nation are trained. So, it is very important for the institution to be aware of what is happening at the global level. Maybe the slope of progress is much higher in recent decades compared to earlier. Because I have been here for 45 years, this change is more like an evolution for me rather than abrupt.

I was in the ECE department and even in those days, the Institute used to have a large number of electives, a progressive initiative. I ended up doing a lot of electives from the computer science department. In the early 1980s, this was an iconic department in the Institute. The department was started in 1969, and it was, in some sense, the first experiment of interdisciplinary work. The faculty members were from many departments like electrical, mathematics, aerospace ... some came from outside. It was supposed to work on Grand Challenge Control problems, like those that ISRO, DRDO, and the Department of Atomic Energy solve. So, the department was started with a very specific purpose of automation and control. Gradually, it evolved into the computer science department.

In 1971, it was this department (CSA) that introduced an ME in computer science for the first time in India. The Institute was also the first to start an MTech programme in artificial intelligence, about six years ago. The Institute and the departments have been at the cutting edge.

How has teaching changed both in methods and technology over the years?

It has changed quite a lot in recent years. In my own teaching, there has

been a continuous evolution, but one thing that has remained constant is that I have always believed in blackboard teaching, from the very first course that I taught in 1987 to the most recent.

Post the pandemic, I was teaching using the slides I had prepared during COVID-19. Midway through the course, I took a student poll. 'Do you want me to continue with teaching from the slides or do you want me to start using the blackboard?' 90% said blackboard. So, now I teach the Game Theory class only on the blackboard. In the algorithms and programming class, I am experimenting with teaching from slides because the class has 150 students and there are display monitors throughout the classroom so they can see more easily.

The way we teach has also dramatically changed over the last two or three years, because of the emergence of modern AI tools. You get fantastic code, which is almost flawless [using AI tools]. I co-teach a course with Professor Viraj Kumar, and we decided to encourage students to use AI tools as a part of learning. We teach all the foundations. The programming assignments are of two types. One where they are not supposed to use AI tools and one where they are. We also give them programs generated by GPT-4 with subtle flaws and ask the student to find out if it works for all inputs.

> ***The way we teach has dramatically changed over the last two or three years, because of modern AI tools***

Speaking about AI, there is a lot of concern about this evolving tech. What is your take on this?

Every modern technology has dangers associated with benefits. It's very important that you derive the benefits to the maximum extent and take the measures required to prevent dangers. The degree to which AI has started influencing almost every walk of life is unprecedented. But I think this trait was there with every modern technology.

Is the AI revolution going to be like the industrial revolution?

It depends. For people working in areas like natural language processing or large language models, it has been a very gradual process. But because of AI's dramatic influence and innovations, 90-95% of people feel that it is a revolution. What is dramatic is the pace at which almost every field is getting influenced.

Can you talk about the Game Theory Lab?

Game theory is the science behind microeconomics. It is the analysis of games, which are basically strategic interactions between rational and intelligent individuals. We study how these interactions will happen and how they are driven by individual interests.

Every agent tries to do individual optimisation and maximise his or her own utility. But if everybody is individualistic, then societal goals may not be met. Game theory is all about understanding the effect of individual strategies on societal goals.

Photo courtesy: Yadati Narahari

Yadati Narahari (sitting left) with John Forbes Nash in 2003. The American mathematician made tremendous contributions to Game Theory among other areas and along with fellow game theorists John Harsanyi and Reinhard Selten won the Nobel Prize in Economics in 1994

The question is: Can we design games so that the strategic interactions among the different players will result in social objectives? This is called mechanism design.

Game theory was developed by John von Neumann and Oskar Morgenstern in the 1920s. Seventy years later, there was a marriage between game theory and algorithms, and the branch of algorithmic game theory was born. Many faculty members in the CSA department, starting from me, began working on algorithmic problems in game theory.

Recently, I have found that some of these principles, along with artificial intelligence, can be used in solving some problems in agriculture as well. The project started from a chance meeting with Dr PV Suryakumar from NABARD (National Bank for Agriculture and Rural Development). It was not easy to recruit students [for it] because they wanted to work on projects that helped them fetch a good job. I know that all of them will be interested in deep learning. I was using deep learning for many of these problems. So, I called it deep learning-based crop planning, deep learning-based crop recommendation, deep learning-based crop price prediction, and so on. This was a mechanism design for attracting students!

We have also implemented our learnings, where we actually demonstrated our algorithms through mobile apps.

Could you tell us about your role in establishing DIGITS?

It was the brainchild of the then Director, Professor Anurag Kumar. There was a unit called TINA: Telecom and Internet Access. In 2015, we wanted to start a separate IT office for the Institute. I coined the name Digital Campus and Information Technology Services or DIGITS.

There were two major problems we wanted to fix. One was email and email servers. IISc was on the educational and research network (ERNET) and every department had an email server, so it was a decentralised operation. We wanted to centralise it. The other one was that there were 16 different databases in the Institute. If you wanted some information about a student, you would get partial information from these databases or a subset of them. There were inconsistencies. For example, when an MTech student becomes a PhD student, one database will say that she is still in MTech. Another will say she is doing PhD, and a third – because the degree certificate for MTech was issued – would say she has left. We wanted to have a single source of truth.

And of course, associated with that there were administrative processes – HR, purchase, finance, projects, and security processes – which we wanted to streamline.

The first objective, namely the email service, was solved by using Microsoft Azure and a single email gateway from the Institute. It was a complex operation because we had to migrate 6,000 to 7,000 users to the new system.

For the second one, it was a major decision. The DIGITS core team would have weekly meetings with the Director. By 2016, it was decided that we would go in for an enterprise resource planning package. After much deliberation and an elaborate process, SAP was selected. We decided to have somebody to help us implement SAP and Wipro won the contract in competitive bidding. With their help, we started the implementation of SAP from 2017. In 2019, we went live. We went live with Student Lifecycle Management in 2020.

It was tough. I am a person who always had maximum goodwill from almost everyone in the Institute and for those three years, I lost all of it (*laughs*).

You have had several roles and worn different hats ...

Little did I imagine that I would be officiating as Director of the Centre for Brain Research because brain research is not my area. My job was a great challenge: to walk in the shoes of Professor Vijayalakshmi Ravindranath, who built CBR brick by brick. Someone was required to maintain the momentum and I was contacted because I had administrative experience. I was on the governing board of CBR for quite some time ever since its inception. I was there as the Director for about 19 months; I maintained the momentum of the place and ensured that the new Director was selected.

Whenever the Institute wanted me to do something, I rarely said no because the Institute has given so much to me.

Photo: KG Haridasan

Inauguration of DIGITS building. Narahari (second right next to the plaque) was key to its vision and setting up

Peaks of Joy

- Parth Kumar

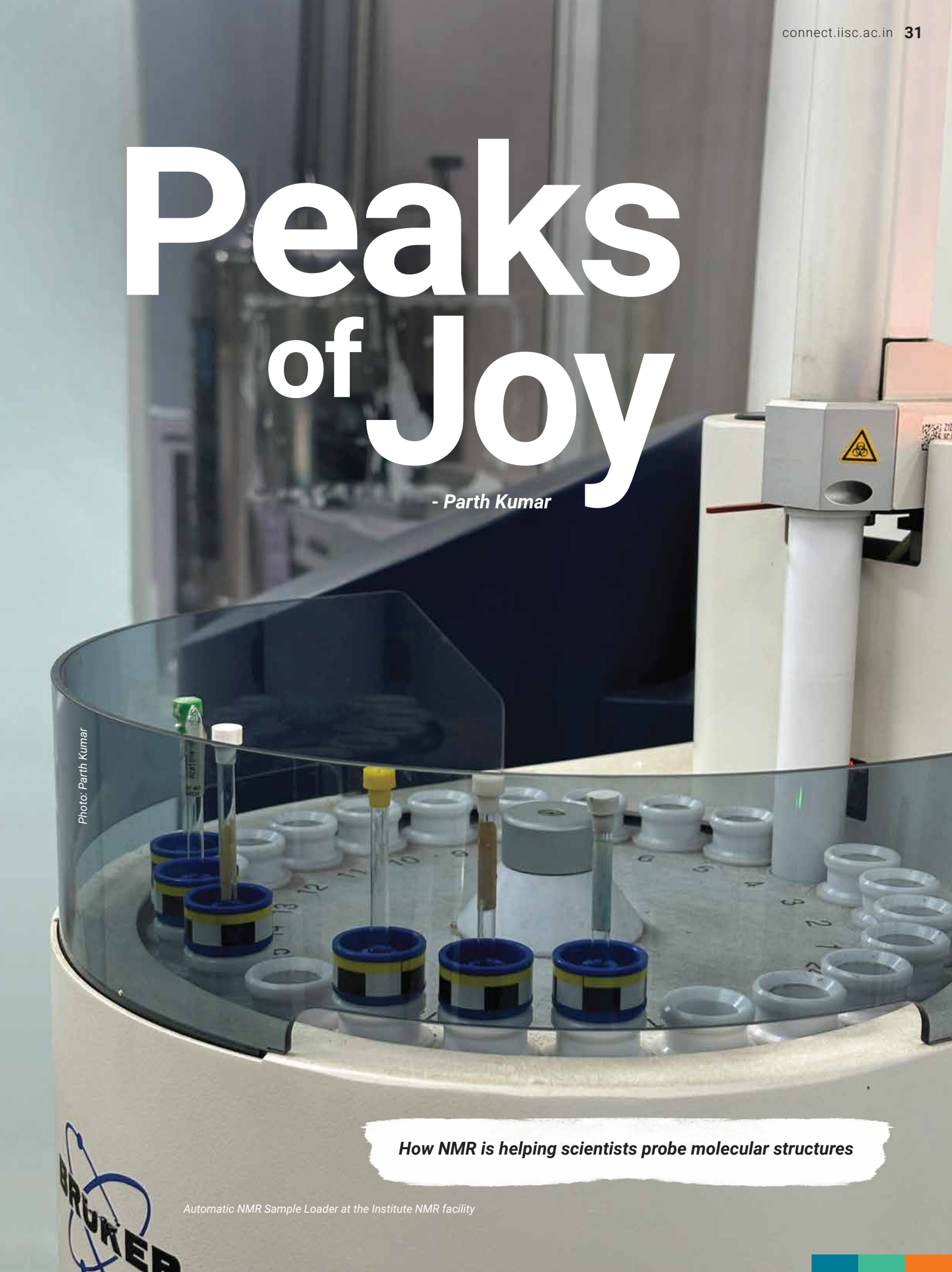


Photo: Parth Kumar

How NMR is helping scientists probe molecular structures

Automatic NMR Sample Loader at the Institute NMR facility

It was after six on a Monday evening in September, and Durga Prasad Hari was in a hurry. Holding a thin glass tube in his hand, he walked quickly to the common instrument facility on the ground floor of the Chemical Sciences building, two students tailing after him. After unlocking the door, he climbed up a small step stool and, with quivering hands, inserted the glass tube into a big, fat cylindrical machine. He pressed a few buttons, and the three of them waited with bated breath to see what would happen.

The machine they were using is a Nuclear Magnetic Resonance (NMR) spectrometer. It is an indispensable tool in unravelling molecular structures, be it organic compounds in synthetic chemistry or complex biological molecules like proteins. Anyone who has worked with NMR will tell you how frustrating it is to get a good spectrogram. But they would also be the first to tell you that the exhilaration of getting a flawless spectrogram makes the effort worth it.

Like other spectroscopic techniques, NMR tracks how light interacts with matter. The nuclei of many atoms, such as hydrogen, behave like tiny magnets. When placed in a strong magnetic field, these tiny magnets seek to align themselves along the field – like a compass needle pointing north.

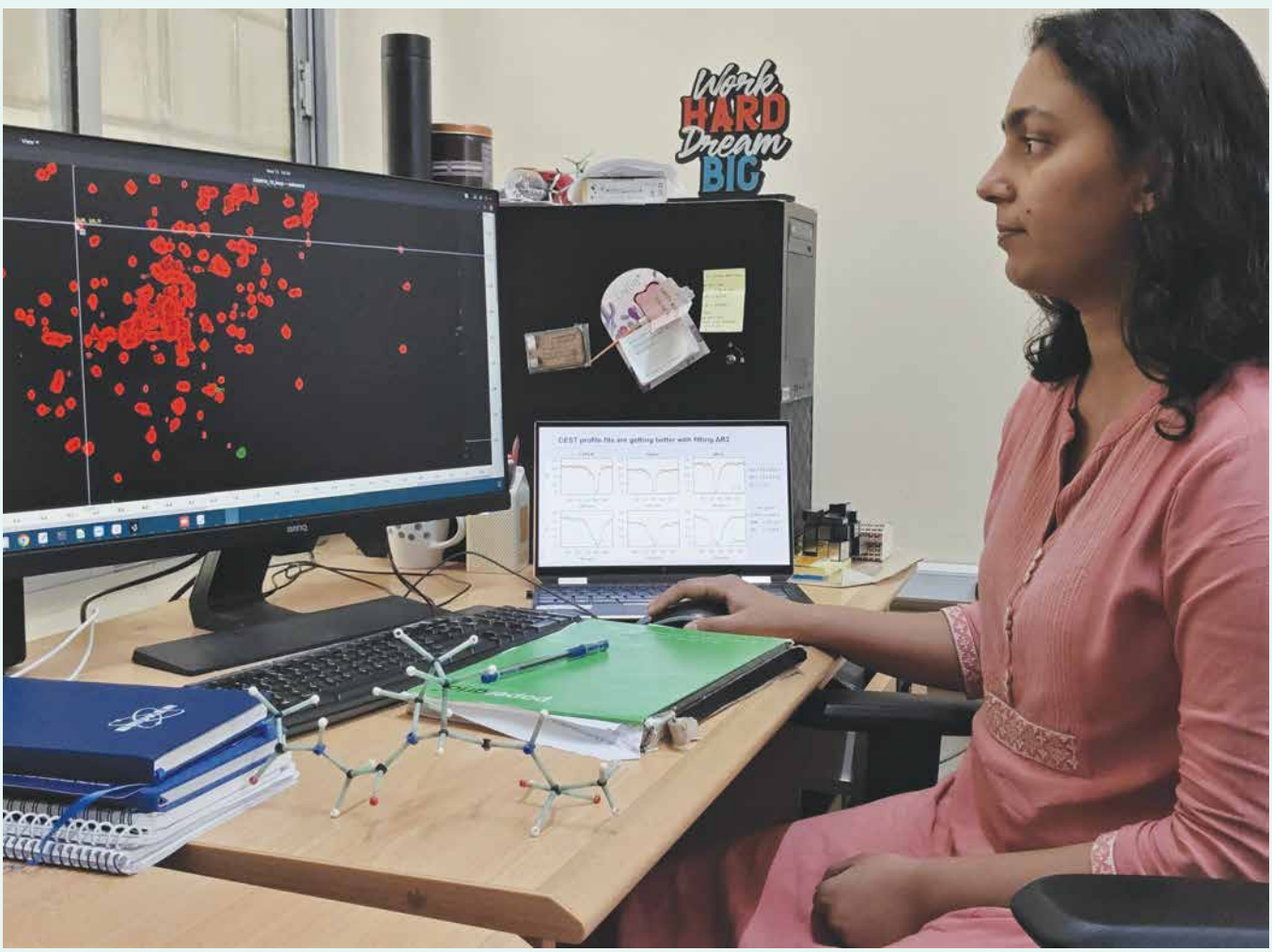
When light falls on a nucleus, the latter gains energy, flips its orientation, and aligns in the opposite direction. However, the nucleus doesn't like being in this "high energy" state, and quickly flips back to its original alignment, releasing the energy it gained.

The amount of energy released depends on the movement of its electrons and other atoms surrounding it. This means that each atomic nucleus within a molecule will respond to a unique frequency of light wave, called the resonance frequency. For example, hydrogen atoms in ethanol (CH_3CH_2OH) have a different resonance frequency compared to those in ethane (CH_3CH_3) simply because their molecular arrangement is different.

> ***Every molecule will have a completely different NMR spectrum, which acts as its "fingerprint"***

And that's exactly what NMR tells us – it identifies the resonance frequencies of different atomic nuclei in a molecule, which appear as 'peaks' on a spectrogram. Every molecule will have a completely different NMR spectrum, which acts as a "fingerprint" of that molecule. This makes it a great method to conclusively determine the structures of organic compounds as well as biological molecules like proteins. The goal in synthetic chemistry is to get a "clean" NMR having all the peaks corresponding to the molecule, without any unwanted peaks which indicate the presence of impurities.

Photo: Bodhisatwa Nandi



Claris Niya Varghese, a student in Ashok Sekhar's lab, analysing an NMR spectrum

"NMR is an instrument that we use in the lab daily," says Hari, Assistant Professor at the Department of Organic Chemistry. It can help scientists estimate the efficiency of an organic reaction, map different spatial configurations of the same molecule, or study the kinetics of a chemical reaction. It can also help probe enzyme-substrate binding in biological systems, and design materials with specific binding capacities.

"For other techniques like X-ray crystallography, you need the compound to be a solid crystal," explains Muhammad Arbaaz S, PhD student at the Materials Research Centre (MRC). "But NMR is so versatile and flexible that you can analyse compounds in the solid as well as solution phase. And it's not just a preliminary test – it's a very reliable confirmation of the identity and purity of a compound."

Once, while analysing the NMR spectrum of a new class of molecules, Arbaaz stumbled upon something unusual. "The peaks in NMR are usually sharp, but I observed that this compound gave somewhat wavy peaks. I spoke to more people to understand what this might mean, and found that my molecule is magnetic!" Such materials with spontaneous magnetism have widespread applications in capacitors, memory devices, and even generating bioelectricity. Arbaaz excitedly adds: "I never expected that a strange observation with NMR would push me to explore an entirely different direction with my work."

Photo: Parth Kumar

700 MHz NMR Spectrometer at the NMR Research Centre

Probing fleeting proteins

Across the road from MRC sits the Molecular Biophysics Unit (MBU), where structural biologists have been using NMR to probe biological phenomena, particularly how intrinsically disordered proteins (IDPs) work.

Unlike most proteins, IDPs do not have a stable, folded structure and adopt a variety of dynamic conformations. IDPs typically control biochemical processes by binding to partner molecules like DNA and other proteins. For most proteins, the structure dictates their function in a cell. So, how exactly do IDPs have specific functions without a fixed structure?

Ashok Sekhar, Associate Professor at MBU, investigated an IDP called cytidine repressor, which binds to DNA and prevents certain genes from performing their function. "We figured out that the disordered state of this protein is the one which [exists] around 90% of the time. But it transiently exists in a folded conformation with a millisecond lifetime – and we were able to characterise this state using NMR," he explains.

Tracking this transient conformation is crucial because the cytidine repressor is only functional when it is folded. "It's like trying to start your car with a piece of spaghetti, instead of a key with a well-defined shape," adds Ashok. "Every once in a while, the spaghetti forms a car key, and at that time, the car is able to start. This was interesting because it was not known earlier that intrinsically disordered proteins can transiently fold even without the targets they bind to."

Compounds studied by synthetic organic chemists usually have only a few dozen hydrogen atoms, but proteins are huge molecules, with several hundreds of these atoms. All the atoms are in a different chemical environment, surrounded by different neighbours, and each gives a distinct peak in the NMR spectrum. It becomes much harder to analyse the peaks, and it takes much longer to acquire the data. The best way is to leave the sample in the NMR machine and keep measuring the resonance frequencies again and again. This would allow it to catch new NMR signals that show up when there is a sudden and temporary change in the molecule's conformation.

"Methods like X-ray crystallography have a harder time characterising fluctuations in structure – what we call molecular dynamics," Ashok says. "But NMR is so powerful that it can detect states that have lifetimes of just a fraction of a second in solution."

> ***NMR is so powerful that it can detect states that have lifetimes of just a fraction of a second in solution***

NMR is already one of the most powerful techniques today, but people are working on making it even better and more extensive in scope – such as combining NMR with AI tools to hasten protein analysis.

"Using NMR to visualise larger biomolecules, accessing conformations with even shorter lifetimes, speeding up data acquisition and making it more sensitive – these are some of the things people are trying," explains Ashok. "The other area that people are pushing is called in-cell NMR, where we can visualise molecules inside living cells using NMR spectroscopy. The possibilities are endless!"

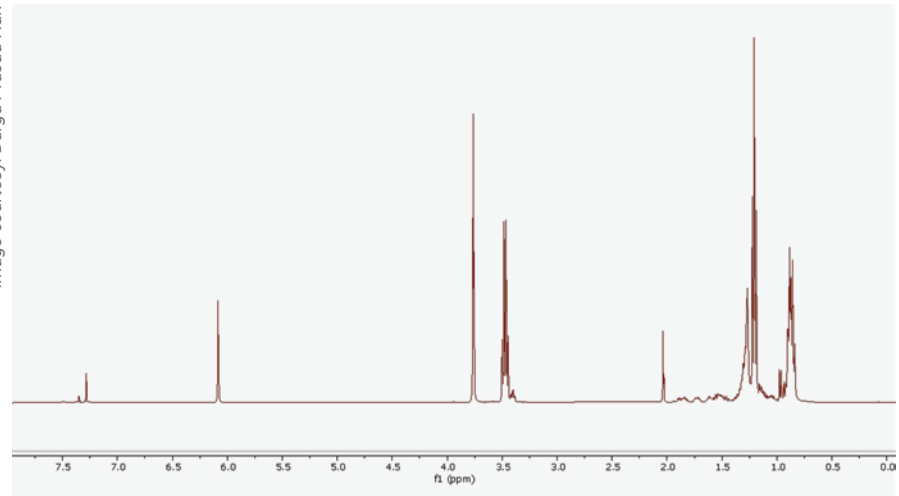
An indispensable tool

IISc has more than half a dozen NMR machines spread around the campus. The Chemical Sciences building houses four of them – two in the Department of Organic Chemistry, and two in the Department of Inorganic and Physical Chemistry. They look like something from a futuristic space settlement – sleek, cylindrical towers around three to four metres tall. Their huge magnets are kept cool using liquid helium and liquid nitrogen.

"There is, of course, a very strong magnetic field," says Hari. "We are advised to not go near the NMR with any metallic objects when we go to load the sample. But we don't stay there very long, so it's safe."

When the machine breaks down, a lot of work comes to a standstill. It is virtually impossible to move ahead in organic synthesis without getting a confirmatory NMR. This becomes a problem when your compound is unstable and may break down by the time you get the chance to run an NMR.

Image courtesy: Durga Prasad Hari



Proton NMR spectrum of propellane

There are dedicated technicians in the department who run the samples for the students. But Hari explains that the machine is straightforward to operate, and it is possible for one to analyse their own sample. "Sometimes, when we have exciting results [or an unstable molecule] and the technicians aren't there, I cannot wait for the next day. I always tell my students to give me the samples, and I run them on my own."

Hari's lab is working on a class of molecules called propellanes, which have three triangular rings of carbon atoms fused together, and look like a TV tower or a propeller. These are highly strained molecules – the angles between their bonds make them highly reactive. This reactivity can easily be harnessed to convert them into various other compounds. However, this also makes propellanes very unstable, and the NMR has to be checked immediately after separating the compound (which is done at -78°C). Even a slight delay may cause the molecule to degrade, Hari explains.

When patience pays off

Two minutes felt like two decades to Hari, but the NMR sample he put into the machine was finally done scanning. As he and his students analysed the data, their excitement grew.

The peaks in the NMR spectrum showed without doubt that they had successfully synthesised the propellane. "When you get the NMR data and it shows you the peaks you were hoping for, it's just like looking at your [exam] results in the10th grade!" Hari says.

Synthesising organic compounds is an incredibly long and tedious process, from setting up a chemical reaction to spending countless hours purifying and separating the compound of interest from an unknown mixture – which may not even have the compound! Researchers often have to carry out the same reaction again and again, varying different parameters like the amount of reactant, temperature and solvent, to figure out what works best. After weeks or even months of hard work, everything comes down to what the NMR analysis shows.

"The unsaid truth is that NMR invariably gives you a huge dopamine rush," explains Arbaaz.

Once, Arbaaz had been trying out a particular reaction for a very long time, but failing to get the right spectrum repeatedly. "The incorrect NMR broke my heart every day," he narrates. "Then I came across a new protocol for the reaction, and I got a beautiful NMR [spectrum] which matched perfectly. That's the thing – NMR may disappoint you initially, but once you get it, it's like you're on top of the world."

Arbaaz is now working on synthesising a new compound. Though he hasn't got the expected results even after 20 times, he doesn't plan on giving up. "Whatever happens," he says, "I'll keep working towards that NMR."

Parth Kumar is a second year BSc (Research) student at IISc and a science writing intern at the Office of Communications

Photo courtesy: Rohini Balakrishnan

Bias and Behaviour

- Vaibhav Sharma

Can animal studies be truly objective?

A representation of predator-prey interaction between bats and katydids

In the early 20th century, a horse in Berlin captured the world's attention with its mathematical proficiency. When asked an arithmetic question, Hans, the horse, would start tapping his hooves and stop when he arrived at the correct number. This remarkable feat elevated Hans' status to genius.

A psychologist named Oskar Pfungst, however, sought more than just a tacit acceptance of the horse's intellectual prowess. Through carefully crafted experiments, Pfungst proved that Hans was responding to subtle, microscopic cues from the face of the questionnaire. The hoof taps were in response to involuntary signs from the human. The "Clever Hans effect" thus was the result of human bias in the interpretation of animal behaviour.

Eliminating bias

There is an important lesson here – an acknowledgement that we need to observe animals objectively and avoid projecting human emotions or motivations on them. In the last century, considerable efforts have been made to design experiments that can eliminate the inherent bias of the researcher.

"We try to base our conclusions on observed behaviours rather than subjectively assumed mental states," says Rohini Balakrishnan, Professor at the Centre for Ecological Sciences (CES), who studies crickets and bats. She feels that even seemingly neutral terms can be misleading. "When we talk about an animal's behaviour as a strategy, it's easy to imagine the animal consciously evaluating its actions," she explains. "But in reality, we're just studying whether these actions lead to survival or reproductive success."

> ***In studying animal behaviour, anthropomorphism – attributing human qualities to animals – can be a significant challenge***

In studying animal behaviour, anthropomorphism – attributing human qualities to animals – can be a significant challenge.

"When humans and monkeys perform the same tasks, they often behave differently. These differences can easily be misinterpreted if we do not account for the species' unique ways of perceiving or making decisions," notes SP Arun, Professor at the Centre for Neuroscience (CNS) whose area of focus is visual perception in humans and monkeys.

On the field

Even in a carefully designed experiment, biases remain a persistent challenge, particularly in fieldwork where it is difficult to control the environmental and social variables. Rohini recalls a time when her team observed female crickets seemingly "rejecting" certain males during mate selection.

"We interpreted this behaviour as a rejection," she says, "but when my former student ran simulations, we realised that it could simply be a result of how the females localise sound in a complex acoustic environment where multiple male calls overlap and mix."

This discovery is a reminder of how our confirmation bias can colour the interpretation of animal behaviour, even when a simpler explanation may exist.

Photo courtesy: Saskya van Nouhuys

Saskya van Nouhuys (right) with a student in Finland, working on a behavioural experiment on a wasp that parasitises butterfly eggs

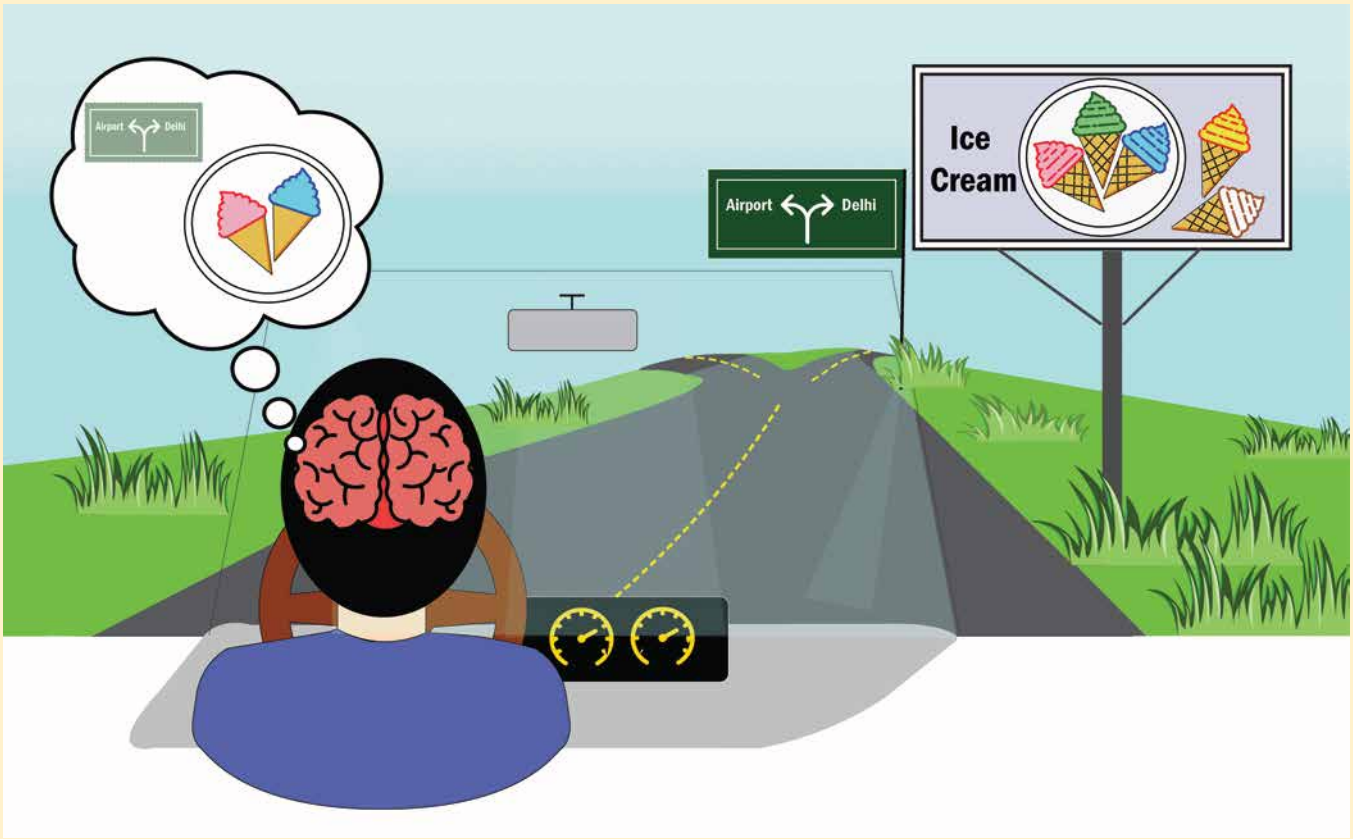


Image courtesy: Swagata Halder and Deepak Velgapuni Raya

An illustration of the attentional blink effect. On an unfamiliar road towards the airport, a driver's attention is caught by the ice cream advertisement, causing them to momentarily miss the directions sign i.e. focusing on one piece of information can lead to missing other information for a brief period

Saskya van Nouhuys, Associate Professor at CES, who studies wasps that parasitise other insects by laying eggs in them, recollects how bias can even shape the research trajectories. “We assumed that a wasp species, being large, parasitised butterfly caterpillars, but after years of failed experiments, I observed them parasitising the eggs instead,” she explains.

This observation was remarkable. The wasps were laying eggs inside the butterfly eggs. When these butterfly eggs hatched, the wasps developed inside the growing caterpillars and later emerged as adult wasps.

“The animal's size is such a good reference that nobody would even question it,” Saskya adds; this breakthrough was a result of simple observation of the natural environment.

Many field researchers spend a lot of time observing animals in their natural habitats to combat bias before designing experiments. “Before conducting field experiments, my students often spend entire seasons just watching the animals,” says Rohini. "That gives immense insights into which manipulations may work, and which might fail, increasing the chances of designing successful experiments."

Bias also influences the interpretation of data and results. At this stage, Saskya emphasises improving communication between her lab members. "Do not be shy about discussing data with people; it can be students, technicians, or other colleagues," she recommends. "And do not be too attached to your expectations."

> ***Our confirmation bias can colour the interpretation of animal behaviour, even when a simpler explanation may exist***

The roots of bias

Although cognitive biases may seem like a problem in studying animal behaviour, they are an inherent part of human existence, one with a deep evolutionary origin.

Sridharan Devarajan, Associate Professor at CNS, who studies attention and decision-making, believes that cognitive biases have an adaptive value. The constant deployment of attention to the external world requires significant cognitive effort. However, by relying on biases based on our past experience, our brain can optimise where and how much to pay attention to. For example, when driving on a familiar route, we may know that some junctions are less crowded than others; this allows us to bias our attention towards the busier junctions. This evolutionary perspective suggests that biases, such as expectation bias or pattern recognition, help animals navigate dangerous environments.

“That's likely why many of the prey animals move as herds because each animal can monitor some part of the environment and raise an alert if something happens there. Predatory animals are the opposite; they do not need to put their attention all over the place. They focus on exactly one out of a few areas because that's where the most vulnerable prey is, and they have to track and catch that one prey,” he informs.

Bias as a tool for interpretation

Not all researchers, however, see bias as a problem that needs to be eliminated. Anindya Sinha, a professor at the National Institute of Advanced Studies (NIAS), Bangalore studying primates in the wild, believes that our inherent biases are a crucial component in scientific thinking. The training of a researcher often defines the class of questions they prioritise. "If you are a geneticist, you could look at a problem in terms of gene function. If I were a biochemist, I could look at perhaps the chemistry of gene expression. And if I am an animal behaviour researcher, I would possibly look at the phenotype produced by these genes," Anindya explains. "Our biases, on their own, are value-neutral. So, it has to be decided contextually whether a certain bias is helping us in our science or taking away and obscuring what is out there."

Anindya advocates for reevaluating the approach towards studying animal behaviour. "There is a philosophical divide, represented by the natural and social sciences. When we say natural sciences, the laws of physics, mechanics, and mathematics come to mind. I think it has been a fundamental problem that we have used this philosophy of science, as encompassed by physics or mechanics, to colour our study of biology."

When we deal with individuals and societies, we cannot directly apply the laws of physics, chemistry, and mathematics, according to Anindya. These are complex systems, with a variety of factors impacting single behaviour.

"Whether a monkey will eat some fruit depends on a range of factors. These factors could be biological, such as age and gender. It can be ecological – are there competitors around? Even more importantly, it could be experiential factors, maybe the monkey did not like the taste of the fruit yesterday. All these come together and determine whether a monkey will eat a fruit or not."

> ***'All our views and assumptions are, in the end, our biases, revealing themselves'***

In such situations, interpretations depend on training, akin to the story of four blind men describing an elephant and doing so differently. While none are wrong, the explanations stem from their individual differences. "All our views and assumptions are, in the end, our biases, revealing themselves," says Anindya.

One's biases are an integral part of learning and understanding the world. Although one must seek to minimise their prejudice to gain an understanding of natural phenomena, there is a need to find a balance.

"You take away all the biases, all the interpretations go away as well," adds Anindya.

To study animals with complete objectivity has been an ideal pursued by many. However, biases do have a role in enriching scientific interpretations. "It is impossible to think of science, whether of animal behaviour or of anything, without factoring the biases which have helped us. As long as we recognise, expose, and clarify our biases, they can promote healthy scientific discourse," Anindya stresses.

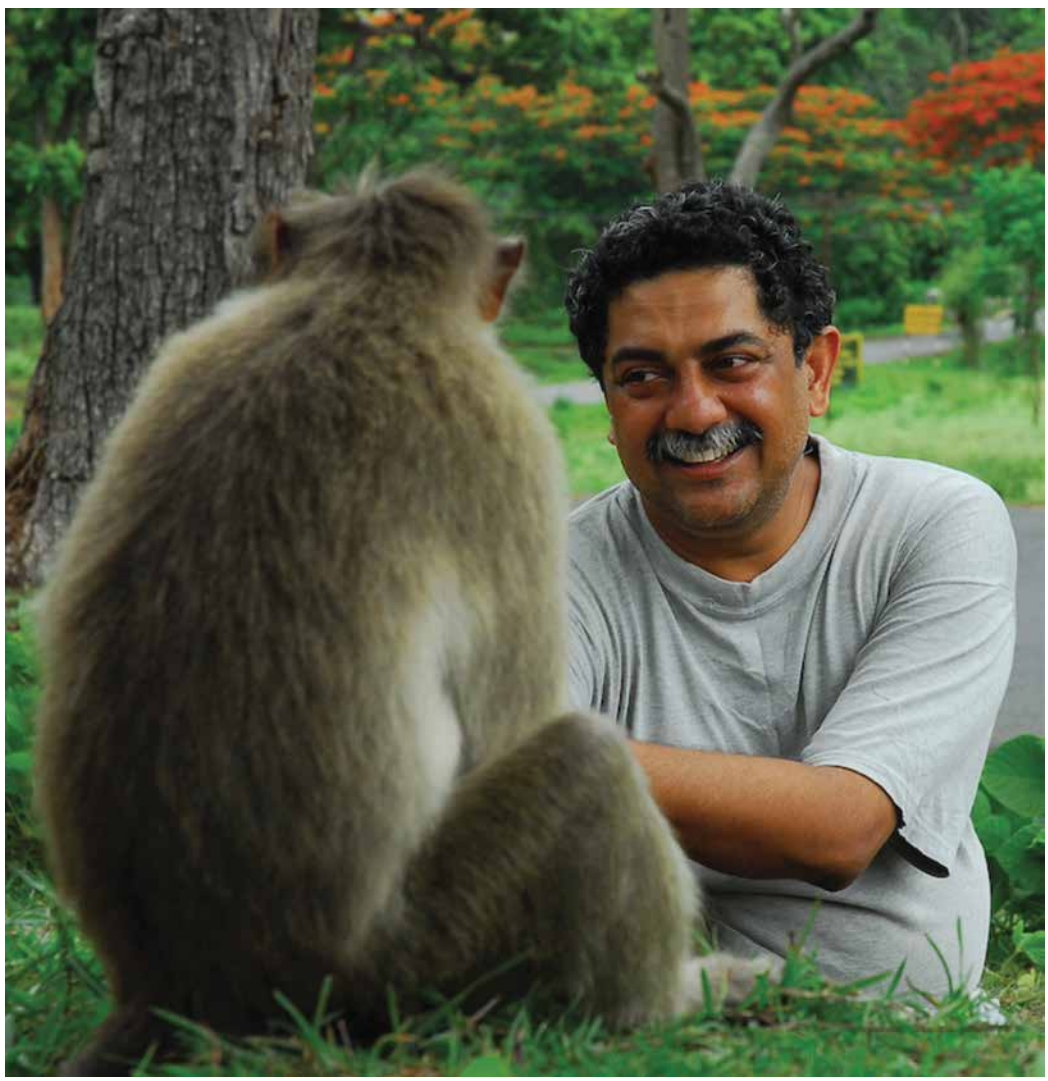


Photo courtesy: Anindya Sinha

Anindya Sinha at work at the Mudumalai Tiger Reserve in 2007

Vaibhav Sharma is an Integrated PhD student in the Department of Microbiology and Cell Biology, IISc and a science writing intern at the Office of Communications

The Great Indian GaN

- Ananthapathmanabhan MS

India needs the right technology and policy to realise a gallium nitride future

Photo: Ashutosh Vishwakarma

Two-inch GaN-on-silicon wafer with power transistors, developed at CeNSE, by Rijo Baby George, a PhD student of Digbijoy Nath, R Muralidharan and Srinivasan Raghavan

Harshada Ahire was caught off guard as she opened the door of the Power Electronics Laboratory in the Department of Electrical Engineering (EE) at IISc, as I stepped into the large room. I was with Vinod John, Professor at EE, and Utsab Kundu, an INSPIRE faculty fellow. Tables along the walls had wires of different colours connected to a screen displaying voltage.

At one of the tables, Harshada, an MTech student, was working on a green board with tiny multicoloured devices; some cylindrical, some spherical, and some that looked misshapen.

"Do you see that tiny black device?" Vinod asked, drawing my attention to a thin black square on the board. "That's it: the GaN [gallium nitride] transistor."

I had previously seen GaN wafers in an infant form, appearing with thin black lines on a lightweight circular disk, in the corridor of the clean room at the Centre for Nano Science and Engineering (CeNSE). Back in 2006, CeNSE served as ground zero for the growth of GaN research at IISc, says Srinivasan Raghavan, its Chair. Since then, several advances have been made in bringing GaN devices closer to reality.

Here and now in the Power Electronics lab, for example, there was a fully functional GaN transistor. Harshada was testing it.

Vinod pointed to another green slab nearby with a GaN transistor. It was assembled by an MTech student developing a power converter, which delivers voltage from a source to a device. The GaN transistor, he explains, makes the design compact while delivering power efficiently.

> ***Among semiconductors, GaN is gaining popularity as the solution to challenges that existing materials like silicon cannot tackle***

Among semiconductors, GaN is gaining popularity as the solution to challenges that existing materials like silicon cannot tackle, in power electronics like EV chargers or RF electronics used in 5G communications.

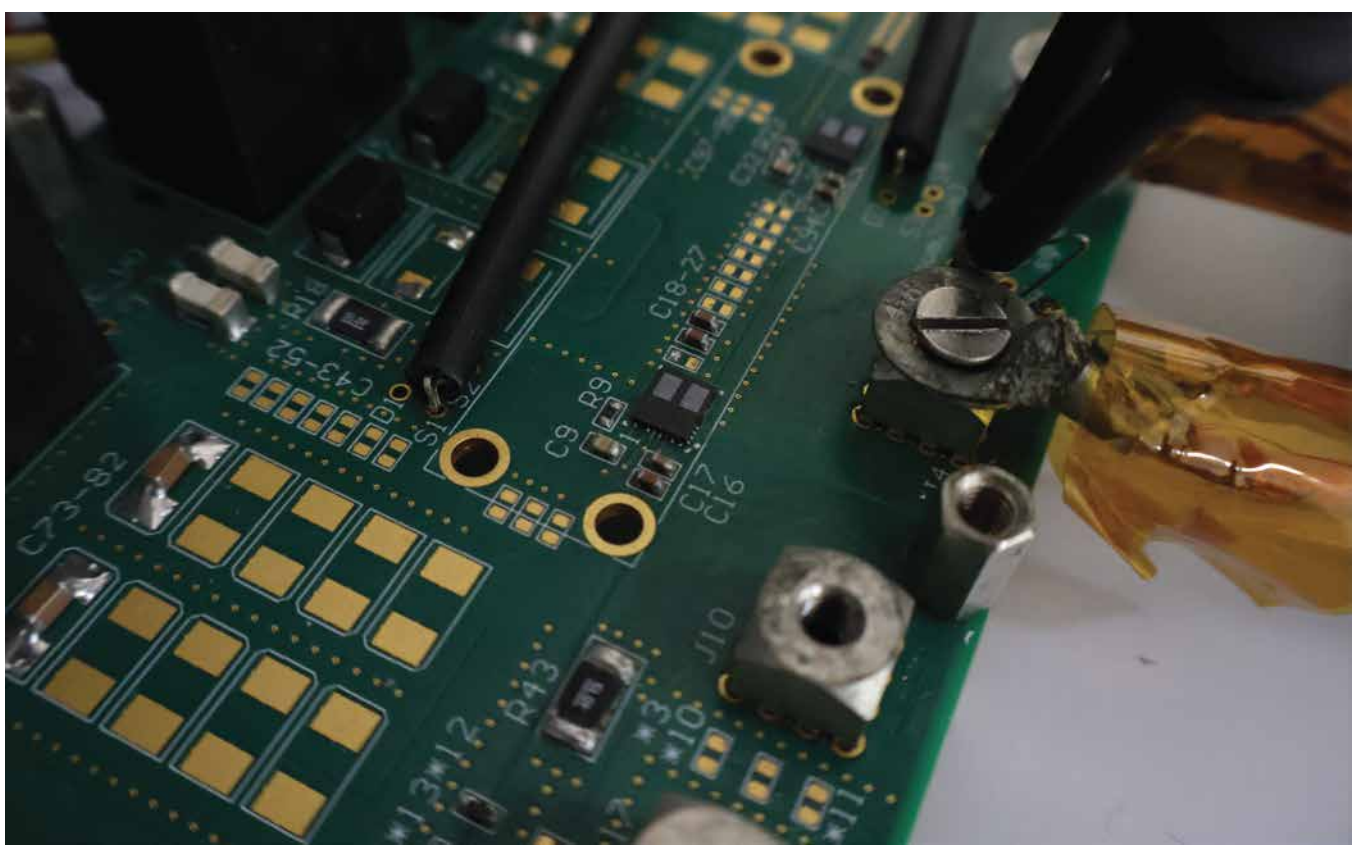
GaN has wide-ranging applications, from wireless communications to space and military applications such as radar.

Another advantage of GaN is its high temperature tolerance. For example, if one wanted to do geothermal experiments or sift through the scorching surface of planet Venus, GaN would be the material of choice, suggests a 2024 study published in *Applied Physics Letters*. "Conventional electronics or devices may not work [in harsh conditions]. We tested [GaN devices] in a simulated Venus environment," says Nitul Rajput, an experimental material scientist at the Technology Innovation Institute, UAE, who was part of this study.

"However, this [GaN] technology, like any other semiconductor technology, requires significant investment," says Mayank Srivastava, Professor at the Department of Electronic Systems Engineering (DESE), and co-founder of AGNIT Semiconductors Private Limited, a startup incubated inside the Gallium Nitride Ecosystem Enabling Centre and Incubator (GEECI), IISc.

Many scientists also believe that GaN cannot completely replace silicon. For example, low-cost computing

Photo: Ananthapathmanabhan MS



A GaN transistor (the black rectangular chip at the centre) on a power board

processors like the *Snapdragon* processors produced on a large scale will still require silicon. “GaN is not in that game," Vinod explains.

How GaN works

Conductors like metals offer very little resistance to the flow of electricity and insulators almost completely restrict it. But in semiconductors, electricity only flows under certain conditions. This makes them a better fit for delicate devices such as integrated circuits used in computers, which rely on countless transistors to function.

When a certain amount of energy is supplied, electrons from the lower energy level, or valence band, jump to the next energy level known as the conduction band. Scientists call this separation the ‘band gap’.

However, at higher temperatures, if the semiconductor produces a lot of free electrons, the semiconducting property is lost. "This will create a lot of free electrons, and it will act like a conductor," explains Digbijoy Nath, Associate Professor at CeNSE and co-founder of AGNIT Semiconductors.

> ***A wide bandgap semiconductor like GaN can withstand a very high electric field or voltage without breaking down***

The band gap is much lower in conventional semiconductors like silicon (1.12 eV), therefore, it takes much less energy for silicon to become a conductor. However, the band gap in gallium nitride (3.4 eV) is wide enough that even at temperatures as high as 500°C, the electrons are not tempted to sabotage the semiconductor nature. A wide bandgap semiconductor can withstand a very high electric field or voltage without breaking down, a property similar to an insulator.

“It's very interesting that in a material which is otherwise very insulating, you get a pool of electrons that have very high conductivity or very low resistivity,” explains Srinivasan. One of the pioneers of GaN research at IISc, he is also the lead founder of AGNIT, and the PI of the project that was tasked with setting up GEECI, which is India’s first low-volume GaN foundry outside of the strategic sector.

Srinivasan explains that in a specific state, GaN behaves like an insulator by resisting any flow of current, and when “switched on,” it will conduct electricity as smoothly as a conductor – a fascinating versatility which can be used for building devices for many applications.

For instance, in power electronics, engineers look for efficient ways to take power from sources such as big transformers and deliver it across household equipment. "We may have noticed the sizes [of chargers] are getting smaller. One of the reasons is GaN," says Srinivasan.

Conventional semiconductors have limitations when it comes to high-frequency communications, whereas GaN is ideal for this purpose. "At one point, it might have taken half an hour to one hour to download a movie. Now, when you go to these higher operating frequencies like in 5G, you can download a movie in 30 seconds," says Srinivasan. "That is where GaN RF electronics plays a role.”

The Making of GaN

Semiconductors are made either from pure elements – typically silicon or germanium – or compounds such as GaN.

GaN is fabricated by mixing compounds containing nitrogen and gallium using a method known as Metal Organic Chemical Vapour Deposition (MOCVD) carried out at high temperatures of 1,000°C or above, and pressures as low as 10 times less than atmospheric pressure at sea level. “This deposition is so complicated that the scientists who were involved in the first demonstration were given a Nobel prize,” says Srinivasan, who helped establish this capability in the clean room at CeNSE. “Without a consistent materials platform, establishing device and systems technology is impossible,” he adds.

While GaN transistors are not as small as other silicon-based chips, similar high-tech and high-precision machines are required to make them. It takes about 10 different types of machines and about seven days to make a single GaN device.

> ***It takes about 10 different types of machines and about seven days to make a single GaN device***

But building a GaN production centre requires not only the right technology but also a proper funding mechanism that drives production on a large scale, experts suggest. In addition, as is the case with any technology, realising a gallium nitride ecosystem needs good science that translates to market requirements

“Anything which is a capital intensive [effort], and returns are not immediate, is difficult to scale [up] in the country, particularly when the investor mindset is to invest in software, apps, Fintech and companies which can give faster returns with least investments,” says Mayank.

Eye for industry

In India, GaN production is still at the research scale.

This is because producing GaN devices in bulk to suit market needs is challenging. During testing, things can go wrong at many levels, and the number of devices that pass to the next stage gets smaller. For the industry, the dropout rates of new devices are a significant challenge. Thus, commercial fabrication requires huge capital investment.

Despite these financial constraints, some entrepreneurs have entered the fray. Among them is Hareesh Chandrasekar, the current CEO of AGNIT Semiconductors.

As part of his doctoral research in 2009, Hareesh set out to understand how the GaN surface interacts with that of silicon. "[Back then], people here [in IISc] were making small systems, power converters and so on at the Department of Electrical Engineering," Hareesh recollects. "We had a solid

research base with a strong foundation, so we thought about scaling up this technology."

Those foundations go back to 2009 when a large team of people, including Srinivasan and Navakanta Bhat, Professor at CeNSE and current Dean, Division of Interdisciplinary Sciences, decided to set up a GaN material platform, an endeavour that Hareesh was also roped into. Later, the team was joined by several others including Mayank, Digbijoy, R Muralidharan, Madhusudan Aatre and Shankar Kumar Selvaraja.

“After the material platform was established, we thought that we should start making devices, around 2014,” says Srinivasan.

A large team of people including G Narayanan, Vinod John, Mayank, Digbijoy, Muralidharan, KN Bhat, MM Nayak, Navakanta Bhat and Srinivasan demonstrated India’s first depletion mode GaN power transistor, iGaN540 and its switching in a DC-DC convertor. This iGaN540 effort nucleated the materials to devices to systems GaN power technology platform in IISc. In 2020, Mayank and his team demonstrated India’s first GaN-based e-mode High Electron Mobility Transistor (HEMT) for power applications. In 2023, Digbijoy and Kaushik Basu from EE collaborated on developing yet another depletion-mode technology and its incorporation in a DC-DC convertor for switching, the kind that will be used in electric vehicle battery chargers. Similar efforts coordinated by Digbijoy are in the RF front, on devices used for 5G and radars.

Amidst these efforts, work was also in progress to set up a GaN foundry. “In 2015, one evening, Navakant and I were sitting in the office chatting about this. We thought, ‘Why can't we set up a GaN foundry instead of a silicon foundry?’”

recalls Srinivasan. “Although a niche technology, setting up a GaN fabrication lab is easier compared to setting up a silicon one as you don't need a large volume to be profitable.”

> ***GEECI is now a semiconductor wafer and device production facility for GaN-based applications***

In 2016, the team worked for nearly six months to draft and submit a Rs 2,000-3,000 crore project report to the Government of India for setting up a GaN large-volume production facility. In 2021, the government sanctioned Rs 300 crores to set up GEECI, a low-volume production facility at IISc.

GEECI is now a semiconductor wafer and device production facility for GaN-based applications.

Photo courtesy: Tanuja Goyal

GaN device samples being loaded onto a microscope at GEECI

GEECI's efforts are aimed at developing commercially relevant power devices for applications in fast chargers and miniaturised power electronics.

Vinod feels that efforts should be made to ensure that the technology goes beyond the academic setting and into the market, where good business and a cost-efficient industry will help meet consumer needs.

For a start-up like AGNIT to succeed, Hareesh and Mayank assert that the devices built should be customised to have their own Unique Selling Proposition and must beat existing price points.

To support indigenous development of semiconductors like GaN, the Government of India has drafted a "comprehensive programme for the development of semiconductors and display manufacturing ecosystem … with an outlay of Rs 76,000 crore," according to the Ministry of Electronics and Information technology (MeitY). But Mayank believes that more than subsidy programmes, the government needs to also put in place a comprehensive policy and plan.

P for Policy

"In India we don't have strong semiconductor R&D programmes, and what we see is a pinch of salt compared to the rest of the world," Mayank says.

A GaN-centric policy should ensure strong industry-academia engagement, where academia work on industry-relevant problems and industry must have a vision for the next 10-15 years driving futuristic research through academia and well-funded academic programmes, he elaborates.

According to Chris Miller, author of the book *Chip* Wars, most low- and middle-income countries do not play a role in the chip industry. "[But] India is different because of its vast base of chip designers. Today, India is one of the leading countries measured by the number of engineers engaged in semiconductor design," he opines.

While government subsidies can support building a fabrication facility, it will take longer for companies to see profits, according to Pranay Kotasthane, who co-authored the book *When The Chips Are Down* along with Abhiram Manchi.

Photo courtesy: Tanuja Goyal

GaN devices being inspected using optical microscopy at GEECI

> ***There is a need to secure intellectual property rights for semiconductor designs***

"[This] might lead to the fab being uneconomical and the government will again have to give another round of subsidy to sustain it. This will be a lot of government money driving it rather than customers driving that market. The government can consider getting engineers to develop semiconductor devices. That does not require much money," Pranay points out.

Avinash Koli, a technology policy researcher, feels that there is a need to secure intellectual property rights for semiconductor designs. Reports suggest that India has lower domestic control of patents, unlike countries like China.

The return on the investment for a semiconductor fab is also not guaranteed in the short term. This pushes back investors in India, thus making the GaN industry rely mainly on government funding.

For GaN to become the great Indian GaN, it is becoming increasingly clear that there is not only a need for extending industry-academia collaborations, but also developing indigenous IP, all of which require serious investments.

The Industrious Immunologist

- Ranjini Raghunath

Photo: BioTecNika

GP Talwar blazed trails in indigenous vaccine development

Gursaran Pran Talwar speaking at IMMUNOCON held at IISc in October 2024

In October 1994, Gursaran Pran Talwar was in a fix. He had only a month to leave the National Institute of Immunology (NII), an organisation that he had built from the ground up, as his tenure was coming to an end. But his work on developing what might become the world's first female contraceptive vaccine was just gathering steam.

A few months earlier, Talwar and colleagues had published a landmark study in the *Proceedings of the National Academy of Sciences*, showing how their vaccine prevented pregnancy in all but one of 148 women enrolled in a Phase II clinical trial. The vaccine triggered the production of antibodies against the human chorionic gonadotropin (hCG) hormone, which is critical for embryo implantation. It was expected to be safe since hCG is produced naturally by the body, and no major side-effects were seen in earlier trials.

But their success was swiftly followed by criticism. Some scientists accused the team of rushing to carry out clinical trials without sufficient animal studies. Women's groups questioned whether participants were fully informed about the potential risks of such an experimental strategy. Concerns were raised about whether the vaccine could cause infertility.

It wasn't the first battle that Talwar had fought over a vaccine. Decades earlier, he had led the development of India's first leprosy vaccine at the All India Institute of Medical Sciences (AIIMS). Not only had he competed against two other groups developing similar vaccines, but one of the competitors even claimed that the bacterial strain used for Talwar's vaccine was identical to his.

"If someone works well, there is a reaction against them," Talwar says, with a shrug. The 98 year-old had visited IISc in October this year to attend IMMUNOCON, an annual conference organised by the Indian Immunology Society. "I ignored unsubstantiated aspertions, all of it," he continues. "If I am convinced that I am doing the right thing, and good science is practiced, why should I worry?"

From Lahore to Delhi

Born in Hissar (now part of Haryana) in October 1926 and growing up in Lahore, Talwar recounts having a difficult childhood. Although he was interested in medicine, at his father's urging, he pursued a BSc (Honours) in chemistry and a Master's in chemical engineering. He loved rowing – he would ride his bicycle every morning to rowing practice. "I became captain of the college team. We won all the trophies," he recalls, smiling.

Partition forced him to flee to India – he finished his final year exams in a migrant camp in Delhi in 1948. Two years later, he secured a scholarship to pursue higher studies in Europe. "I chose France because I had a leftist inclination … *liberté, égalité, fraternité,*" he elaborates.

Photo courtesy: Talwar Research Foundation

GP Talwar with the Harper-Nelson trophy awarded when he was captain of the rowing team in Government College, Lahore

At the Institut Pasteur in Paris, he studied fermentation technology, assigned to a division that maintained yeast strains used to make champagnes. "The first time that I tasted champagne, I wondered why it was so special. It had no taste. I was not interested," he recalls. He was then transferred to the biochemistry division, where he got to work with Nobel laureate Jacques Monod. After completing a DSc degree, he pursued a postdoc in Germany under a Humboldt fellowship.

In 1956, Talwar came across a pamphlet advertising the launch of the first AIIMS in Delhi, and applied for a faculty position. "I did not expect that I would get selected," he says. "To my surprise, I was offered an associate professorship of biochemistry. I was the second faculty member to join."

Talwar's first few years at AIIMS flew by in overseeing whatever was required to raise the fledgling institute – from setting up laboratories to teaching biochemistry. "Biochemistry in most medical institutions was then a part of physiology. Its teaching was boring and minimal … My job was not only to introduce a contemporary, interesting, and exciting course in biochemistry for students … but also to educate my faculty colleagues on what modern biochemistry offered for their disciplines," he writes in a 2005 perspective in the *Journal of Biosciences*. He was also enjoying his research on growth hormones.

It wasn't until 1970 that Talwar started thinking about vaccines. That year, an international WHO contingent visited AIIMS and urged Talwar to lead a Regional Training Centre, to tackle the growing burden of leprosy in India. Talwar was reluctant because he had no clue about the disease. The team then asked: With India having the highest number of leprosy cases in the world, shouldn't Indian scientists, rather than Americans, work on this problem? Talwar agreed. "It took me in a different direction," he says. "I had to work for a cause."

Sparring with a scourge

Leprosy is an ugly disease, Talwar points out. Caused by *Mycobacterium leprae*, it affects the nerves, throat, skin, and eyes of patients, leaving them disfigured and disabled. Talwar and colleagues focused on identifying what was happening in multibacillary patients – those who develop a large number of skin lesions. They found that immune cells called lymphocytes were not getting activated in response to *M. leprae*, which prevented the cells from identifying certain components of the bacterium and mounting an immune response.

Talwar then wondered if a vaccine could trigger this activation. *M. leprae* was not a useful vaccine candidate because it does not grow in a lab dish, and does not trigger an immune response in such patients anyway. His team, therefore, turned to a close relative – a harmless, fast-growing bacterium called *Mycobacterium w.* Its genome sequence was determined and thereafter it was renamed *Mycobacterium indicus pranii* (MIP).

Clinical trials – including a large-scale trial among four lakh patients and healthy household contacts in Uttar Pradesh under the National Leprosy Control Programme – showed that combining MIP with standard multi-drug therapy (MDT) cleared *M. leprae* much faster, cutting down the treatment time by months. It also protected healthy family members of the patient from getting the disease.

Image: Taru Verma, DpN lab, IISc

Atomic Force Microscopic image of Mycobacterium indicus pranii (MIP)

> ***The leprosy vaccine's effects were found to persist for at least six years after the first dose***

The vaccine's effects were found to persist for at least six years after the first dose. It became the first indigenous leprosy vaccine to get approval from both the Drugs Controller General of India and the US Food and Drug Administration. Cadila Pharmaceuticals bought the licence for MIP and started selling it under the name "Immuvac".

The WHO declared India leprosy-free in 2005. "The stigma hasn't reduced," Talwar points out. "[Though] we've reduced the number of leprosy cases, the disease is not eradicated."

Contraceptives and construction

Like leprosy, Talwar's work on the contraceptive vaccine was spurred by a social problem.

In the early 1970s, he would travel frequently to Banaras Hindu University for their Governing Council meetings in Varanasi. On a walk around the city, he came across impoverished women looking "thin as rods" who shared their woes of having more children than they could afford to feed. "I asked them: 'Family planning *kyun nahi karte [why don't you go for family planning]?'* They replied: 'None of the options suits us.'"

Talwar realised that there was a need for a contraceptive that would not cause harmful side-effects like bleeding and delayed menstrual cycles. His team zeroed in on hCG, a glycoprotein that has two components called alpha and beta subunits. They took the beta subunit and fused it to the tetanus toxin to boost the production of antibodies. The first clinical trials showed that it could trigger anti-hCG antibodies in women. A follow-up study in four countries supported by the Population Council, an international nonprofit, confirmed that the vaccine was safe and effective.

In subsequent studies, the team linked beta hCG to the alpha subunit of ovine

Photo courtesy: Talwar Research Foundation

GP Talwar (second from right) with Prime Minister Indira Gandhi (left) in August 1980

luteinising hormone (oLH), which produced higher titres of antibodies. In the 1994 study, out of 1,224 cycles tracked, only one pregnancy happened. The effects were reversible, Talwar says. If the women did not take a booster dose for about three months, they could conceive again and bear normal children.

By this time, Talwar had also become keen on promoting immunology in India. As a Jawaharlal Nehru Fellow, he met with Prime Minister Indira Gandhi, and made a case for the subject, pointing to how immunisations had lowered child mortality. "I remember having written the proposal for a 'Centre for Immunology' during a transatlantic flight, helped by lavish servings of champagne and caviar," he writes in the perspective. The National Institute of Immunology (NII) was born out of this proposal, and inaugurated on 6 October 1986.

Talwar spent the next few years building the institute on a slice of land filled with "rocks and ravines" in the Jawaharlal Nehru University campus. "In less than three years, the main central building, auditorium, experimental animal house, primate facility, hostel for post-graduates, and 20 residences for faculty were built and made functional," he writes. "This may well be the fastest pace at which a composite research institute has been built, nationally or internationally, without compromising on quality of facilities, or scientific potential."

> ***Talwar realised that there was a need for a contraceptive that would not cause harmful side-effects***

Talwar insisted that NII should be a residential campus. "There was no public transport available at that time, in that area," he explains. He also wanted NII to become a "multidisciplinary institute" that would promote intense "inter-laboratory collaborations for taking a research lead to a potential product." He was keen that the institute should attract talented Indian scientists working abroad. NII, thus, became a focal centre for immunology in the country.

"Dr Talwar has brought up an entire generation of Indian immunologists," Soumya Swaminathan, former Director-General of ICMR and former Chief Scientist at WHO, once told the *Indian Express*. "Most directors at immunology institutes in India today were either taught by him or mentored by him. He is the father of Indian Immunology."

Rising to challenges

At IMMUNOCON, former IISc Director G Padmanaban quipped to the audience that Talwar had been aptly named ("sword") because he had been fighting all his life.

Talwar's mother died when he was eight days old and life with his stepmother was not easy, he says. When partition split the country, he fled with the clothes on his back and took shelter in a friend's house, before reuniting with his father in India.

"My work in leprosy and also on the beta hCG vaccine faced innumerable hurdles," Talwar writes. A rival group at the Cancer Research Institute in

Photo courtesy: Talwar Research Foundation

GP Talwar (centre) with JRD Tata (right) and S Ramachandran, Secretary of the Department of Biotechnology (left), at the then newly established National Institute of Immunology

Bombay accused him of using their bacterial strain for his vaccine. Talwar countered that MIP was unique. He and his colleagues also published a detailed genetic analysis, differentiating it from 30 other species of *Mycobacteria*.

> ***'My work in leprosy and also on the beta hCG vaccine faced innumerable hurdles'***

As for the anti-hCG vaccine, the WHO declined to fund Talwar and backed a rival vaccine being developed by scientist Vernon Stevens at Ohio State University. The Department of Biotechnology in India also cut its funding for the vaccine, and downgraded it from a high-priority mission to a regular research project.

Debates about the ethics of such a vaccine also delayed its development. Contraception and conception were and continue to be sensitive issues linked to strong religious and cultural beliefs.

"Vaccine development is a long process. Procedures, procedures, procedures. *Itni permission leni padti hai [so many approvals are needed],*" Talwar rues. "You have to have not only the insight but also the capacity to see it through."

When Talwar left NII, a friend identified a position at the nearby International Centre for Genetic Engineering and Biotechnology where he could continue his research. By then, he had also secured a grant from the Rockefeller Institute in the USA to continue his work on the anti-hCG vaccine at his own research foundation in Delhi.

Talwar's team recently started testing a combination of MIP and a new version of their anti-hCG vaccine, a genetically engineered recombinant containing the beta subunit of hCG linked to the heat-labile enterotoxin of *E. coli* (LTB), for contraception. Clinical trials, supported by ICMR, were stalled when some women developed nodules at the injection site. The team found a workaround – if the combination is given intramuscularly, no nodules were formed. He is now hopeful that the clinical trials will continue, once sufficient vaccine numbers can be manufactured for the trials.

Talwar just celebrated his 98th birthday on 2 October this year. "I [still] go to the lab every day, and my aim is timely completion of trials," he says. His team is also working on immunotherapy for advanced-stage, difficult-to-treat cancers which express hCG ectopically (on the cell surface).

"I think the going is not bad," Talwar adds, with a smile. "The mission of completion of trials and conveyance of benefits to users within my lifetime is what I strive for."

Photo: BioTecNika

Talwar (right) with his son Pratap Talwar (left) at IMMUNOCON