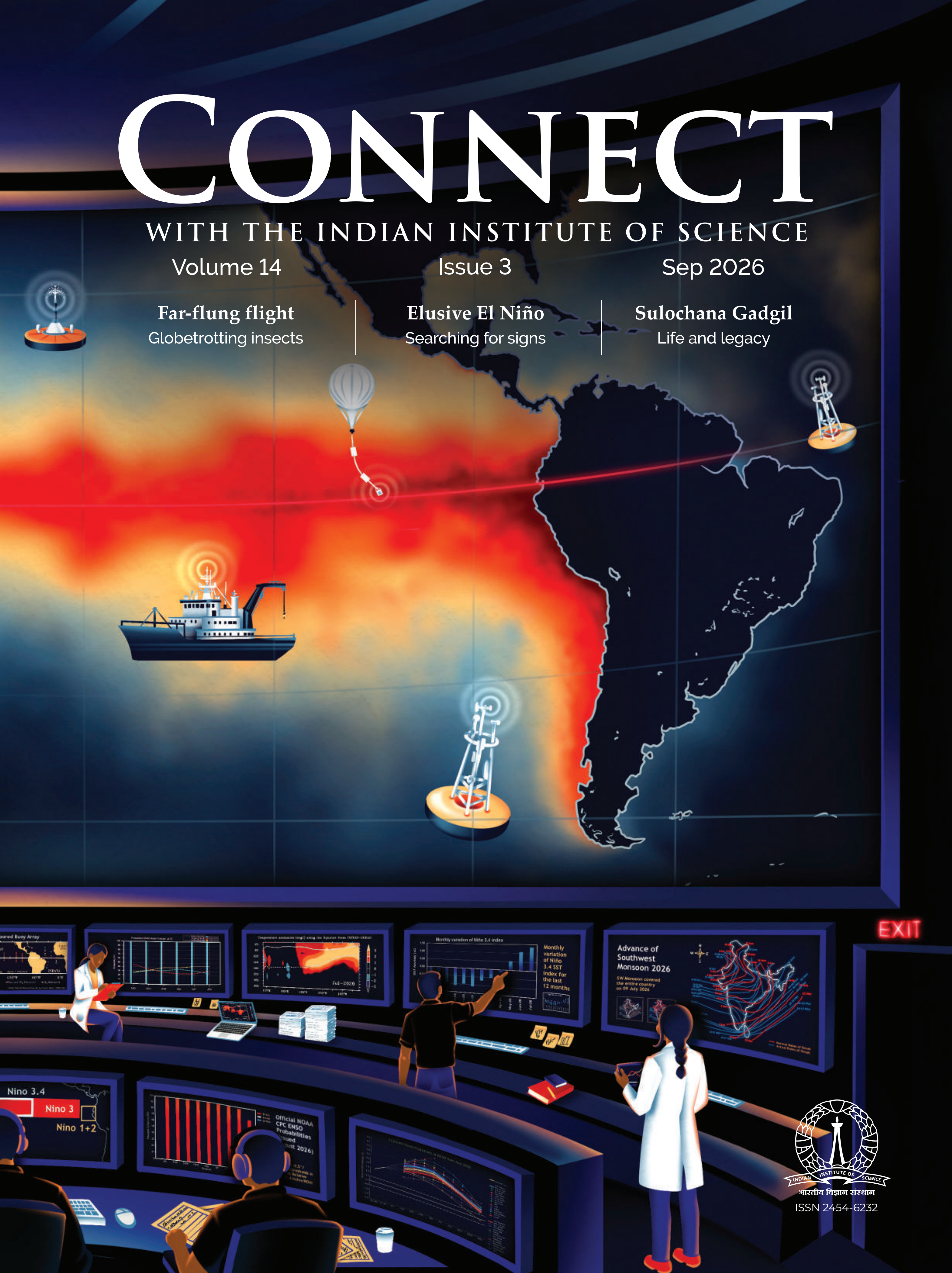

CONNECT

WITH THE INDIAN INSTITUTE OF SCIENCE

Volume 14 Issue 3 Sep 2026

Far-flung flight
Globetrotting insects

Elusive El Niño
Searching for signs

Sulochana Gadgil
Life and legacy

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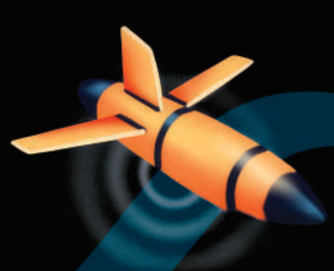
In This Issue



EDITORIAL

Dear readers,

For the last few weeks, we've been seeing ominous world maps with a sinister red blob on the news. They herald the El Niño event this year, predicted to be "supersized" and "record-shattering". Why is El Niño such an elusive entity, and how can we better predict its arrival and aftereffects? Our cover story traces the century-long history of how scientists learned to read the signs, and what challenges still hamper early prediction.

In other stories, we explore the extraordinary journeys taken by insects across the globe, the brilliant structural colours found in nature, and the techniques that help make industrial chemical processes more sustainable.

On campus, we examined how third spaces are crucial for unlocking new scientific perspectives, and asked students about their favourite monsoon memories. A student gives us a peek into the shenanigans in UG labs, while another spotlights how research was done before the advent of computers.

This issue features two interviews – one with Professor Emeritus Gautam R Desiraju, a pioneer in crystal engineering, and another with KG Haridasan, a former staff member and the Institute's go-to photographer. We also revisited the life and legacy of Sulochana Gadgil, a pioneer of monsoon studies in India.

As always, don't miss our crossword and a fun task on the last page.

Happy reading!

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Inside UG Labs

- Manauv Vyas

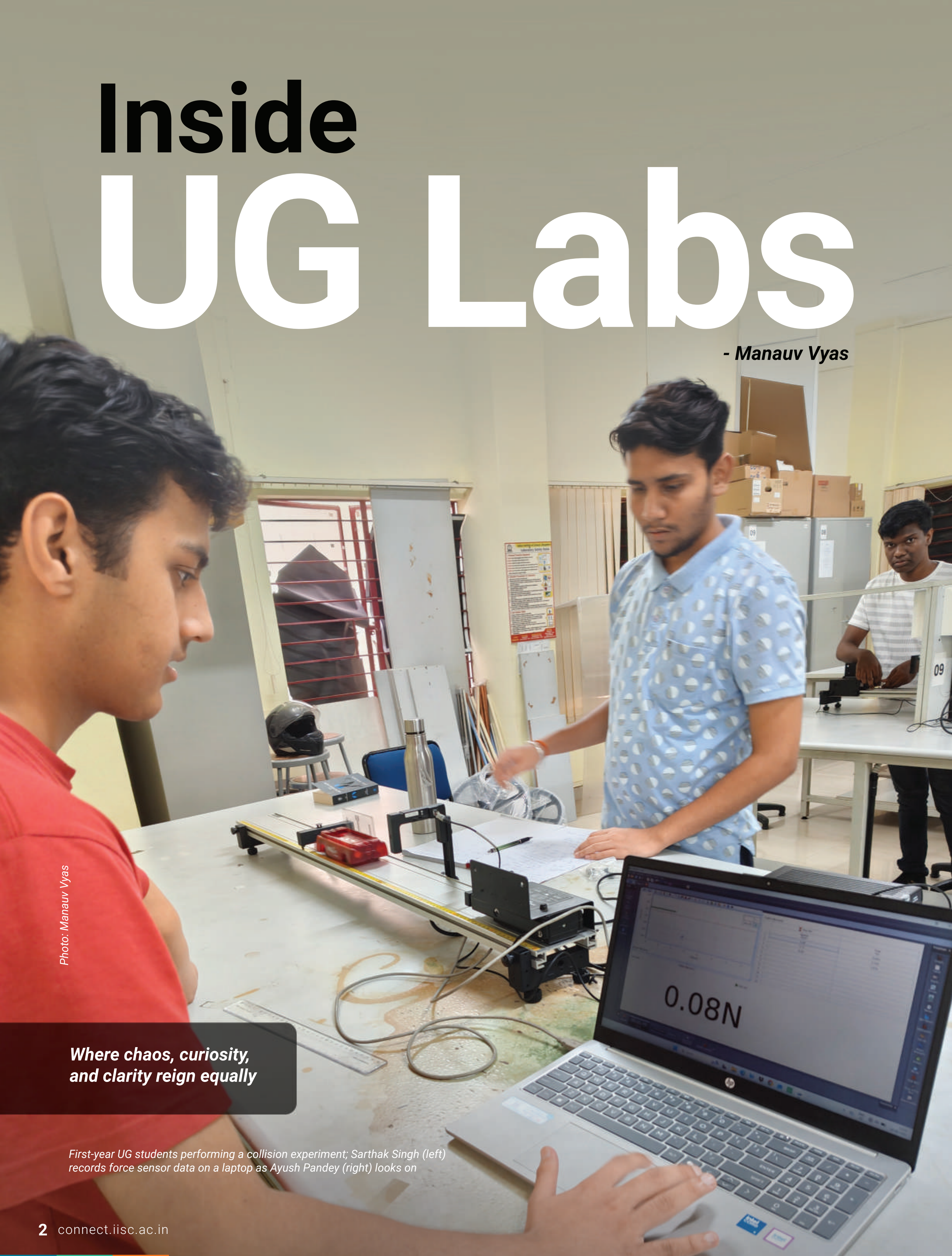


Photo: Manauv Vyas

Where chaos, curiosity, and clarity reign equally

First-year UG students performing a collision experiment; Sarthak Singh (left) records force sensor data on a laptop as Ayush Pandey (right) looks on

Amrit Mahendra Joseph still gets a faraway look in his eyes when you bring up his first-year undergraduate physics lab at IISc. The former UG student, who just completed his Master's in mathematics, laughs about it now, but back then, an incident involving the impulse-momentum theorem felt like physical torture. On paper, the experiment is straightforward: measure the impulse imparted when a moving cart collides with a bumper using two different methods, which should yield identical results. The first method uses a high-precision photogate sensor to track the cart's change in momentum – simple mass multiplied by velocity. The second calculates the area under a force-time graph, captured by a force sensor embedded right in the bumper to measure the impact during those fleeting milliseconds of collision.

The physics was simple. The math was clean. But experiments aren't done on paper. They are performed in the chaotic reality of a lab. And for Amrit, that reality was about to unravel.

He simply could not fathom what was going wrong. He restarted the photogate and the force sensors, replaced the cart and the bumper, and repeatedly rechecked his units and decimal points. Yet, no matter what he did, the two methods simply refused to align. They weren't just slightly off; they were in entirely different dimensions! The error margin? A staggering 2000%.

Amrit left no stone unturned. But after four failed attempts to minimise the discrepancy, he ultimately threw in the towel. He summoned the lab instructor and declared that the apparatus was either broken or had woken up and chosen to rebel against the laws of physics. The instructor, with years of experience fixing broken experiments and tutoring clueless students, calmly walked over to Amrit's station to show him how it was done. Amrit stood by, hopelessly torn. Should he pray for the apparatus to magically work so he could finally get the data and be done with it? Or should he pray for it to fail again, vindicating his claim and proving that he was not the one at fault?

Amrit isn't the only student with an embarrassing anecdote from the UG labs. Contrary to popular belief, we all have a lot of silly stories to tell – of spilled chemicals, forged data points (shh!), and downright instrument betrayal. While textbooks present science as a series of inevitable triumphs, the truth is that experimental science is less about the 'Eureka!' moment and more about the journey of getting there. The chasm between the blackboard and the bench is far wider than we initially imagine – and labs are where we realise this.

Contrary to popular belief, we [UG students] all have a lot of silly stories to tell – of spilled chemicals, forged data points (shh!), and downright instrument betrayal

In a physics lab, even a standard falling-body problem refuses to follow the textbook script – air resistance inevitably gatecrashes the party. Any veteran chemist would tell you how restricting the formation of unwanted side products is often more troublesome than making the main products. As for biological cells in a culture, I can personally vouch for this: the weather and the economy are not nearly as volatile as the moods of these microscopic Petri plate princes. After a point, one needs to accept that trying and failing is the norm. What really matters is whether you have the grit to pick yourself up again to repeat the cycle. Again and again. In fact, success is accidental – when you do claim to have succeeded, lab instructors and teaching assistants (TAs) tend to look at you with more scepticism and suspicion than a convicted criminal.

A (curve) fitting example

The ultimate test of this grit arrived once during our first year physics lab end-semester exams. We had been promised experiments that resemble the ones we had already done, but with slight variations. What we weren't told was the scale of those variations.

My assigned task was to calculate the coefficient of friction between a cart and an inclined plane. Besides these two, I was given a stopwatch, a bunch of different weights, and an inclinometer (to measure the angle of inclination). The instructions were deceptively simple: vary the angle of the incline three times, repeat the process with different weights added to the cart, and compile the data into two linear graphs whose slopes would directly yield the coefficient of friction.

With a couple of free-body diagrams and some algebra, it sounds fairly straightforward, doesn't it? I thought so too – until I realised the catch: *Which exact quantities was I supposed to plot?* Deciding to defer this crisis to later, I focused on getting the readings

Photo: Manauv Vyas

First year UG student Advay Javali (right) launches a ballistic pendulum, whose bob has a rotary motion sensor to track its angular position and velocity. The data is recorded on a laptop operated by Aditya Kumar (left), another first-year UG student. The experiment is meant to verify the conservation of angular momentum first. However, that proved to be a herculean task in its own right.

I found myself staring blankly at the apparatus, struggling to figure out which part plugged into where, let alone knowing how to coax a coherent reading out of it. Following a protracted (and entirely futile) battle trying to fit the inclinometer into place, I turned to my trusty protractor to save the day. While we *had* worked on determining the coefficient of friction as part of our curriculum, we had used sophisticated tracking software then. Thus, this avatar of the experiment was entirely unfamiliar and more like bumping into a long-lost childhood friend 20 years later, only remembering their name and nothing else.

As if things weren't bad enough, the PhD TAs make sure to personally pop up at your table every 15 minutes – not so much to help you as to remind you exactly how far behind you are. "You should have finished setting up your apparatus by now!" When you finally crack and ask, "What am I doing wrong?" they don't answer directly. Instead, they give you a smile – a kind, pitying smile that is best translated to: "Everything, my boy!"

In the end, after much head-scratching, I managed to come up with a monstrous, ugly-looking expression (both on the sheet and on my face) combining various quantities, which, miraculously, did yield a linear graph. Was it the right answer? For the sake of my mental well-being, I chose to never find out.

A tale of two reagents

As we transition from the controlled chaos of UG labs into the mayhem of actual research, we realise that these failures were in fact the clichéd stepping stones in our journey as scientists. If you obtain an otherworldly error margin, you can at least turn to the instructor in the UG lab. But in the real world, the guidance vanishes. You chart your own course. In these moments, patience is key. The wait can be agonisingly long, and the light at the end of the tunnel may at times seem a distant dream. But when your efforts finally bear fruit, the satisfaction is unparalleled.

Speaking of long waits bearing fruit, the biology lab deserves a special mention. The queue for the microscope is sometimes second only to the queue outside our messes when special lunch is served. During one such wait, the curious alchemist in me was suddenly intrigued when I saw nearly full bottles of ethanol and acetic acid on the lab shelves. There they stood; poor things, I thought, crying for their contents to be used. As I waited in the queue, I could empathise with their imagined identity crisis. You see, I believe that the sole purpose of a chemical reagent is to sign off from this world with a flourish. Unfortunately for the two liquids, their day of chemical glory did not seem on the cards, rather, an anticlimactic death by expiration was looming large.

With this deep emotional understanding (and an equal measure of boredom), I made up my mind to help them. I would give them the meaning their lives deserved.

My messing around had literally borne fruity-smelling compounds!

I discreetly took a few drops of both, mixed them together and warmed it slightly, like I had read in class (sulphuric acid – a catalyst for the reaction – was not to be found anywhere, unfortunately). Slowly but surely a faint, unmistakable scent began to waft from the beaker. An ester – a class of chemicals with fruity aromas – had formed. My messing around had literally borne fruity-smelling compounds!

In fact, our instructors encourage such inquisitiveness. Eswara Rao Tatta, the biology lab instructor, explains that the enthusiasm to try out things beyond our stipulated experiments is what will shape us into better scientists. "We might overlook or take certain aspects for granted, but when a student questions us about it, it makes us wonder too," says Tyby Monachan, TA in the physics lab. "I have learnt many new things in that manner, just by interacting with students, and while correcting their lab reports."

One of the most daunting tasks for instructors is ensuring that lab work stays synchronised with the fast-moving frontiers of modern science. Mamata Mahato and Siddharta De, the chemistry lab instructors, say that they often try to weave contemporary breakthroughs into the curriculum.

"[For example], the 2025 Nobel Prize in Chemistry was awarded for the synthesis of a new class of molecules called metal-organic frameworks. Inspired by it, we added an experiment on the facile synthesis of a simple

Photo: Manauv Vyas

Second-year UG student Divyansh Arora (left) operating a Rotavapor under the supervision of TA Akshata Raveendra Hegde (right). A Rotavapor is used to evaporate volatile organic solvents at much lower temperatures by lowering the pressure in the flask, to isolate pure compounds dissolved in the solvent metal-organic framework (ZIF-8) to our curriculum. We also demonstrate its use in adsorbing methyl blue dye from water," Mamata explains.

These metal-organic frameworks (MOFs) are more than mere academic curiosities; they hold immense potential for tackling global crises from carbon capture and harvesting water from desert air to storing toxic gases and driving chemical catalysis.

The TAs also view their roles as extending beyond just technical guidance and grading. Ariakutty CS, a Physics lab TA, sees her role as a facilitator, ensuring that no student gets left behind and everyone gets to experience all the experiments firsthand. In the biology lab, TAs Asiya Rehman and Uma N often strike up casual conversations with us. They provide a steady, reassuring presence that every undergrad fresher needs, because it is the first time away from home for most of us.

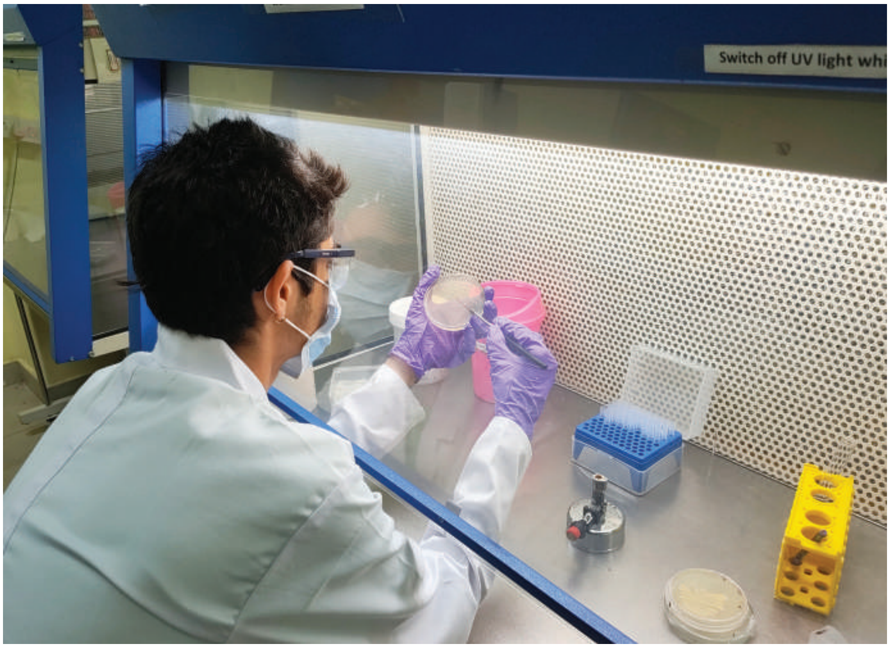


Photo: Manauv Vyas

Kireeti Chanduri, a first-year UG student, streaking E. coli *on a Petri dish in a Laminar Air Flow cabinet*

Been there, done that

Of course, we cannot talk about UG labs without mentioning the delicate art of value manipulation. We've all been there during a chemistry titration – your first reading was 10.1 ml, your second a solid 10.2, and then disaster strikes. On the third run, you cruise up to 10.1, and then 10.2, and 10.3 as well. And that stubborn tint of $KMnO_4$ remains in the pink of its health, refusing to disappear. By the time the colour vanishes, the burette reads a soul-crushing 10.7 ml. Glancing around, you see your friends already packing up to head out for evening snacks. This creates a moral dilemma: do you repeat the titration chasing a legitimate third reading, or do you choose freedom?

Naturally, you choose freedom. With the meniscus sitting defiantly at 10.7, you wait for the TAs to get engrossed in a deep discussion with a nearby student. Then, you seize the moment. Stealthy as a ninja, you quietly top up the burette with fresh $KMnO_4$ until the burette column climbs back to exactly 10.2 ml. "Aha," you whisper to yourself, "concordance!" With a somewhat troubled conscience but a signed lab manual (yay!), you're out the door before the pink has even settled in the flask.

Sometimes, however, you can't just fudge a reading. In the biology lab, despite more than 15 redos, not finding the *Drosophila*'s polytene chromosomes under the microscope hurts. Not least because you *must* submit a picture of those chromosomes in your report. Such testing times require you to probe deep – not into the *Drosophila*, but into your pockets to treat your friend at Sarvam. *"Yaar, send me your chromosomes picture na!"*

While we come up with creative techniques to salvage our failed experiments, the instructors have also come up with creative ideas to test our lab skills. The biology lab instructors once concocted a truly unique exam pattern – a cross between a quiz show and a game of musical chairs! The students were split into batches of 20 each. There were a total of 20 questions to be answered, and each question was assigned to a unique lab station. Every student would be assigned one station to begin with and given exactly one minute to answer the question. Once the time elapses, all the students shift to the next station for the next minute. And on it goes for 20 frantic minutes. This way, they could include microscopic slides, samples, and instruments from varied experiments to accompany the usual theoretical questions.

Indeed, lab exams necessitate elaborate preparation by the TAs and instructors. Setting the questions, printing them, preparing the slides, and samples are all tasks that the TAs and instructors race against time to complete. Tyby and Ariakutty admit having spent hours doing the experiments themselves ahead of the exams to ensure that the apparatus is working properly, and the readings aren't significantly off.

But sometimes, it is just not meant to be. Just ask the instructor at Amrit's table. Confident in his expertise, he reconfigured the entire apparatus to produce the cleanest readings possible. He then calmly switched on the power supply. The system started running, and Amrit's mind began racing. The sensors worked tirelessly and spit out their readings.

Out came the calculators. The error margin? 2100% this time! The instructor stared at the screen, frozen in disbelief. Amrit heaved a sigh of relief, his sanity instantly restored – it wasn't his fault after all. Finally, the instructor turned to him and said, with a heavy sigh: "You know what, turn your reading in."

Clearly, physics had taken the day off, and the weary instructor was happy to clock out as well.

Manauv Vyas is a second-year undergraduate student and a science writing intern at the Office of Communications.

(Edited by Ranjini Raghunath)

Chasing El Niño

- Ashmita Gupta

How scientists learned to see it coming

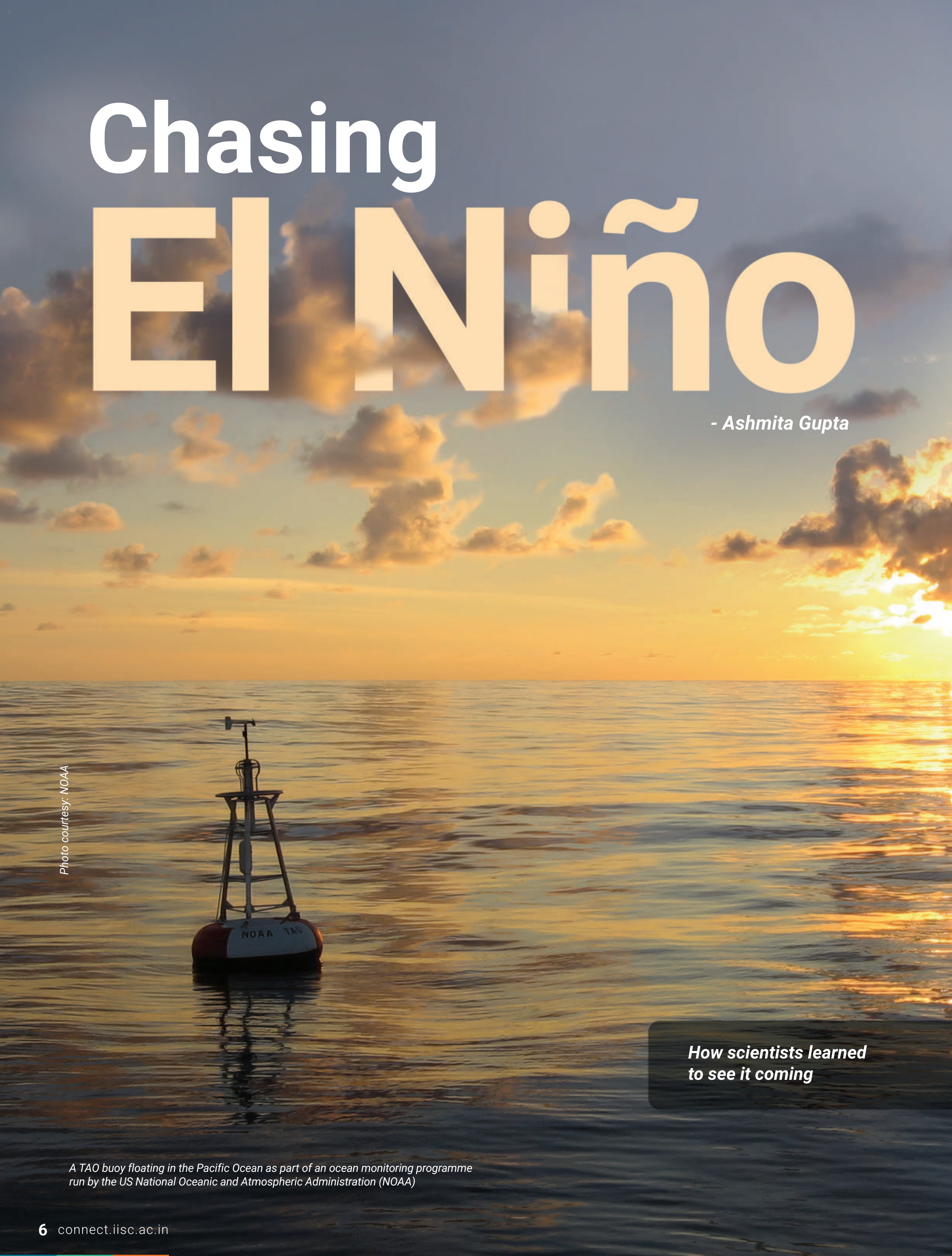


Photo courtesy: NOAA

A TAO buoy floating in the Pacific Ocean as part of an ocean monitoring programme run by the US National Oceanic and Atmospheric Administration (NOAA)

A failed monsoon triggered the Great Famine of 1876-1878, which killed an estimated 5-10 million people in India. The tragedy sent officials in the British Raj into a frenzy, and the Indian Meteorological Department was tasked with preparing a seasonal forecast of the Southwest Monsoon rains. At that time, IMD had to make do with informal data, like Himalayan snowfall levels, but none of it was statistically rigorous. A second monsoon failure and famine in 1899 only increased pressure on the department.

In 1904, the department brought in Sir Gilbert Walker, a Cambridge-trained mathematician, as the director general of observatories in colonial India. He inherited the bleak assignment of explaining why the monsoons kept failing year after year. He dove right into the mountain of data – decades of atmospheric pressure records from weather stations scattered across the globe. When he wasn't standing on Simla's Annandale grounds throwing boomerangs (he was called "Boomerang Walker" during his university years) or peering at birds through his telescope, he ran complex analyses of atmospheric pressure, rainfall, river levels, snowpack, and even sunspot activity, trying to make sense of the numbers.

Slowly, a pattern emerged. He noticed that when atmospheric pressure was high over the Pacific, it tended to run low over the Indian Ocean, and vice versa, as if the two oceans on opposite sides of the planet were see-sawing. He called it the Southern Oscillation. While he suggested that ocean circulation and temperatures might play a role in driving this oscillation, he couldn't figure out the physical mechanism, primarily due to a lack of data from the oceans. As a result, his theory was met with scepticism by most meteorologists of his time.

Meanwhile, a seemingly unrelated pattern had been wreaking havoc in the lives of Peruvian fishermen on the other side of the globe for centuries. The cold, nutrient-rich current that usually fed their catch would, during some years, give way to warm, nutrient-poor water, gutting fishing for months at a stretch. They called it *El Niño de Navidad* (the "Christ Child," as the warming usually peaked around Christmas).

It wasn't until the 1960s, when Norwegian-American meteorologist Jacob Bjerknes started looking at real-time temperature readings from a weather station on Canton Island in the Pacific Ocean, that a link between El Niño and the Southern Oscillation emerged. Bjerknes determined that Walker's pressure seesaw moved in lockstep with sea-surface temperature: warm water in the eastern Pacific meant low pressure; cool water meant high pressure. Bjerknes called the underlying engine the Walker Circulation. He showed that Walker's Southern Oscillation and El Niño were two parts of the same coupled ocean-atmosphere system – the phenomenon scientists now call ENSO.

ENSO occurs when the east-to-west equatorial trade winds weaken, causing warm Pacific water that would normally pile up near Asia to slosh back east, shutting off the expected cold upwelling near South America. The ocean and the atmosphere, it turns out, are co-culprits.

ENSO has been stirring up trouble for thousands, if not millions of years. Paleoclimate records point to warmer seas and heavier rains stretching back to the last ice age. Some historians have linked the phenomenon to the collapse of ancient civilisations like the Moche and the Inca, and even to the European crop failures that led to the French Revolution in 1788-89. At least three catastrophic famines in the late 19th century struck India in years now recognised as major El Niño events. Nobody knew at the time that a patch of warm water thousands of miles away was steering their weather.

That has somewhat changed over the last century. Scientists have spent decades seeking an explanation for a pattern that, for most of human history, manifested in a ruined harvest here or empty fishing nets there. By the late 20th century, they figured out the cause and mechanisms. But what they couldn't yet find was a way to watch it happen in real time and predict its occurrence. That gap became painfully clear in 1982.

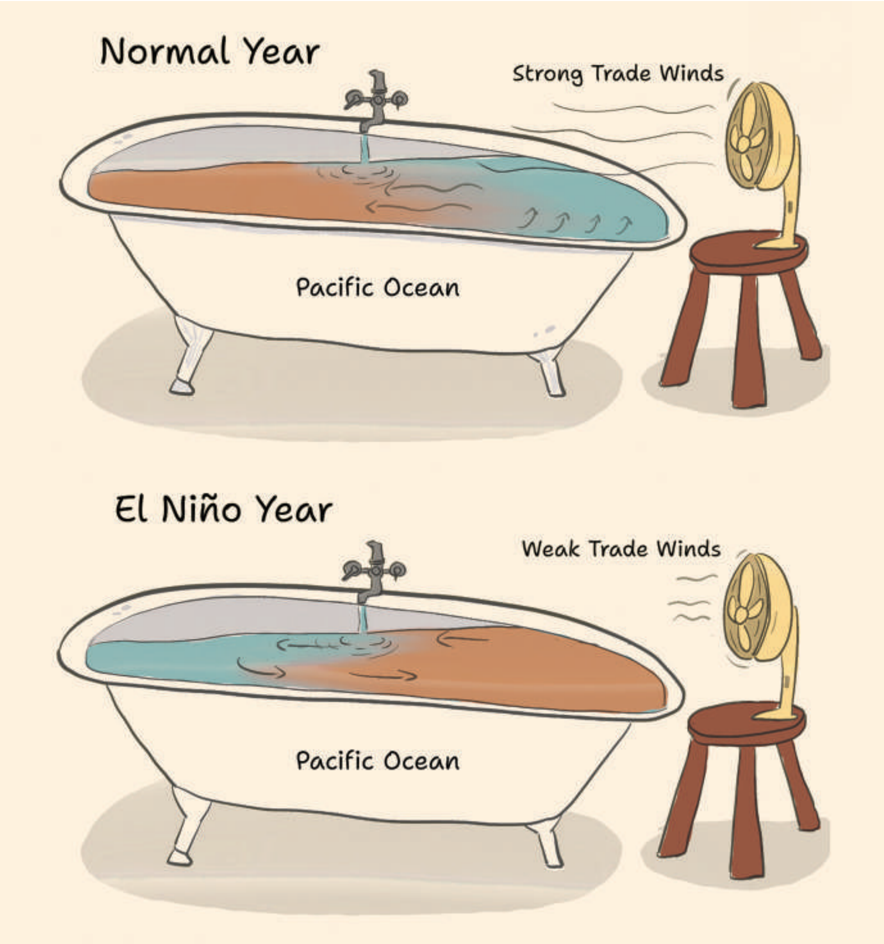


Illustration: Ashmita Gupta

Under normal circumstances, warm water pooling on the surface is pushed towards the left by trade winds. During El Niño, trade winds weaken, allowing warm water to slosh back to the deeper end – towards South America

Seeing through smoke

On 4 April 1982, Mexico's El Chichón volcano erupted, hurling ash and sulphur dioxide high into the stratosphere. It could not have picked a worse moment. Thousands of miles away, across the tropical Pacific, an enormous El Niño was already beginning to build. El Chichón's plume drifted straight into the path of the few satellite instruments capable of tracking the El Niño, scrambling their readings of sea-surface temperature and forcing them, quite literally, to see through the smoke.

The El Niño of 1982–83 ended up being the field's founding trauma. Numbers failed to capture the full scale of devastation. Parts of coastal Peru, where the norm was six inches of rain per year, received close to 11 feet. Coastal rivers reportedly carried a thousand times their usual flow, and near the fishing village of Paita, sea-surface temperature jumped more than 7°F in a single day. Australia, Indonesia, and southern Africa went the opposite way, battered by drought, dust storms, and bushfires. In the eastern Pacific, some reefs lost up to 95% of their coral. The human toll was roughly 1,300 to 2,000 deaths worldwide, with property and livelihood losses close to $4 trillion. The US National Oceanic and Atmospheric Administration (NOAA) would later describe the event as one that was "neither predicted nor detected until nearly at its peak."

All of it traced back to a shift in ocean temperature that, at the time, almost nobody had the instruments in place to see coming. Satellites had only just begun providing regular ocean coverage, and much of the tropical Pacific was still monitored, if at all, by whichever ships happened to be passing through.

"1982-83 was a revelation that we needed better observing systems in the tropical Pacific," says Michelle L'Heureux, who leads the ENSO team at NOAA's Climate Prediction Centre. "The event exposed the lack of real-time observations in the tropical Pacific and led to major investments in ocean observations," adds Roxy Koll, a climate scientist at the Indian Institute of Tropical Meteorology, Pune.

'The 1982-83 El Niño event was a revelation that we needed better observing systems in the tropical Pacific'

The Tropical Ocean Global Atmosphere (TOGA) programme, a decade-long international research effort, was founded in 1985. Its centrepiece: the TAO/TRITON array.

Unlike the drifting Argo floats that would come decades later, the TAO buoys were fixed in place along the equatorial Pacific, providing a concentrated, unblinking watch over the one stretch of ocean that mattered most. A standard buoy has a two-metre fibreglass ring with an aluminium mast anchored to the seafloor and trailing a 500-metre cable with temperature sensors at 10 different depths. Wind, humidity, air temperature, and sea-surface temperature are read off instruments on the mast. Several times a day, the data is beamed to satellites and relayed to shore stations, where it becomes publicly available within hours.

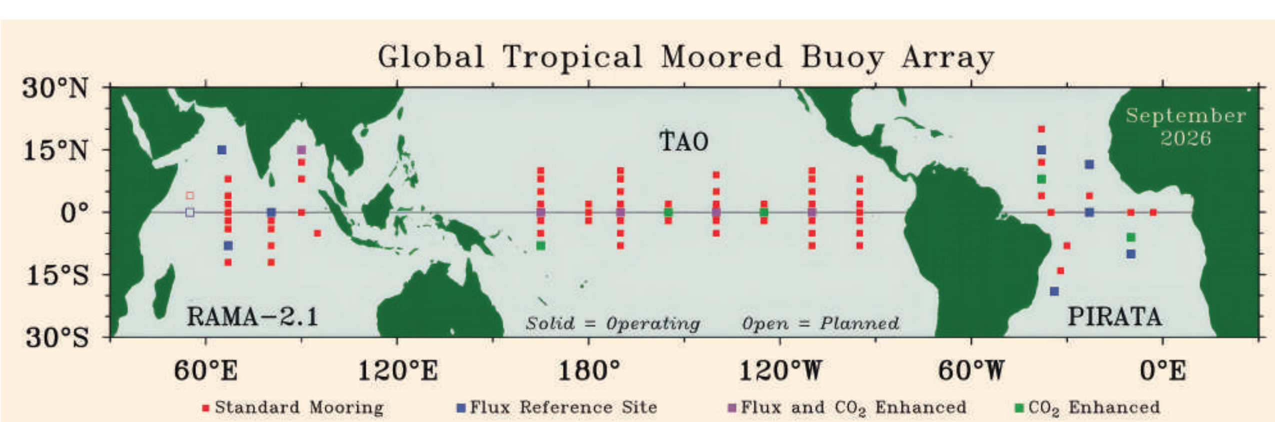
The buoys were built to answer a question that satellites fundamentally couldn't. "Satellites cannot see the subsurface temperature or the bottom of the ocean," explains Arindam Chakraborty, Professor at the Centre for Atmospheric and Ocean Sciences (CAOS), IISc. "So, people have put sensors that go deep into the ocean."

Once the TOGA-Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE, as it was called) got underway a few years later, its sensors were able to pick up a slow eastward crawl of unusually warm water along the equator, weeks or months before it ever reached the surface – pulses now known as equatorial Kelvin waves. A thermistor reading warmer than normal – partway down that cable, long before anything changes at the surface – became the "subsurface heat signal" that would, decades later, turn into the most trusted early-warning sign of an impending El Niño.

Patterns to physics

Sometime in the mid-1980s, over a Fourth of July weekend, American oceanographer Mark Cane sat by a lake reading a paper which claimed that El Niño could be predicted by tracking the depth of the thermocline – the horizontal boundary between warm surface water and the colder water beneath – in the far western tropical Pacific.

A decade earlier, oceanographer Klaus Wyrtki had proposed that El Niño was preceded by an unusual buildup of warm water in the western Pacific. When the trade winds relaxed, he argued, the stored water could surge eastward, depressing the thermocline and heating up surface waters off South America. In 1974, Wyrtki and his colleagues even attempted to put the idea to the test: after an El Niño was forecast for early 1975, they organised an oceanographic



A map showing the locations of the Global Tropical Moored Buoy Array programme's buoys, including the TAO/TRITON arrays

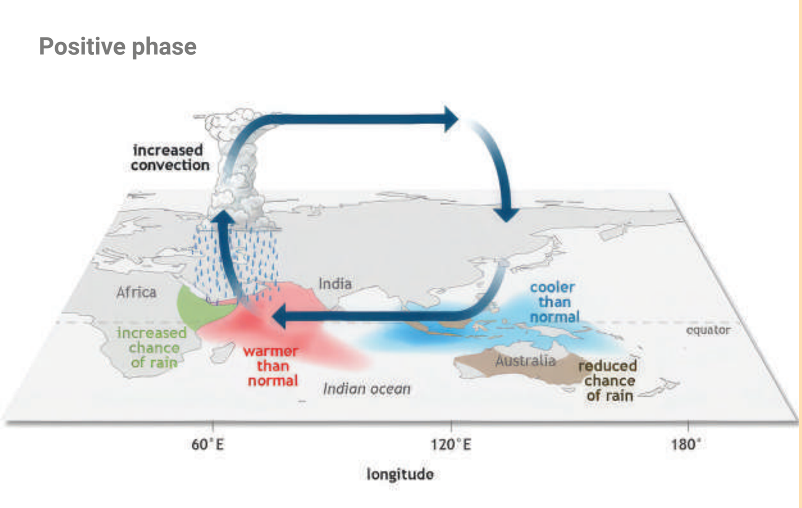
Image courtesy: Global Tropical Moored Buoy Array Project office, NOAA/PMEL expedition to watch the Pacific as the event developed. The warming appeared, but quickly fizzled out.

By the time Cane encountered that paper, scientists had begun to suspect that the ocean's depths might contain clues to an El Niño before it appeared at the surface. Cane, a Brooklyn-born applied mathematician trained under renowned meteorologist Jule Charney at MIT, wasn't convinced. But it raised an interesting question: Could the thermocline still be hiding a realistic early warning sign, for reasons that the paper's author hadn't yet identified? Cane and his student, Stephen Zebiak, had a hunch about what that sign could be. In the coupled ocean-atmosphere feedback that Bjerknes had described, a change in trade winds pushes warm water east, which should, in turn, reshape the thermocline across the whole Pacific basin – meaning that its *depth* wasn't just a symptom of El Niño, but potentially an early signal of one building up.

That hunch didn't come out of nowhere. For several years already, Cane and Zebiak had been building one of the world's first coupled ocean-atmosphere computer models capable of simulating ENSO. The model divided the Pacific Ocean into a grid, tracking wind, sea surface temperature, and ocean currents in each square. It used mathematical equations to predict how these three push and pull each other – for example, warm water reshaping wind movement and vice versa – and mimic how ENSO conditions unfold. Unlike the statistical forecasts that dominated seasonal prediction at the time, it didn't scan historical records for recurring patterns; it encoded the actual physics (movement, properties) of ocean-atmosphere interaction and let ENSO conditions emerge from that alone. Cane and Zebiak's goal at first was simply to find out if the physics by itself, with no help from historical statistics, could simulate ENSO patterns.

As it turned out, left to run with no historical event programmed in, the model fell into a repeating warm-cool cycle that looked unmistakably like real ENSO. The obvious next question was whether the same equations could calculate what would happen next. When Cane and Zebiak tried exactly that, the model produced a striking result: an El Niño appeared likely to develop in 1986.

The Indian Ocean Dipole



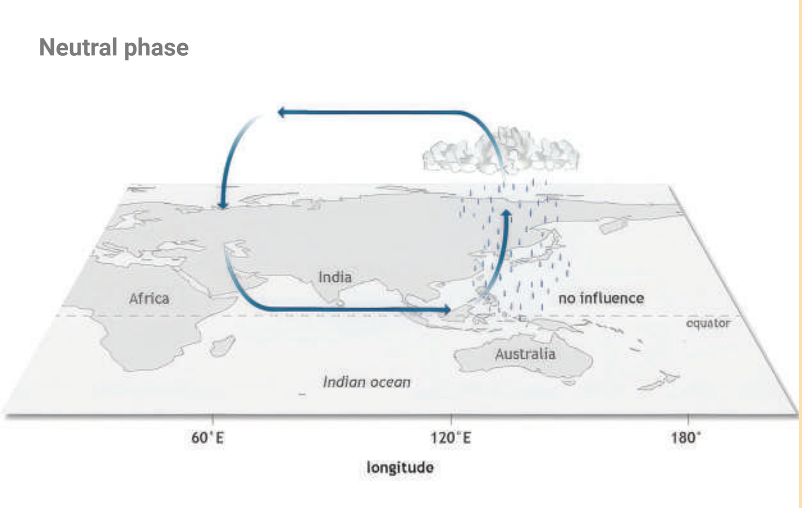


Image courtesy: NOAA Climate.gov

For a while, Indian forecasters saw a correlation between El Niño and the monsoon: warm Pacific meant weak monsoon and therefore drought. Then, in 1999, a team of scientists – NH Saji, BN Goswami, PN Vinayachandran, and T Yamagata, publishing in *Nature* – identified a second player that had been hiding in plain sight. The Indian Ocean Dipole (IOD) is a seesaw of warming and cooling between the western and eastern Indian Ocean, typically peaking around July through September – right in the middle of monsoon season.

In its "positive" phase, warm water pools in the west while the waters off Sumatra turn unusually cool, and depending on how that lines up with what the Pacific is doing, it can blunt El Niño's usual drying effect on India or sharpen it considerably. "This was a new discovery ... that completely alters the impact El Niño may have on the Indian monsoon," says J Srinivasan, Honorary Professor at CAOS, IISc. It's part of why the strong El Niño of 1997 never produced the drought that the old playbook predicted. The Pacific was pulling one way, and the Indian Ocean – for reasons nobody had thought to look for yet – was quietly pulling another. Even now, scientists like Arindam are careful not to oversell how well understood that tug-of-war is.

"In that first stage, we were just out to simulate ENSO," Cane later recalled in an interview published in *National Science Review* in November 2018. "We weren't even thinking about prediction."

They took the forecast to the director of Columbia University's Lamont-Doherty Earth Observatory, and after scrutiny, it was cautiously approved for release. In 1986, the team published the forecast in *Nature* and, in a move unusual for climate scientists at the time, held a press conference to explain it publicly.

The forecast proved largely correct, and for the first time, a physics-based model had anticipated an El Niño before it fully emerged.

Seasonal forecasting was still a young science, and the tropical Pacific had a habit of humbling those who claimed too much certainty

Yet one successful prediction was not enough to convince everyone. Seasonal forecasting was still a young science, and the tropical Pacific had a habit of humbling those who claimed too much certainty. It would take another decade – and another giant El Niño – before forecasting moved from an intriguing experiment to an accepted scientific capability.

That test arrived in 1997.

"The 1997-98 event was relatively well predicted," says Michelle. "We saw it coming well in advance of its impacts." Across the USA, winter temperatures and rainfall lined up closely enough with the forecast that agencies and governments could plan around it in advance.

But the triumph masked a harder truth. Forecasting an El Niño was becoming easier. Forecasting what it would do remained difficult. "I would argue that all the El Niño events since then have been a bit less predictable than 1997-98," Michelle says. "We now appreciate that you can get a wider variety of possible outcomes than suggested by the forecast success of 1997-98."

Every event since has uncovered new surprises. In 1999, another player entered the scene: the Indian Ocean Dipole, a seesaw of warming and cooling between the eastern and western Indian Ocean *(see box on page 9)*, which scrambled what had looked like a clear link between El Niño and a weak Indian monsoon. That complication turned out to be the pattern of the following decades: every clean signal that the field found came bundled with new sources of noise.

Building better machines

In 2002, India's statistical models called for a near-normal monsoon. Instead, the rains failed catastrophically partway through the season. "We got one of the most severe droughts," says Ravi Nanjundiah, Professor at CAOS, who has worked closely with India's forecasting agencies. "Models, not just in India but all over the world, were not able to catch it."

Every part of the seasonal forecasting system came under scrutiny, leading to a series of incremental improvements to observations, model resolution, computing power, and forecasting methods.

A seasonal forecast, unlike a weather forecast, was never meant to say exactly what will happen on a given day. It's a statement about shifted odds: Given how the Pacific looks right now, is a weak monsoon over central India more or less likely than usual this year? Getting those odds right, and getting better at stating them confidently, became the real goal for the next two decades.

Model resolution was one of the first targets. Adam at the UK Met Office compares the change to the pixels on a digital photograph. The ocean models of the early 2000s carved the Pacific into blocks roughly 100 km wide, coarse enough to blur out entire ocean currents. Today's models run at a quarter of that size – blocks closer to 25 km wide – fine enough to resolve features like the Gulf Stream that used to simply vanish into the average.

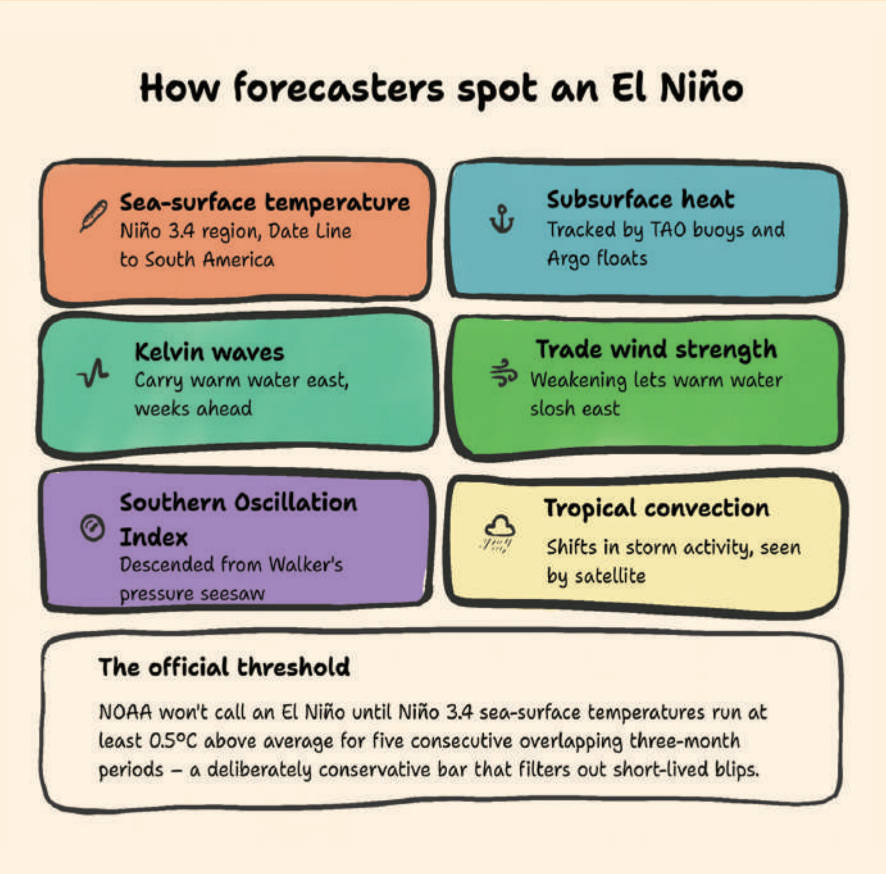
Alongside the models, the monitoring network continued to expand. The Argo programme, launched in the early 2000s, scattered thousands of autonomous floats across the world's oceans – diving down about two kilometres and back every 10 days, measuring temperature and salinity as they went. They filled the gaps in the vast stretches of open ocean that the TAO buoys, tied to the equator, couldn't cover.

The other shift was less visible but arguably more important. Scientists stopped pretending that forecasting had a single right answer. Instead of running one simulation and calling it a forecast, weather agencies began running and digesting data from dozens simultaneously. "We [now] do about 50 such simulations to give you a single forecast," says Ravi. Outside the tropics, where the atmosphere is less noisy and El Niño's influence is more diffuse, Adam's group has found that even that isn't quite enough. "You really need 50 or even 100 forecasts to see what's actually happening," he says.

What actually matters, says Roxy, is not just a single reading but the dialogue between them. "A surface warming in the central-east Pacific becomes more consequential when the atmosphere responds, because that is when El Niño begins to influence tropical rainfall and circulation more broadly."

Still, none of this makes forecasting certain. "It's so, so important to communicate uncertainty," says Michelle. "We cannot tell you that there will be a 100% chance of some outcome due to El Niño, but we can tell you the odds of such an outcome." NOAA's Climate Prediction Centre puts out a formal discussion every month. As the 2026 El Niño developed, the July discussion read: "El Niño continues and will strengthen through the end of the year, with a 97% chance it will persist through early spring 2027." This means that for this winter, NOAA's seasonal outlook favours wetter-than-normal conditions across much of the southern USA and above-normal temperatures across much of the West – "favours" being the operative word, not "guarantees." Instead of absolute certainty, it provided a forecast close enough to it that farmers, water managers, and governments can plan around it.

Srinivasan explains why communicating this uncertainty clearly matters. In 2015, with an El Niño developing much like this year's, the IMD predicted a drought. But by late August, rainfall was tracking normal, and the drought was nowhere in sight. At a meeting in August, Srinivasan recalls, the Prime Minister asked the Secretary of the Ministry of Earth Sciences why the forecast was wrong. "Immediately after the meeting, the monsoon started going down, and from August and September, the monsoon was so bad that we had a drought," Srinivasan says. The forecast hadn't failed; it had just been early. "Monsoon can be quite surprising," he says, with resigned amusement.



Infographic: Ashmita Gupta

Today, scientists are quick to point out what forecasting still can't account for. Chief among them is the spring predictability barrier *(see box on page 12)*, a blind spot that has frustrated researchers for decades and one that Michelle does not expect to disappear anytime soon. "It may be one of those intractable issues we may not ever completely overcome," she says.

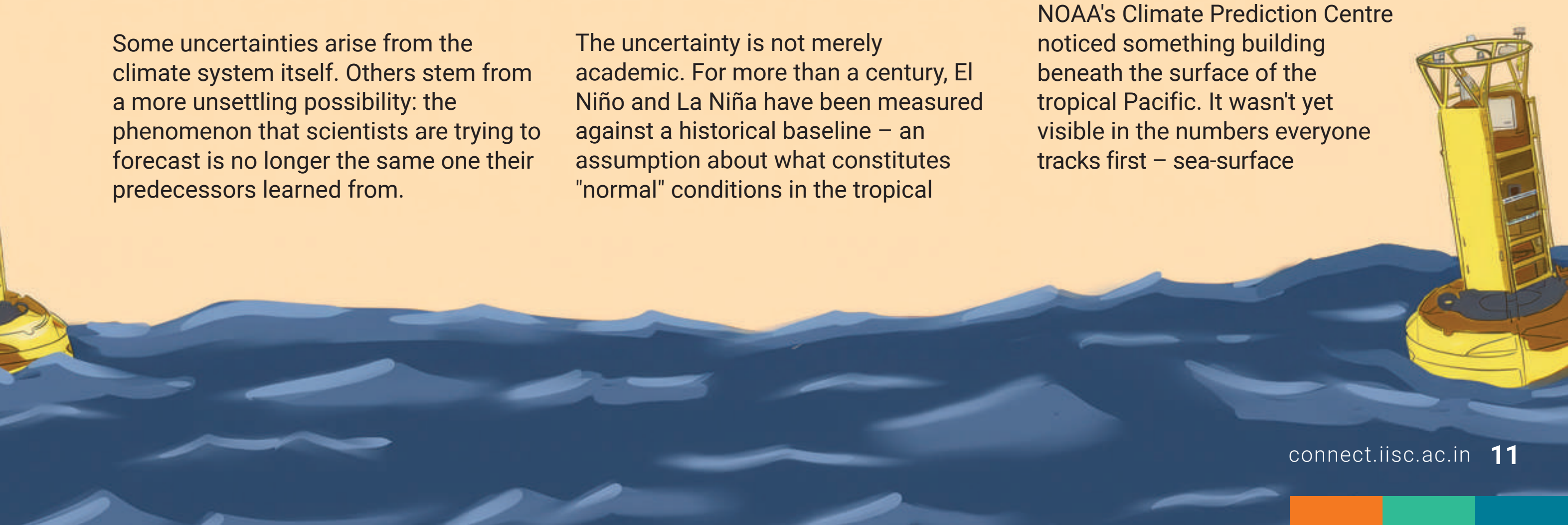
Some uncertainties arise from the climate system itself. Others stem from a more unsettling possibility: the phenomenon that scientists are trying to forecast is no longer the same one their predecessors learned from.

As oceans warm up and marine heatwaves become more common, researchers have begun asking whether El Niño itself is changing – or whether only its impacts are. "A lot of work has been done to understand how global warming affects El Niño," says Srinivasan. "But unfortunately, there is no consensus." Adam draws the same distinction. He is confident that El Niño's consequences are becoming more severe because they are unfolding on a warmer planet, but he is far less certain that the phenomenon itself is changing. "We're not 100% sure about that," he says. "We don't have full agreement between all the computer models."

The uncertainty is not merely academic. For more than a century, El Niño and La Niña have been measured against a historical baseline – an assumption about what constitutes "normal" conditions in the tropical Pacific. But as the oceans steadily warm up, that baseline itself is beginning to shift. Michelle says that researchers are increasingly grappling with the possibility that today's events have to be measured against a different yardstick than those of previous decades. In 2026, NOAA adopted the Relative Oceanic Niño Index in part to account for that changing background state. Still, how much global warming is influencing ENSO remains one of the field's open questions.

Present tense

In December 2025, the ENSO team at NOAA's Climate Prediction Centre noticed something building beneath the surface of the tropical Pacific. It wasn't yet visible in the numbers everyone tracks first – sea-surface



The Spring Predictability Barrier

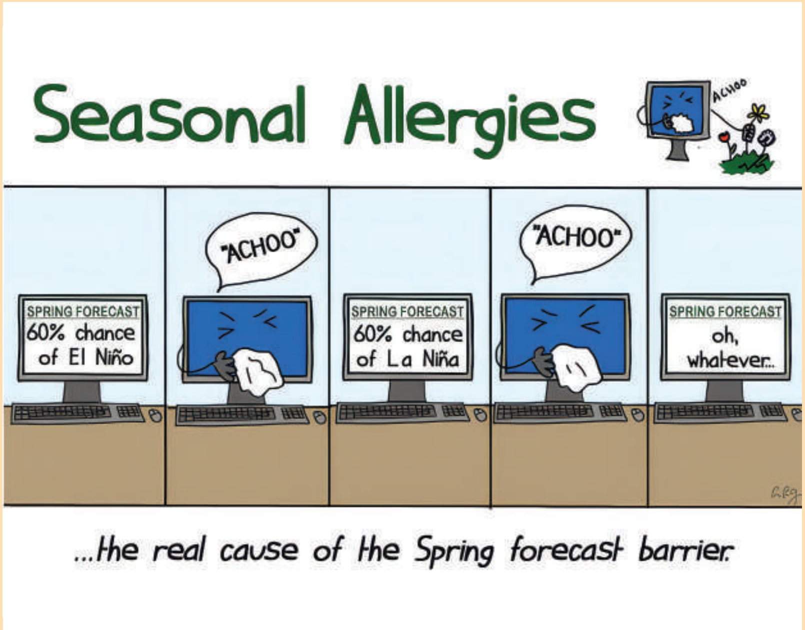


Illustration courtesy: Emily Greenhalgh, NOAA Climate.gov

Every spring, ENSO forecasts get noticeably less reliable, no matter how good the models are or how much data is fed into them. Around March and April, the tropical Pacific is transitioning between phases, and the signals that forecasters lean on the rest of the year – subsurface heat, trade wind strength, sea-surface temperature – are at their weakest and noisiest. A forecast issued in February can call the coming summer with real confidence. But the one issued in April is often still guesswork. It's not a data or a computing problem; it's built into the physics of the season itself – the ocean genuinely is harder to read at that specific point in its yearly cycle for everyone, regardless of how good their tools are. This spring predictability barrier has stumped scientists for decades.

In 2024, Arindam's group finally found a workaround. They were studying decade-scale cycles in Indian rainfall and surface pressure when they noticed a distinct pattern of variability in sea-level pressure over the southern Pacific Ocean that shows up every spring – right in the dead zone of the barrier. They call it the ENSO Transition Mode, or ETM. "It is not the primary mechanism that develops an ENSO," Arindam says, "but it helps the development." When that spring pressure signal runs stronger than usual, it can make a developing El Niño stronger or a developing La Niña weaker. Arindam is careful to call it a contributing factor, not a cause, but it gives forecasters something real to weigh in on, right in the exact months when the usual signals go quiet. The discovery is now one of the few tools chipping visible cracks in a barrier that was assumed to be unbreakable.

temperature was still unremarkable – but deeper still, a slow accumulation of warm water was spreading east along the equator. "One of the biggest clues that an El Niño may be coming is the build-up of subsurface oceanic heat across the equatorial Pacific Ocean," says Michelle. "We saw the heat increase begin in November/December 2025, and almost immediately, the prediction models started anticipating the possible formation of El Niño for mid-2026." By the time NOAA issued its December outlook, the odds had already shifted – El Niño was now more likely than a neutral or La Niña state.

"We do not always have that much lead time – it really is only with the stronger El Niños do we potentially see them coming well in advance," she says. "Weak to moderate El Niños are often only anticipated a few months in advance, if at all." The 2026 event, from the very start, had the signature of something big, which is precisely why the team caught it as early as it did.

The UK Met Office has gone as far as saying that it's now "very likely" that 2027 will end up the hottest year on record – the extra warmth from the ocean taking time to fully surface in global temperatures. Below-average monsoon rains have already been recorded across India this year, and Atlantic hurricane activity has been suppressed.

'El Niño is never boring. Every event is different and distinct in its own way'

"Riding on the background ocean warming signal, [it] is predicted to be one of the strongest El Niños we have ever recorded," says Roxy. Adam estimates that climate change may be adding roughly half a degree Celsius to the event's warmth.

Researchers are already looking for new tools to improve forecasting. Both Roxy and Adam point to artificial intelligence and machine learning as the next major shift – not necessarily as a replacement for physics-based models, but as partners to them. "AI methods have been shown to make more skillful weather forecasts than traditional models," Adam says. "I wouldn't be too surprised if they eventually change some conventional approaches in seasonal prediction too." Ravi imagines a hybrid future, with machine learning embedded within physics-based models, improving the parts of the system that scientists still struggle to represent accurately.

Predicting whether an El Niño will form is no longer the only question. "The more relevant question is how it will affect rainfall, heat, crops, reservoirs, health, fisheries, and ecosystems," says Roxy. That shift has forced researchers to look beyond the Pacific, toward interconnected systems such as the Indian Ocean, which can store heat, reshape atmospheric circulation, and influence weather long after Pacific anomalies begin to fade. Roxy's own work suggests that the familiar relationship between El Niño and India's monsoon is no longer uniform – they show that it strengthens over the north of the country, holds roughly steady in the south, and weakens over central India where local weather calls its own shots.

Underneath all of it sits the same challenge that has troubled the field for more than a century: seeing what lies beneath the ocean's surface. Even with satellites, Argo floats, and a buoy network stretching across the equatorial Pacific, scientists are, in a sense, still chasing warm water through an impossibly vast and murky system.

On the upside, they are no longer running fully blind. A century of observations, buoys, satellites, and models has turned El Niño from a mystery that revealed itself only in hindsight into something humanity can watch build – imperfectly, incompletely, but at least in time to act.

As for the phenomenon, it continues to beguile the scientists who study it. "El Niño is never boring," Michelle says. "Every event is different and distinct in its own way."

(Edited by Ranjini Raghunath)

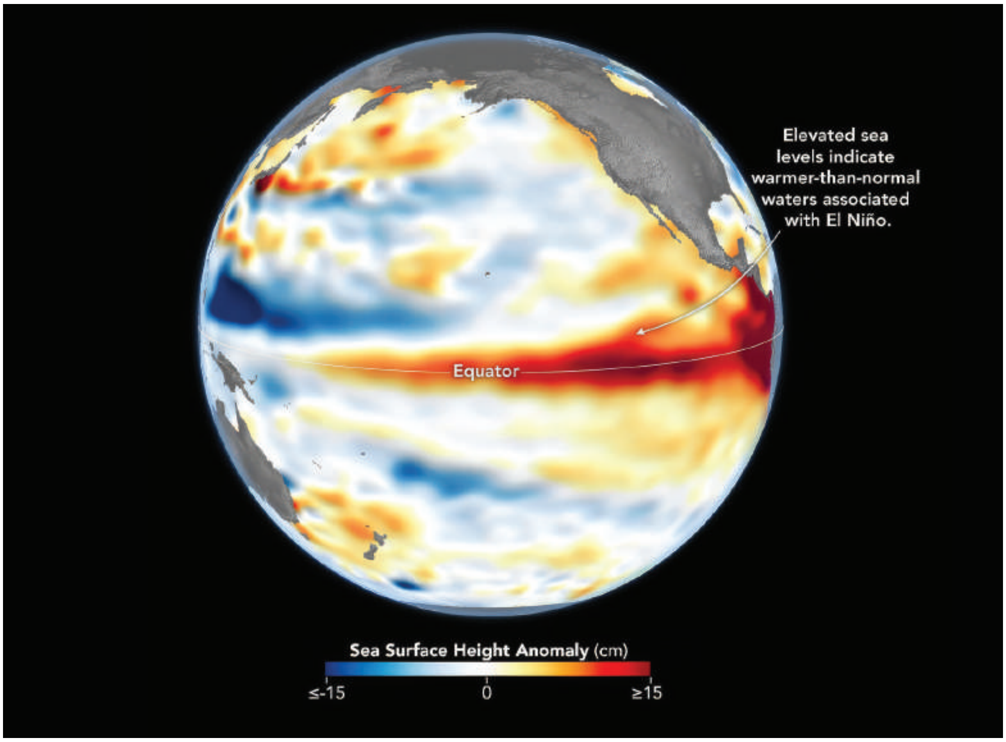
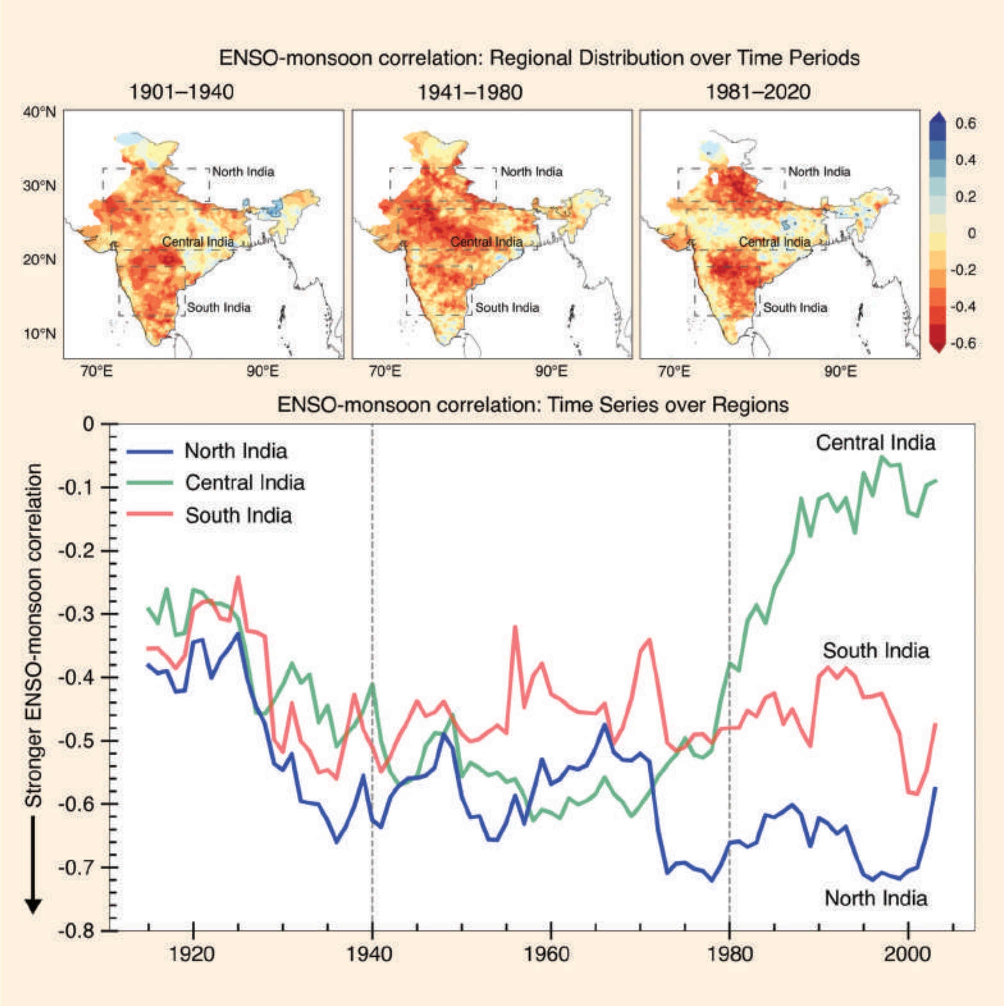


Image courtesy: NASA Earth Observatory/Lauren Dauphin

Higher-than-normal sea surfaces (red) are visible in the central and eastern Pacific on 8 June 2026, a few days before El Niño was declared



Courtesy: Roxy Koll

ENSO-monsoon correlation over different timeframes, across different regions over India

‘If you want to learn something, IISc has people who know it’

- Interview by Sandeep Menon

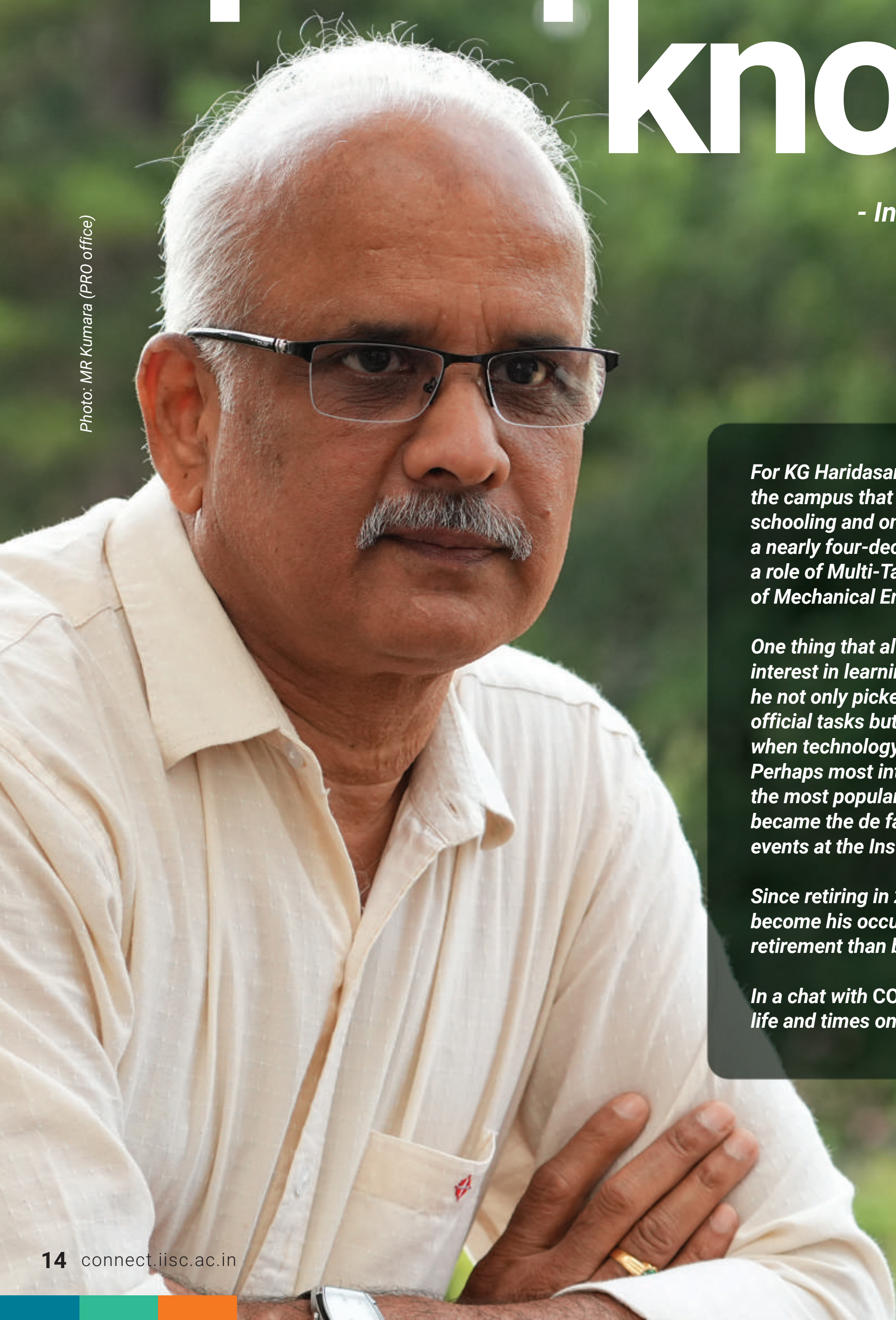


Photo: MR Kumara (PRO office)

For KG Haridasan, IISc is truly home. It was on the campus that he grew up, did most of his schooling and on-the-job training, culminating in a nearly four-decade-long stint which ended with a role of Multi-Tasking Staff at the Department of Mechanical Engineering.

One thing that always drove Haridasan was his interest in learning. It held him in good stead as he not only picked up on the nuances of his official tasks but also helped him stay abreast when technology evolved at a rapid pace. Perhaps most interestingly, it made him one of the most popular staff members at IISc as he became the de facto photographer for all major events at the Institute.

Since retiring in 2024, his vocation has truly become his occupation, leaving him ‘busier after retirement than before.’

In a chat with CONNECT, Haridasan traces his life and times on campus.

Can we talk about your childhood, which was in this very institution?

My father worked here for nearly 33 years. He worked in the mess and then in the hostel as an attender. He was a permanent employee. He retired in 1983. We lived in the quarters here; I was born here and studied here in a Kannada-medium Government Model Primary School till grade seven. Then I switched to the English-medium stream at MS Ramaiah High School. I found it difficult to understand the subjects, but I managed and finished matriculation in 1980. I wanted to study further, but due to my family background and circumstances, I could not.

You know, when I was studying in grade six or so, we used to roam in these forests. There were fewer buildings. Wherever you look, you would see greenery, and the climate in the 1970s was really cold, freezing. You couldn't even see the other side of the road. Over the years, new departments have come up. It had changed a lot by the time I retired in 2024.

Photo courtesy: KG Haridasan

KG Haridasan (fifth from right) with research scholars, staff, and project assistants from the Foundry Lab at the Department of Mechanical Engineering in the mid 1990s

How did you end up working at IISc?

After matriculation, my father suggested that I do an apprenticeship in a technical company. I tried, but I didn't get in. I then worked for nearly two years in an engineering workshop, where I learned lathe work, drilling, welding, manufacturing tools, and so on. After that, my father recommended my name to Prof S Seshan. He was a faculty member at the Department of Mechanical Engineering. Because of him, I got a job on a project in the Department of Metallurgy (now Materials Engineering) in 1983. I worked for nearly one and a half years with Prof GNK Iyengar, on material melting, heat treatment, property analysis, and so on. Then I got in with Prof Seshan on another project; I joined as a 'mechanic' in the foundry lab. So, I learned foundry, melting, moulding, several types of casting, some property analysis like hardness testing, elongation, sand testing, microstructure study, and more. I also learned black and white film developing and printing. Prof Seshan really supported me. On 14 May 1986, I got a permanent job in his lab at IISc.

Besides getting a salary, I wanted to learn something because I always had ambitions to learn further. That did not happen, but I did get a chance to be in a learning institute, which gave me a platform to learn various types of work and technical skills. I also worked with other faculty members, including Prof MR Seshadri, Prof MN Srinivasan, Prof KS Sreenivasa Murthy, and Prof Satish Vasu Kailas. They all supported me and used to teach me about materials, different properties and alloys, and so on. I even learned how to use an optical microscope and how to take a microscope photograph.

I worked as a full-time employee for 38 years and 10 months. I can say that it is only because of Prof Seshan and others that I am here today. Whatever I have learned, whatever I eat, my family's life, it is because of him.

Photo courtesy: KG Haridasan

KG Haridasan receives a watch as a memento from former IISc Director CNR Rao

You stayed on the campus your whole life?

My father retired in 1983 and moved back to Kerala, but I stayed with a distant relative on the campus for two years. They used to work here as a cook in Roddam Narasimha's house. I stayed with them till I got a permanent position. When I was working on the project before that, I was getting only Rs 200. I was also just 19, so I didn't dare to live alone. In 1987, I got married and moved out of the campus, but we got a living quarters in the HMT campus in 1993-94. IISc has taken a contract there for housing. In 1997-98, we went out again and then around 2000-2002, we moved back to the campus.

Photo courtesy: KG Haridasan

KG Haridasan (second from right) with colleagues and a research assistant in 1988

How did you get into photography and become the go-to man for the job in the Institute?

Photography was part of my job. We used film cameras and film technology in those days. We used to manually develop and print everything. There was a lot of consultancy work from other companies for testing. Whatever work was being done, we had to capture it.

For students, their publications had to be submitted in hard copy, with photos pasted into their theses. I had to capture experimental setups. I used to print 300-400 prints a night; it was demanding work. So, I learned about photography, and then I learned how to take photographs. Shamanna (another fellow staff member) was my guru in photography; he taught me how to take microscope photographs, about different lenses and different magnifications, how to use light, and other such things. Then he taught me macro photography. I was keen to learn because it was all about creativity. Slowly, people started to recognise me as the one who takes photographs.

What was the first event that you took photographs for, which kickstarted your parallel photography career?

My first event was in 1992. A student got married, and his reception was held in our community hall. He asked me to take photographs. Until then, I was taking only departmental photographs. Then all the staff learned that I knew photography and developing, and I knew how to make slides for projection. Because of this, faculty members used to call me to help make slides. I ended up working with most of the faculty members at IISc. Alongside that, I also did my photography.

Now you take photos for almost all the events at IISc ...

Yes, after retirement, I have been taking a lot more. I am busier now than I was when I was working.

And what are you learning now? It looks like you have spent most of your life upskilling yourself one way or another.

Yeah, I'm extremely interested in learning new things and about modern technology. I want to learn AI, but because of my pending work and other events, I have not been able to concentrate on it. I know how to use AI, but I want to create more complicated things and tell stories through it. I will do it very soon.

Did you ever think of leaving IISc for other opportunities?

Many students and faculty members suggested that I study further; even my family said so. They all said that I should go to evening college. They all supported me, but I don't know why I didn't continue. Everything requires money, and those constraints were there. I didn't apply anywhere else for jobs either. This is the best place anyway. All the amenities are available. My son, Dr H Pradeep Kumar, studied here, then completed his MBA, and holds an honorary doctorate.

All your life, you have stayed in and around IISc. What does this place mean to you?

I can say that this is a temple of knowledge. During my school days, I used to learn yoga from Ashok Kumar, a student in the Department of Chemical Engineering. His experiments took place at night and lasted several hours. I used to sit with him after dinner and work till 12.30-2 am. He would also teach me about his work. I say this to show that if you have an interest, you can learn anything here. If you want to learn something, IISc has people who know it and will encourage and help. They are all truly kind people here.

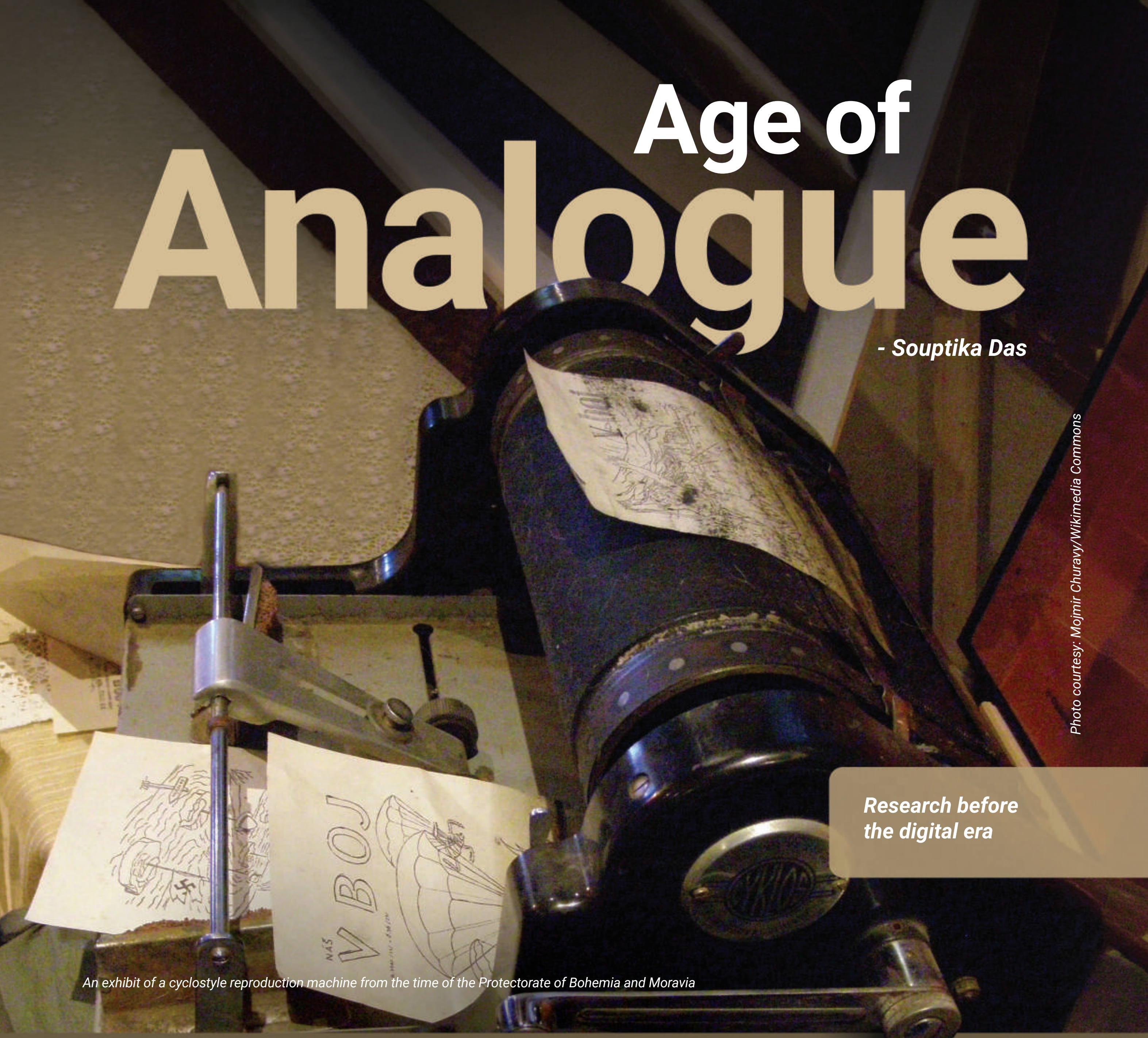
(Edited by Abinaya Kalyanasundaram)

Photo courtesy: KG Haridasan

KG Haridasan receiving a memento and certificate from former IISc Director Goverdhan Mehta after completing 15 years of service at the Institute in 2001

Age of Analogue

- *Souptika Das*



An exhibit of a cyclostyle reproduction machine from the time of the Protectorate of Bohemia and Moravia

Photo courtesy: Mojmir Churavy/Wikimedia Commons

Research before the digital era

When Raghavendra Gadagkar, Professor and National Science Chair at the Centre for Ecological Sciences (CES), IISc, was a graduate student, he came across a 1958 article in *Scientific American* by American psychologist Eckhard H Hess. Hess had done research on imprinting in animals and written about how early experiences in animals influence and shape adult behaviour. Hess and others had found through their experiments that young ducklings who had to face hurdles in their path demonstrated stronger imprinting. Because they had to expend efforts to either remove or overcome the obstacle, their learning patterns were stronger than those of control ducklings.

Gadagkar draws an analogy from this insight to the process of doing research. The harder it is to do something, the greater the possibility of learning. He would know; he belongs to a pre-computers, pre-Internet, and pre-ChatGPT generation of researchers, who had their work cut out for them.

Today, computers have transformed the process of research into something faster, more accessible, and infinitely more connected. From typing manuscripts to running analysis on massive datasets, technology has reshaped every part of academic work. The internet made journals, archives, and global collaborations just a click away. For researchers who began their careers in the 2000s, the use of computers became non-negotiable.

We take notes on laptops, store years' worth of data on cloud drives, download datasets in seconds, and run statistical analyses using sophisticated software. Research papers from across the world are available almost instantly, as are audio recordings and videos, lectures and seminars, and colourful illustrations. And now, with the almost forced integration of AI into every search engine, you get AI-generated summaries for every paper even before you ask for it!

Imagine a time before all of this, when there was no internet, no computers, no photocopying machines. Researchers who began their work between the 1960s and 1980s will tell you very different stories. Every stage of research was slower and often far more uncertain than it is today.

Did the presence of hurdles make pre-internet research much harder or more enriching?

Pen-and-paper to printers

"It was a different game. [There were] no computers. The whole process [of writing and editing] took a long time, and when we had to revise, it would start all over again," recalls Kusala Rajendran, former Professor at the Centre for Earth Sciences (CEaS), IISc. In 1980, she joined the Centre for Earth Sciences at Trivandrum as a young geophysicist. After completing her doctoral research at the University of South Carolina, she returned to India in 1993, the same year that the Latur/Killari earthquake struck. She recounts how difficult it was to coordinate logistics out in the field, in Killari, Maharashtra, where she was dispatched for seismic forensic analysis along with her collaborator and husband CP Rajendran. Every step of doing the research – finding accommodation, contacting drivers, and facing multiple language barriers – was difficult largely due to the lack of internet.

Most writing was done manually using pen and paper or typed out using a typewriter. Instead of the comment bubbles that your supervisor now adds to your Google Doc in the middle of night, most edits on paper used to be handwritten. Committed reviewers used to go one step ahead and use red ink and remarks in the margins to suggest changes.

Illustrations for papers were drawn manually. A professional draughtsperson would use references provided by the authors to carefully trace it with India ink on a light-sensitive paper. This tracing would be placed over a sheet of light-sensitive diazo paper and exposed to ultraviolet light in a dark chamber. When placed in a chamber containing ammonia vapour, ammonia reacts with unexposed areas of diazo coating, revealing dark lines wherever the India ink blocks light. Thus, one could get a nice, sharp copy of the original illustration.

Today, getting copies of papers is not really something you would think twice about. There are printing and Xerox centres everywhere and colour printers in almost every lab. However, photocopying machines were introduced in India only in the late 1980s. Before that, researchers in institutes relied on making handwritten copies of papers. In 1879, David Gestetner came up with the design for a machine called the cyclostyling machine, which made taking copies of documents much easier. Using a wax stencil, words were typed out and a stencil would get perforated with holes to give the impression of letters. The stencil was then put on a rotating drum with ink and rolled on paper to get printed text. This method made generating multiple copies of papers much easier.

In countries like the USA, things seemed to have been slightly more convenient for scientists with systems and equipment that made writing and printing easier. Chandan Dasgupta, a theoretical physicist, pursued his doctoral and postdoctoral research in the USA in the 1970s and joined IISc as an assistant professor in 1987. He shares his experience of research outside India.

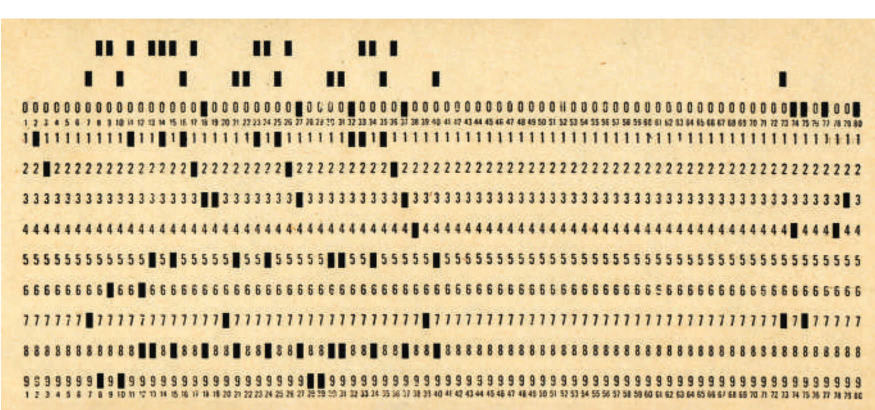


Photo courtesy: Pete Birkinshaw/Wikimedia Commons

Punched card for input in the first generation of computers

Special typewriters were introduced to the market in the USA which made typing out special characters less of a hassle, one of which is the *IBM Selectric* which debuted in 1961. Traditional typewriters had the individual metal swinging arms assigned to each letter, such that when individual letters were hit on the keyboard, the corresponding metal arm would strike the page. The *IBM Selectric* made this system a bit more flexible by replacing the arms with a rotating typeball that had all letters embossed on it, such that it could rotate in different angles to leave an impression of different letters. This also allowed typists to include different scientific notations in the papers, simply by replacing the typeball. For theoretical physicists who had to include a lot of equations in their papers, this proved immensely helpful. However, despite these advancements, researchers still had to write manuscripts manually and give them to secretaries who could type it out properly, since not everyone was trained to use these typewriters.

Running codes for statistical analyses and other calculations was also not as straightforward as it is today. Codes had to be punched on a deck of cards and handed over to computer operators. They would then return the results or required output in 12-24 hours. Most computers now run codes and even detect syntax errors almost instantaneously. However, in the pre-digitisation era, you would realise your mistake only once the output was generated – after 24 hours.

Researchers then also relied on the draughtsperson to get precise and accurate graphs by providing them datasets. Similarly, since data repositories like Dryad, Zenodo, and GitHub didn't exist back then, to get data from graphs in published research papers, researchers relied on the expertise of the same draughtsperson. The draughtsperson would trace coordinates in the graphs and give the relevant data to the researchers.

Another area that modern technologies have revolutionised is accessing information. But what did finding papers or references look like decades ago?

Before Ctrl+F

With search engine optimisation and the system of adding keywords in papers, finding papers in one's area of interest is quite easy now. However, before Google and DuckDuckGo, researchers usually had to resort to following a paper trail of cited publications.

When Gadagkar began his research journey at CES in the early 1980s, he was keen on studying the evolution of social behaviour in insects like paper wasps. His memories of doing science are filled with long hours in libraries, handwritten notes, slow correspondence, and the patience that scholarship once demanded by default. Every part of the research process was slow and yet, seemed to be more “intentional” than it is today, he recalls.

Being a voracious reader, Gadagkar continues to rely heavily on libraries even today. Back then, he had no choice. “We used to go physically to the library to retrieve any kind of information. Very often, we stumbled upon things we were not looking for,” he reminisces. "That doesn't happen today. People borrow e-books and audiobooks but don't go to the library, which actually stocks all of these. The library culture has disappeared.”

Today, all journals are available online. In the 1980s and earlier, however, libraries were the primary source of journals, research papers, and back issues for a student.

Alternatively, students often resorted to snail mailing authors for specific papers in their field of study, especially those published recently. And most authors obliged. “Most journals would provide some hard copies free of charge that the author would distribute on request,” shares Kusala. Papers were mailed by post, delivered via sea or land transportation, and it would take 2-3 weeks. Air mail was a slightly more expensive option that students occasionally relied on, with papers delivered sooner, within 3-4 days.

Around the year 2000, the transition from physical papers to online platforms began, and researchers like Kusala, who moved to IISc after 2005, had full access to online journals.

The current generation also heavily relies on social media to connect to global science. Back then, however, there were fewer researchers in most fields. The overall academic network was much more sparse without the internet, but the network itself was very strong and reliable, according to Gadagkar. Most young researchers sent postcards to authors all over the world to get printed copies and the authors would also very often oblige. Gadagkar fondly remembers how he used to get replies from the authors with a signed printed copy of the paper. “99% of them replied and I could technically access any paper by just sending a postcard. These were signed or autographed. They were valuable and precious to me. I collected them over the years.”

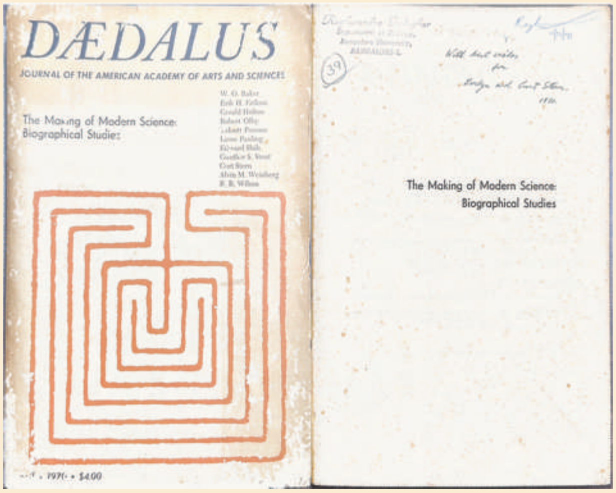


Photo courtesy: Raghavendra Gadagkar

Sample of a signed reprint that Raghavendra Gadagkar received when he wrote to the authors of the manuscript

Academic networking was not easy, but it was meaningful and qualitatively richer, according to Gadagkar. “As an undergrad, I had a good international network,” he says. “Once, I wrote back to a Canadian scientist in marine biology with reference to her work, suggesting improvisation to the published methodology by air mail. The professor was duly impressed and invited me to join her lab as a PhD student.”

Fund-amental issues

Attending a conference is another major facet of academic life. But the number of conferences earlier was fewer compared to now.

In the rare event that students came to know about a conference, it was through a common university telegram system. Consequently, there was also very little funding allocated for such international conferences, as was the likelihood that a student could attend these events.

In those days, funding for doing research as well as setting up labs was low but did not seem to be as limited as it is today, says Vidyanand Nanjundiah, former Professor at the Department of Developmental Biology and Genetics (DBG), and CES, IISc.

“When I was a student doing theoretical work, research life was relatively easy. Later, after joining IISc, I discovered that students had to scrounge on laboratory expenses, especially when something needed to be imported. Even so, my impression is that when it came to doing interesting work, funding was rarely a primary constraint. Student fellowships were small but students were not burdened by the thought of having to raise a part of research funding themselves. In a sense, it was a super abundant environment,” he recalls. Research was “more exploratory” in nature, he says. “Ideas were thrown at you.”

There was a “lot of interest and a sense of purpose among the young researchers,” Nanjundiah adds. “Doing science was fun.”

He also points to how the increased pace of research has now triggered a “big rush” to publish or perish. “All of the things that we consider as easy now – typing out manuscripts, posting on websites, mailing immediately – give the false impression that the system is functioning more efficiently,” he says.

The process of academic research was, is, and will remain laborious and demanding, despite the promise of rewarding results. The internet and digitisation of resources may have improved networking and accessibility to some resources, but the lack thereof was what made earlier researchers resourceful and innovative. On the other hand, competition for funding and resources has considerably increased now.

Every generation of researchers has had to face and overcome unique challenges in their journey. That is exactly what makes the pursuit interesting.

“The whole point of research is that it is not easy,” Gadagkar adds. “Research was never meant to be fast. Where is the fun in doing quick and easy things?”

Souptika Das is a former MSc student at IISc and a former science writing intern at the Office of Communications

(Edited by Ranjini Raghunath)

Clean Reactions

- Sindhu M

The growth of Green Chemistry

Photo courtesy: Durga Prasad Hari

Conventional drug manufacturing frequently relies on metal catalysts and stoichiometric reagents, resulting in substantial amounts of toxic waste. In contrast, Hari's lab utilises visible-light photocatalysis as an environmentally friendly and sustainable approach

A weathered, nearly half-century-old plaque hangs on the wall of Paul Anastas' office at Yale University – an unusual keepsake for an academic. Its story dates back to the 1970s in Quincy, Massachusetts, where eight-year-old Paul watched his neighbourhood wetlands get taken over by glass-fronted insurance and bank buildings. To soothe his distress, his father suggested taking action: "If you really care about something, care enough to learn about it," he said. So, Paul did. He wrote an essay on the wetland, which won the Presidential Medal. "Perhaps more than anything else," he would later admit to The New York Academy of Sciences, "that set me on the direction of wanting to be a scientist and to think about environmental issues."

Among Paul's friends at school was John Warner, a young, creative, and free-spirited aspiring musician, with a flair for the dizzyingly extemporaneous genre of jazz. The two later attended the University of Massachusetts, where Paul majored in chemistry while John studied music and played for the 'Elements' band. John's artistic dreams, however, came to a crushing end when the band's drummer unexpectedly passed away.

John found a tether in elective chemistry and his old pal. The two joined a research group, co-authoring papers before parting ways to pursue doctorates. Paul later ended up at the United States Environmental Protection Agency (EPA). John, meanwhile, became a chemist for the Polaroid Corporation, where he went on to invent a technique for developing photographic images without the toxic heavy metals and acid fixatives used in conventional methods. Called Non-Covalent Derivatisation (NCD), John's method used weaker molecular interactions, such as hydrogen bonding and van der Waals forces, to bind the dye molecules to the photographic substrate.

But under the Toxic Substances Control Act, new chemical processes required approval from the EPA to be scaled up, and John's innovation was rejected. The reason? This method was novel, and the NCD employed molecular interactions with no prior regulatory history. "Because it's different, the EPA made it difficult to regulate," John later told *In These Times*. "Isn't anything that is better for the environment going to be different?"

Polaroid sent Warner to give a seminar defending the technology, and it was there that he ran into the branch chief at the EPA's Office of Pollution Prevention and Toxics – his old friend Paul Anastas. The two old friends realised that they were both working towards more sustainable chemistry practices from different angles. To reconcile the regulatory hurdles, they began working together and introduced Green Chemistry – the design of chemicals and reactions that are benign by intention rather than by regulation. It flipped the focus from managing chemical harm to preventing it in the first place. Their book *Green Chemistry: Theory and Practice*, published in 1998, laid out twelve principles for making chemistry safer and more sustainable.

At first, chemists were sceptical. The orthodoxy held that the breaking and forming of strong chemical bonds demanded heat, high pressure, and aggressive solvents. In chemical reactions, molecules go up a metaphorical energy hill powered by heat, become unstable, and break and reform into products going down the hill. Conventionally, heat is used to push the reactants up the energy hill. Mild and benign, in the prevailing view, meant slow and ineffective.

That assumption began to crack around 15 years later, when Richard R Schrock, Yves Chauvin, and Robert H Grubbs won the 2005 Nobel Prize in chemistry for olefin metathesis – a reaction, often described as a 'molecular dance' where two molecules containing carbon-carbon double bonds approach one another, swap their partners, and part ways. The reaction proceeds under mild conditions, generating little to no hazardous byproducts.

While this convinced chemists that complicated chemical synthesis could be done sustainably, most consequential chemical reactions in industries still stubbornly remain energy-intensive. Green Chemistry faithfuls continued their push, seeking to find areas where they could make a difference.

One such person is Durga Prasad Hari, Assistant Professor at the Department of Organic Chemistry, IISc, who saw an opportunity to manufacture medicines and drugs more efficiently.

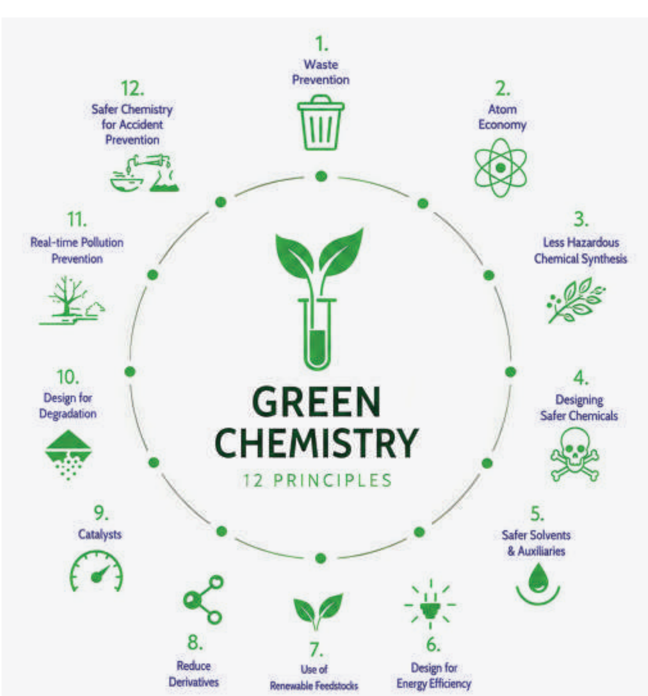


Image: Sindhu M via ChatGPT

The 12 principles of Green Chemistry, outlined by Paul Anastas and John Warner in 1998

The tension within

From ibuprofen to paracetamol, the world is familiar, sometimes overly so, with medications. Interestingly, many of these drugs share a common benzene backbone – a flat ring of six carbon atoms with three alternating electron-rich double bonds. The electron clouds of the double bond hover above and below the benzene ring, available to react and form new connections.

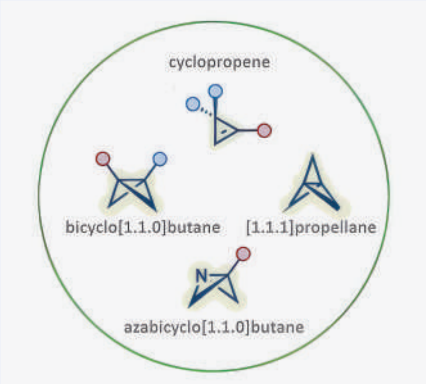
But coaxing them to react is hard. It requires high temperatures to overcome the ring's natural stability, corrosive reagents to activate the right bonds, and toxic solvents that are hard to handle and dispose of. It also produces heaps of metal waste. The conventional method, the Friedel-Crafts reaction, is used to graft carbon chains onto benzene and related rings to build the molecular backbones of drugs like ibuprofen, as well as synthetic dyes and detergents. This reaction uses aluminium chloride as a catalyst, which gets trapped in the final product. So, a fresh batch is used each time, leading to waste piling up.

To reduce these redundancies, Hari looked inward. Rather than providing external energy to the chemical reactions, Hari considered using the energy stored within the compounds. In cyclic compounds, carbon atoms are connected as rings of various sizes. Larger rings, like cyclohexane with six carbons, are more stable, while smaller rings, like cyclopropane with three carbons, are strained because their bond angles deviate from the ideal tetrahedral shape. One cyclopropane molecule is eager to snap open and release the stored energy like a coiled spring, packing about 27 kcal/mol of strain energy.

Hari's team is using this energy within strained cyclopropane molecules to synthesise larger, 3D ring structures called bioisosteres, which can replace benzene rings in drug molecules. "It [bioisostere] is like a TV tower structure with arms and legs stretched out. So, it has a high chance to interact with other chemicals and form stable C-H bonds," explains Hari.

These stable 3D bioisosteres solve another problem. When a patient takes a pill, much of it never arrives at the target site because the double bonds in benzene are oxidised by enzymes in the liver. In comparison, bioisosteres' strong

Photo courtesy: Durga Prasad Hari



Durga Prasad Hari's lab uses the energy within strained cyclopropane molecules, such as cyclopropene, bicyclo[1.1.0]butane, and [1.1.1]propellane, to synthesise larger, 3D ring structures called bioisosteres, which can replace benzene rings in drug molecules

C-H bonds are hard for the liver to degrade, allowing more efficient drug delivery.

Metal catalyst waste in drug manufacturing is a parallel issue, and Hari's group is tackling it by using light as a reagent. Both light and metal catalysts generate short-lived intermediaries such as carbenes, which can reform into the product. Carbenes are carbon atoms with only two bonds instead of the usual four. This leaves two non-bonding electrons, making it unstable and extremely reactive. The two electrons may occupy the same orbital as in singlet carbenes or separate orbitals as in triplet carbenes. Singlet carbenes react in a concerted process, while triplet carbenes react in a two-step process.

Metal catalysts typically generate only singlet carbene intermediates and have hence been used widely. But the catch with light as a catalyst is that it tends to produce a mixture of singlet and triplet carbenes, which can lead to multiple reaction pathways, mixed products, and lower yields, which is a problem when one specific pure compound is needed. So, Hari's team found a way to tackle this – adding high temperatures with light shifts the equilibrium toward singlet carbene, while adding electricity favours the generation of triplet carbenes, opening routes to new chemical synthesis not possible with metal catalysts.

While sunlight – free, abundant and renewable – is an appealing choice to scale up light-powered reactions, it arrives as a potpourri of wavelengths and colours, whereas chemical reactions demand precision. In the large vessels in which chemical manufacturing processes are carried out, blue and green light will be absorbed by proteins and enzymes, leaving the reactants in the dark. The answer to this problem lies at the other end of the spectrum – infrared light, which reaches its target without being ambushed. "We are now developing reactions that run on an infrared light source. It is low in energy, and not many substrates absorb in that wavelength," adds Hari hopefully.

Gentle solvents

In January 2018, commuters skirting Bellandur lake, Bengaluru, encountered a baffling sight – the water body was on fire. Once a wetland teeming with migratory birds, it has since become infamous. A thick, toxic white froth had built on the surface due to detergent waste and effluents discharged from nearby industries. When it ignited, it burned for hours. Interestingly, the chemicals responsible for this are not exotic but rather century-old organic solvents and industrial compounds that are the backbone of chemical manufacturing.

To perform chemical reactions, the reactants must be well mixed within the same solvent. Organic compounds do not dissolve well in water and require excess amounts of nonpolar solvents, such as chlorinated solvents, to fully dissolve the reactants, thereby generating toxic carcinogenic waste.

Green chemists like Susanta Hazra, Assistant Professor in the Department of Inorganic and Physical Chemistry (IPC), IISc, are finding ways to avoid the use of such toxic solvents. "Nature has been performing reactions in water for billions of years," says Susanta. His lab works on detergent-like molecules called micelles, which help perform organic chemical reactions in water.

Micelles are molecules with a water-repelling inner core surrounded by a water-loving outer region. In water, these molecules spontaneously assemble into tiny spheres with the water-repelling cores pointing inward, away from the surrounding water. Grease and oil are captured inside this hydrophobic core and carried away when the water is rinsed off.

Susanta's lab exploits the same structure. The hydrophobic core of a micelle acts as a tiny reaction vessel, capturing organic reactants that would otherwise be insoluble in water. So, the reactants are crowded inside the micelle, and they collide more frequently and react faster. The result is a reaction that proceeds efficiently in water, without organic solvents, and often with better selectivity and reaction speeds.

Chemists have spent a century synthesising chemicals in organic solvents. But for millions of years, living cells have been running complex chemistry such as building proteins, breaking down sugars, and synthesising hormones in water. The secret lies in enzymes – proteins folded into precise 3D shapes to accelerate specific chemical reactions. Debasis Das, Associate Professor at IPC, takes inspiration from nature and uses enzymes to perform organic chemical synthesis in water.

The active site of the enzyme, where reactants bind and the product forms, is buried deep inside the enzyme. It is surrounded by a layer of amino acids that provides a suitable environment for hydrophobic substrates to bind and products to form.

"There are many enzymes naturally that catalyse a wide range of chemical reactions in water, but they have not been explored fully," says Debasis. For

Image courtesy: K Jayaprakash/made using Gemini AI and Blender

The UndB enzyme can be harnessed for the biocatalytic production of hydrocarbons, which have the potential to serve as drop-in biofuels example, the enzyme UndB (a fatty acid decarboxylase) has the remarkable ability to convert fatty acids into terminal alkenes, which are important as fuels, polymers, and lubricants. But the enzyme can only carry out the reaction about 10-12 times before it stops working. To fix this, Debasis' group resorted to protein engineering.

They found that the reaction produces hydrogen peroxide, which binds to the enzyme and inactivates it. To get rid of the hydrogen peroxide, the team added another enzyme, catalase, to degrade it. This substantially increased the activity of the UndB enzyme.

So, they combined UndB and catalase to produce a chimeric protein and cloned it into bacteria. When these bacteria are fed fatty acids and electron-rich compounds, they whip up terminal alkenes – hydrocarbon chains with a reactive carbon-carbon double bond at the end, which are used as versatile building blocks to make everything from lubricants and detergents to plastics and biofuels. The group has successfully taken this reaction from tiny microcentrifuge tubes to litre-scale flasks in the lab. They soon hope to test it in bioreactors with a capacity of 1,000 litres.

Closing the loop

Navneet Kumar Gupta spent his early years in a semi-rural area, closely observing farming life. It was only years later, while training to be a chemist, that he learned how practices such as burning agricultural residues and the heavy reliance on fossil resources contribute significantly to greenhouse gas emissions.

"I wanted to use chemistry for sustainability," he says. That instinct took him through a Master's thesis in biomass conversion at JAIST, Japan and then a PhD in sustainable catalysis at TU Munich, and eventually to IISc, where he is now Assistant Professor at the Centre for Sustainable Technologies (CST). His lab works at the interface of Green Chemistry, focusing on carbon circularity, biomass conversion, plastic recycling and upcycling, and CO_2 utilisation.

Under the Paris Agreement, nations have committed to reaching net-zero emissions by the mid-21st century, and carbon capture and carbon circularity technologies have emerged as key strategies. In parallel, carbon credit frameworks allow industries to invest in carbon-neutral technologies that either permanently sequester CO_2 or convert it into value-added chemicals and materials.

In Navneet's lab, a major focus is on biomass-to-chemicals and biomass-to-fuels pathways, with particular attention to producing aviation fuels and fuel blends. Biomass is first depolymerised into sugars, which can be used to produce furanics. These furanics act as key platform chemicals for fuel precursor production and are further converted into fuel-range hydrocarbons.

As a CO_2 utilisation strategy, the lab is focused on converting carbon dioxide into cyclic carbonates, which can serve as key intermediates for plastic production.

The lab also works on recycling existing plastics. Polyethene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and other common packaging plastics are broken down using catalysts into their original building blocks or chemical intermediates. These can then be reused for producing new plastics or fuel-related chemicals. The carbon in these plastics, originally derived from petroleum at significant environmental cost, stays in circulation rather than being incinerated or landfilled.

The road not taken, yet

Here's the challenge. Greener alternatives are often costlier to develop and implement, giving industries little incentive to abandon established but environmentally damaging processes. "Only the economic costs of chemical reactions are considered, but the cost to the environment is more important," Susanta points out. When a student shows him a reaction that works, his first question is how many of the 12 principles of Green Chemistry does it satisfy?

"Traditional organic chemistry has developed over centuries, with well-established infrastructure and relatively lower costs," explains Navneet. "Green chemistry is still relatively new and lacks the same level of industrial-scale support." To bridge this gap, he emphasises that industry, academia, and policymakers must work together to translate Green Chemistry innovations from the lab to industrial scale.

Photo courtesy: Agrima Pandey/GreenCatLab

High-pressure reactor unit for direct biomass valorisation to fuels and chemicals at severe reaction conditions

India has long promised to tighten its chemical safety regime, with proposals modelled on the EU's REACH (Regulation, Evaluation, Authorisation, and Restriction of Chemicals) framework. But progress has been slow.

When Miteni, an Italian chemical plant, shut down in 2018 after contaminating the drinking water of 350,000 people with per- and polyfluoroalkyl substances (PFAS, also known as 'forever chemicals'), its machinery was dismantled, packed into freight containers, and reassembled in Maharashtra.

India, whose chemical sector is projected to hit a trillion dollars by 2040, must accelerate its transition to Green Chemistry. Otherwise, the costs can be dramatic. The burning lake in Bengaluru reminds one of Rachel Carson's idyllic town in *Silent Spring*, where the birds stopped singing. In that seminal work, she wrote: "The road we have long been travelling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road – the one 'less travelled by' – offers our last, our only chance to reach a destination that assures the preservation of our earth."

Green Chemistry is that road.

Sindhu M is a PhD student in the Department of Bioengineering, IISc and a former science writing intern at the Office of Communications

(Edited by Sandeep Menon, Abinaya Kalyanasundaram)

CONNECT ASKS

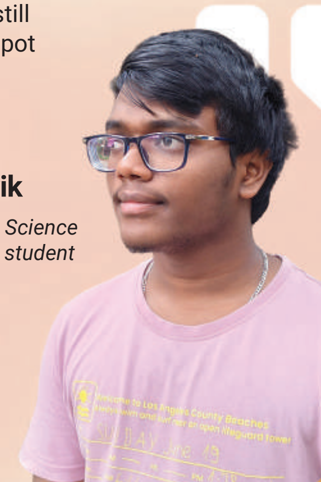
What is your favourite monsoon memory?

The monsoon will always remind me of my childhood days in a small village in Punjab, nearly 15 years ago. It used to rain heavily around July or August. Once the school van dropped us off at home, we'd rush inside, throw our bags on the bed, and immediately run back out in the rain in our uniforms to gather the neighbourhood kids. We'd splash water, dance, and check off a bucket-list dream by playing cricket in the rain. Normally, our village had street-by-street rivalries – say, *gully 1* versus *gully 2* – but the rain united us all into one big group. We'd race paper boats down the street drains, and whoever's boat won got to bat first in cricket later that evening! After the rain stopped came the inevitable scolding from parents, followed by a warm shower, wrapping up in a blanket, and sipping hot tea. Thinking back, I realised those were really golden days.

Keshav Goyal

MMgmt student,
Department of Management Studies

I love getting drenched in the rain – it's so much fun, pleasantly cold, and the cool breeze feels amazing. Having ice cream while it rains makes it even better. Is monsoon my favourite season? Yes, but I don't wait for it too eagerly because winter has its own charm, and summer brings mangoes. But monsoon still holds the top spot for me.



Grandhi VVSM Saatvik

BTech (Materials Science and Engineering) student

During the 2015 floods in Chennai, we had a long break from school. I lived in an area with minimal waterlogging, so all my friends gathered at my place. Because of the power cuts, we had to put our phones away. The weather was unexpectedly pleasant, and we had a blast playing board games we don't usually play, as well as cricket and football outdoors. It was a rare respite from Chennai's unrelenting heat.

Blesso Abraham J

MTech (Quantum Technologies) student, Department of Instrumentation and Applied Physics

I grew up in Madhya Pradesh, where heavy rain only lasted for a couple of months around July and August, so we eagerly anticipated every shower. We particularly used to pray for it to rain in the afternoon, when school ended – our moms couldn't scold us if we got drenched on the way home! One afternoon, it started pouring just when school got over – exactly what I wanted! I cycled through completely empty streets in the rain, and when I reached my housing colony, I found everyone – uncles, aunties, and kids – out in the open, dancing and enjoying the downpour together. Coming from that kind of rare, celebrated monsoon to Bengaluru was a big shift; here, rain can feel relentless! But I still love getting wet in the rain and dancing in it whenever I can.

Shailja Swarnkar

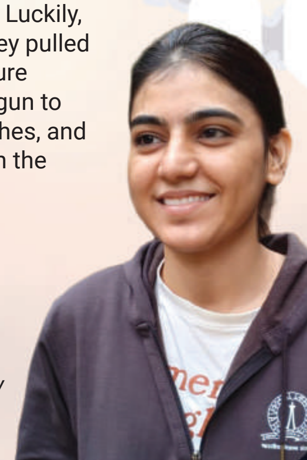
Integrated PhD student, Department of Microbiology and Cell Biology

Bengaluru's monsoon is unique – it rains all the way from May to November, unlike in my hometown in Uttarakhand, where it lasts just a couple of months. As an experimentalist, I often have to commute from the Department of Materials Engineering to the Centre for Nano Science and Engineering (CeNSE) and other departments. And these sudden downpours make it very difficult to adhere to pre-booked slots at other departments (*laughs*). The rain here is completely unpredictable; there are no warning clouds! Back during my first year, when the country was in lockdown due to COVID-19, and I was taking courses online from home, I used to constantly receive emails saying the mess timings were extended due to rain, which made me wonder if the weather was truly that dramatic. Once I arrived on campus, I realised it was all true. But as long as you're indoors – in your room or in the lab – when it pours, it's a welcome change in weather.

Naveen Negi

PhD student,
Department of Materials Engineering

Even though winter is my favourite season, my most vivid memories are all tied to the rain. On Deepavali, I dressed up in my traditional best for a *pooja* at the lab. Midway through my walk from Tunga Hostel to the Chemical Sciences building, the skies suddenly opened up. I was trapped without an umbrella, but as I was already running late, I decided to just keep walking. By the time I reached the lab, I was completely soaked! My lab mates took one look at me and asked, "Is this really how you got dressed for the *pooja?*" (*laughs*). Luckily, being in a lab, they pulled out a high-pressure compressed-air gun to blow-dry my clothes, and I could finally join the festivities.



Poonam

PhD student,
Department of Inorganic and Physical Chemistry

Last year, a friend and I went to the Physics department to check our midterm papers. Once we were done, we saw it was pouring outside, and though we were hesitant at first, we decided to step out after ten minutes and got completely drenched. We wandered over to Jubilee Garden, littered with fallen branches and vibrant flowers. We collected heaps of hibiscus and other flowers to make cool flower arrangements and take photos. Standing in the middle of Jubilee Garden surrounded by all those scattered colours felt straight out of a scene from *Pride* and *Prejudice* – it was absolutely lovely.

Murali Krishna Dirisala

BTech (Mathematics and Computing) student

My favourite monsoon memory happened right here at IISc. Last year, my friend and I got caught in a sudden downpour near Janata Bazaar. At that moment, we didn't care about getting drenched at all – we handed our phones and umbrellas to the security guard and asked him to record us dancing in the rain! It was great fun. Once the rain had relented, on our way back to Tunga Hostel, we stopped outside the Interdisciplinary Research (IDR) building to pluck some beautiful flowers and pin them into our hair. To stay unburdened, we even handed our phones to a complete stranger we had just met (*laughs*)! We simply asked for her room number so we could collect them later. We visited her room an hour later, still dripping wet, and to our pleasant surprise, we discovered she had the cutest pet rabbit! That stranger has since become our friend, and although she has now graduated from IISc, we keep reminiscing about that wild day when we first met.

Pragya Sharma

MTech student,
Department of Aerospace Engineering

(Compiled by Manauv Vyas)

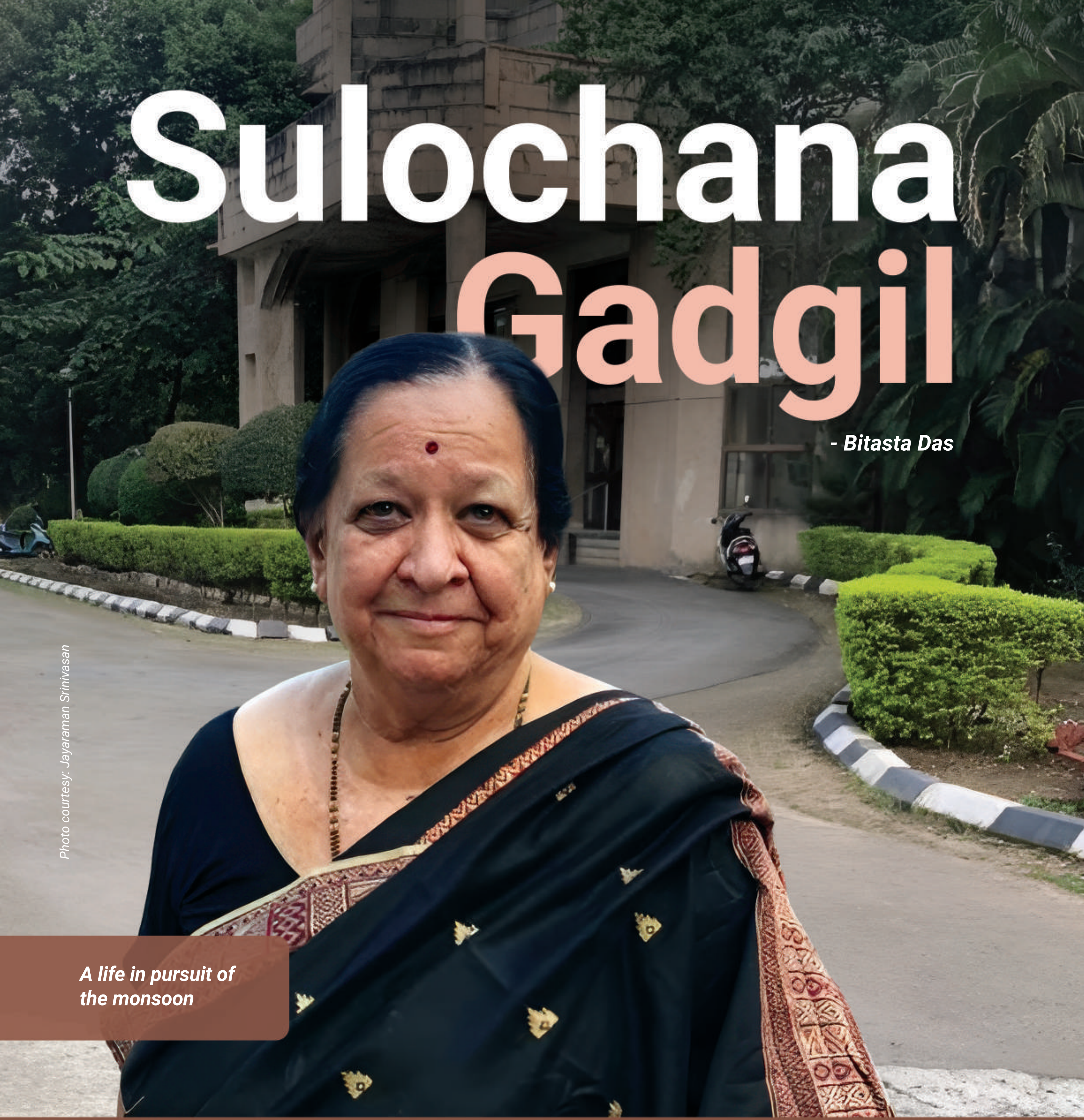


Photo courtesy: Jayaraman Srinivasan

Sulochana Gadgil

- Bitasta Das

A life in pursuit of the monsoon

The year was 1944. Across Poona (now Pune), then in the Bombay Province of British India, the call for Independence echoed through homes, streets, and public spaces. At the heart of the city stood a house that the locals called "Liberty Hall". It belonged to Dr VD Phatak, a respected physician and freedom fighter who had taken part in the historic non-cooperation movement – the Mulshi Satyagraha of the early 1920s. His home was a gathering place for political leaders, activists, and fellow nationalists.

It was in this household that Sulochana Gadgil was born. Her father, the son of Dr VD Phatak, was also a physician with an MD in allopathic medicine. His interests, however, extended well beyond western medicine. He had studied Ayurveda and yoga in depth. Her mother belonged to a vibrant circle of Marathi women writers. As the third of four daughters, Sulochana grew up in a home alive with conversations about medicine, literature, public service, and the nation's future. Yet, unlike most members of her family, she chose a different calling. She chose science. That choice would eventually change the way the world understands one of Earth's most complex weather systems – the Indian monsoon.

Clouds begin to gather

Sulochana's childhood education began in Pune, but it was at Rishi Valley School in Andhra Pradesh that her intellectual temperament found shape. Founded on J Krishnamurti's philosophy of education, the school nurtured curiosity over competition and encouraged students to learn for the sheer pleasure of discovery rather than for scores. It was an outlook that stayed with her.

She chose to remain in the sciences rather than take the more conventional path into engineering

She carried that spirit back to Pune when she joined Fergusson College for her undergraduate studies. She recalled an incident from her college days in her autobiographical article, 'My Tryst with the Monsoon' (*Lilavati's Daughters: The Women Scientists of India*, published by the Indian Academy of Sciences, 2008). During a particularly boring lecture, being unable to sit still any longer, she climbed the classroom's high French window and leapt out. A fellow student, however, noticed this act. His name was Madhav Gadgil, who, years later, became her husband.

Mathematics had captivated Sulochana since childhood. She chose to remain in the sciences rather than take the more conventional path into engineering. She went on to pursue a Master's degree in applied mathematics at the University of Pune. During these years, she and Madhav became engaged and eventually married. Coming from an academic family himself, Madhav believed that they should build not just a life together but also parallel careers in science, a conviction that would shape both their futures.

With scholarships in hand, Sulochana and Madhav left for Harvard University in 1965, where she pursued a PhD in applied mathematics. Drawn to the natural world, she specialised in physical oceanography under renowned American physical oceanographer and mathematician AR Robinson, building a strong foundation in applied mathematics and physics. Exposure to mathematical ecology through Madhav broadened her scientific interests. At the same time, a course in planetary fluid dynamics taught by the renowned meteorologist Jules Charney sparked a lifelong fascination with the monsoon. After completing her PhD, she spent a year as a postdoctoral researcher with Charney at MIT, where she mastered the science of modelling complex systems. This training laid the ground for her pioneering work on the Indian monsoon. It later enabled her to apply mathematical models to agricultural problems, including crop growth, pests, and diseases under a variable climate.

Becoming a monsoon scientist

In 1971, Sulochana and Madhav returned to India. She joined the Indian Institute of Tropical Meteorology (IITM) as a CSIR Pool Officer, where she trained under eminent meteorologists such as R Ananthakrishnan and DR Sikka. These formative years marked the beginning of her lifelong engagement with the Indian monsoon.

"My mother made one small shift in her career from oceanography to meteorology during her postdoctoral studies, though both belong to the broader field of fluid dynamics. It was a deliberate decision, driven by my parents' desire to return to India and contribute to a field where much remained to be explored," says Siddhartha Gadgil, Professor at the Department of Mathematics, IISc, and Sulochana and Madhav's son. Besides Siddhartha, the couple has a daughter named Gauri.

While at IITM, Sulochana was offered a position at the newly established Centre for Theoretical Studies (CTS) at IISc. Founded by the then Director, Satish Dhawan, the Centre was conceived as an interdisciplinary hub that brought together scientists from mathematics, physics, engineering, and biology to tackle complex scientific problems. Sulochana's strong background in applied mathematics and fluid dynamics made her a natural fit for the Centre, which she joined in 1973.

There, she began applying mathematical ideas to atmospheric science, laying the foundation for her pioneering work on monsoon dynamics and ocean-atmosphere interactions. Madhav also joined CTS as a mathematical ecologist. "Many of my parents' close friends are from the CTS days – distinguished biologist Prof H Sharat Chandra, another much younger biologist Prof Vidyanand Nanjundiah, physicist Prof N Mukunda. Slowly, almost everybody moved on to form independent departments," says Siddhartha. Four separate departments came into being at IISc from CTS: Molecular Reproduction, Development and Genetics (now the Department of Developmental Biology and Genetics), Centre for Ecological Sciences, Centre for High Energy Physics, and Centre for Atmospheric Sciences.

Sulochana played a central role in establishing the Centre for Atmospheric Sciences in 1982, with Roddam Narasimha serving as its first Chair. She took over as Chair in 1989 and remained in the position until 1996. During these formative years, she helped establish atmospheric science as a major area of research at the Institute. Under the Centre's evolving research programme, it grew into a leading centre for climate research in India, contributing significantly to the scientific understanding of the monsoon.

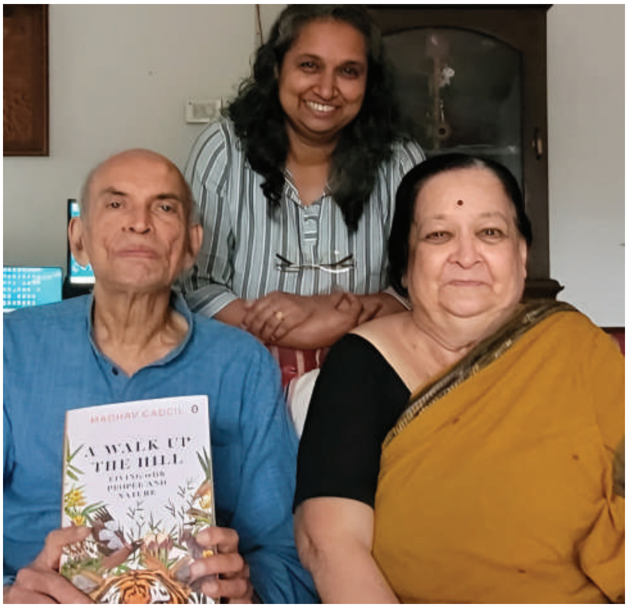


Photo courtesy: PN Vinayachandran

Sulochana Gadgil with Madhav Gadgil and family friend Sunanda

Finding scientific ground

"During the late 1970s and early 1980s, it became increasingly clear that the monsoon was at the heart of India's agricultural economy. The India Meteorological Department (IMD) was primarily focused on short-term weather forecasting. The government wanted the monsoon studied from a longer-term perspective. They sought greater involvement from academic institutions in conducting fundamental research and providing scientific support to the IMD. The Centre for Atmospheric Sciences was established in this context, with a mandate to undertake theoretical studies of the monsoon. Our focus at that time was on understanding climate variability," says well-known climate and atmospheric scientist Jayaraman Srinivasan, retired Professor at the Centre for Atmospheric and Oceanic Sciences and a former colleague and collaborator of Sulochana. "Many things were not available in the 1970s, like satellite data and computing power, yet the centre was able to make original contributions to the understanding of monsoons," he adds.

The Centre's research expanded from theoretical studies of atmospheric dynamics to modelling, satellite observations, and field experiments. In 1996, reflecting its growing interest in the interaction between the atmosphere and the oceans, it was renamed the Centre for Atmospheric and Oceanic Sciences (CAOS). Sulochana was a prolific collaborator, working with scientists across meteorology, atmospheric science, oceanography, and agriculture. Among her frequent collaborators were DR Sikka, PV Joseph, J Srinivasan, PN Vinayachandran, and GS Bhat. Her collaborations also extended to her son, with whom she frequently discussed her work. Together, they examined the links between monsoon variability, agriculture, and the Indian economy, including how monsoon rainfall affected GDP and food-grain production. They co-published two articles.

Photo courtesy: Sulochana Gadgil

Sulochana Gadgil being felicitated in 2016 by Cabinet Minister Harsh Vardhan

The journey takes shape

One of Sulochana's early landmark studies was published in *Nature* in 1984. She and her colleagues showed that monsoon convection over the Indian Ocean increases with sea surface temperature (SST) only up to a critical threshold of about 27.5°C. Beyond this point, warmer waters do not necessarily produce more convection. This demonstrated that atmospheric dynamics play a crucial role alongside ocean temperatures. The finding helped explain the weak relationship often observed between Indian Ocean SST and monsoon rainfall and became an important foundation for later research on monsoon dynamics and ocean–atmosphere interactions. Its significance extended beyond this particular finding: it challenged the simple assumption that warmer ocean waters automatically lead to stronger monsoon activity, highlighting the complex interplay between the ocean and atmosphere. This insight remains relevant to understanding and predicting how the monsoon may respond to a warming climate.

"One could feel the torrential rain when she pronounced 'MONSOON!' She was full of energy and positivity," says Sajani Surendran, Chief Scientist at the CSIR National Institute of Data Science and AI (erstwhile CMMACS, Bengaluru), and Sulochana's student since 1992 and later her associate till the end. "She was an excellent teacher. Her courses on 'Geophysical Fluid Dynamics' and 'Tropical Meteorology and Monsoon' were so popular that they were attended by senior experts, including eminent geophysicist Dr VK Gaur, along with us students."

Sajani fondly recalls that Sulochana strongly believed that, whatever the subject of research, it should ultimately serve the nation and society. "Our work is global in nature. We study phenomena such as the El Niño-Southern Oscillation, mid-latitude weather systems, and processes in the Indian Ocean. But whatever we study has a connection to India, its climate or its economy, because anything that affects the monsoon, directly or indirectly, has consequences for the economy. This was also reflected in Sulochana's work on agriculture, including her studies of groundnut productivity in Anantapur. She examined how sowing dates and the distribution of sub-seasonal rainfall are related, showing how fundamental research on the monsoon could have very practical implications for farmers."

Beyond advancing atmospheric science, she also worked closely with farmers in Karnataka to translate monsoon science into practical strategies

Over the course of her career, Sulochana combined observations, satellite data, and mathematical models to unravel the mechanisms underlying the variability of the Indian monsoon. Her research led to several landmark discoveries, including the identification of northward-moving cloud bands originating over the equatorial Indian Ocean and the crucial role of sea surface temperatures in triggering tropical cloud systems. These findings fundamentally reshaped the scientific understanding of the monsoon, showing that it is part of a planetary-scale atmospheric system rather than simply a land-sea breeze phenomenon. Beyond advancing atmospheric science, she also worked closely with farmers in Karnataka to translate monsoon science into practical strategies for rainfed agriculture, demonstrating how improved rainfall prediction could strengthen agricultural resilience.

Beyond the scientist

Sulochana's pioneering contributions to monsoon meteorology and climate science earned her several prestigious honours. She received the Lifetime Achievement Award from the Ministry of Earth Sciences in 2008 for her outstanding work in atmospheric sciences. She was also honoured with the Norman Borlaug Award for applying climate science to agriculture and the Vikram Sarabhai Award for her contributions to tropical meteorology. In addition, she received the Astronautical Society of India Award and was elected a Fellow of all three Indian science academies – the Indian Academy of Sciences, the Indian National Science Academy, and the National Academy of Sciences, India – reflecting the high esteem in which her scientific work is held.

Sulochana retired from IISc in 2006 after a distinguished career spanning several decades. She continued her association with the Institute as an Honorary Professor until 2011. She passed away on 25 July 2025, leaving behind a life and career that reflected not only scientific accomplishment but also a deep sense of fulfilment.

PN Vinayachandran, current Chair of CAOS, was among Sulochana's students in the early 1990s. He remembers her as a passionate teacher and an inspiring scientist. He recounts her lifelong fascination with the monsoon and her pioneering work in uncovering its connections with ocean science, satellite observations, agriculture, and the economy. "Her fascination for the monsoon is what anybody who met her would remember," he says. He also remembers her as a generous and courageous leader – someone who was always willing to help colleagues and students and never hesitated to raise difficult issues. "She was a great human being," he adds.

Photo courtesy: PN Vinayachandran

Sulochana Gadgil with PN Vinayachandran at her home

"Till the very end, Sulochana continued to enjoy research. Even after she retired and moved to Pune, she would join our weekly 'Monsoon Café' discussions online every Wednesday. Her interest in the monsoon never faded. She was never driven by citations, impact factors, promotions or fame. She published where she felt the work mattered, choosing, for instance, *Current Science* for research relevant to India. She simply enjoyed doing research and had little interest in power or position. That was what made her unique," says Srinivasan.

Photo courtesy: Sanjoy Ghosh/The Week

Sulochana and Madhav Gadgil with their granddaughters, Tara and Revati

He remembers that Sulochana's abiding commitment was to keep national interest at the heart of her work. During her research in Anantapur, where she was investigating how climate variability affected groundnut yields, she invited local farmers to IISc to discuss the issue with scientists. The programme was bilingual: the farmers spoke in Telugu, with their remarks translated into English, while the scientists spoke in English, which was translated into Telugu. The meeting was as much about listening as it was about sharing scientific knowledge. At the end, the farmers thanked Sulochana and expressed their gratitude for inviting them to participate in a discussion about an issue that directly affected their lives. For Sulochana, this was an essential part of doing science – ensuring that research remained connected to the people and problems it was meant to serve.

To Sajani, Sulochana was much more than a distinguished scientist; she was a mentor who shaped the way she approached both science and life. She remembers Sulochana as someone who combined intellectual rigour with extraordinary warmth and generosity. What has stayed with her, among many other things, is the way Sulochana made everyone around her feel valued while remaining deeply committed to research and to the people she mentored.

"She was a very warm, generous, and free-spirited person. She loved cricket, music, reading and good food, and would often bring sweets and delicacies from Pune for her colleagues and friends," Sajani says. She recalls that Sulochana was always ready to help students and colleagues whenever they faced difficulties. Despite her stature as a scientist, she remained approachable and deeply engaged with everyone around her. She was also incredibly dedicated to research. Every evening, she would return to CAOS after work hours for discussions with students and was genuinely interested in every research problem, however small. She was well-read, liberal, and intellectually curious, and had the wonderful habit of laughing wholeheartedly. "That warmth is something I deeply miss," Sajani says. For her, Sulochana's greatest legacy was perhaps not only the science she left behind, but also the people she inspired to think deeply, work generously, and remain curious.

Sulochana Gadgil found purpose and joy in her work, while making space for the many other things that enriched her life. She believed that a fulfilling scientific career need not come at the cost of balance, and her own life reflected that conviction. She wrote in her autobiographical article: "I have always been treated as a capable scientist who happens to be a woman rather than as a woman scientist, and never experienced any gender discrimination. Over the last three decades, as a working scientist in India, I have never witnessed any discrimination against women, whether in the selection of students or for jobs, or in assessment for promotion. In this congenial atmosphere, I believe that women have every opportunity to achieve their potential as scientists."

(Edited by Abinaya Kalyanasundaram)

Nano Hues

- Chandana Valaboju

How small structures create stunning colours in nature

Photo: V Saranathan

Iridescent blue wing scales of the butterfly Morpho aega *at 10x magnification*

In the 19th century, the piercingly blue morpho butterfly captivated the attention of people worldwide; its blue was so brilliant that one could not take their eyes away from it. Understandably, people wanted to extract the colour from the butterflies for human use, such as dyeing clothes or painting vehicles. But when they crushed the butterfly's wings to harvest the colour, they found something mind-boggling. They did not get the magnificent blue powder they were hoping for. The resulting powder was dull grey, or brown even!

How could it be that the same wings, when intact, gave such a wonderful hue but lacked lustre (literally) when crushed? There had already been hints of this phenomenon from the earlier work of two scientists. Robert Hooke, while examining bird feathers under the microscope, noted in his 1665 work *Micrographia* that certain colours seemed to change or disappear when a surface's structure was disturbed – hinting that colour could arise from form rather than substance. Isaac Newton took this further in his 1704 treatise *Opticks*, describing how thin films – of air, soap, or mica – could produce colour purely through their interaction with light, with no dye involved. It would take centuries more, and far finer instruments, before scientists could confirm that this was exactly what was happening on the morpho's wing. The striking blue was due to a neat physical trick called structural colour.

Pigments absorb light of certain wavelengths and reflect the other wavelengths, and the reflected light is what we perceive the colour of the object to be. "Structural colour, however, is a result of light interacting with the organism, including its biological materials. These kinds of colours are made by optical interactions," explains Richard Prum, Professor of Ecology and Evolutionary Biology at Yale University, USA. This interaction changes the nature of the reflected light that we perceive.

If you observe the feathers of a peacock from different angles, the colours seem to change – a property called iridescence. This is caused by nanostructures within the feathers; they interact with light, producing structural colour. The nanostructures do this in two ways. One is by the differential scattering of light – light of smaller wavelengths gets scattered while that of larger wavelengths don't. "Imagine there's a crack in the pavement. If you roll a soccer ball or a basketball over that, the ball will just roll right by. But if you take a tiny little marble and you roll it over the crack, it'll hit it and go blip, right? Its path is disrupted," Richard elucidates.

'Structural colour is a result of light interacting with the organism … made by optical interactions'

The other way is when light interferes with or is reflected by the nanostructures, depending on how they are arranged, how far they are spaced out, and how light passes through them – leading to brilliant, selective reflection of colour.

Unlike pigments, structural colours can produce vivid hues, as the light that emerges after interacting with the nanostructures is a very narrow set of wavelengths. In pigments, a whole bunch of wavelengths are reflected, which reduces the sharpness of the colours.

Structural colour can coexist with traditional pigments as well. "The phenomenon works kind of like a filter. They come in different layers – the structure selects some portion of light, and then the pigment further reduces that portion," explains Vinodkumar Saranathan, Junior Professor Chair at the Research Institute on Insect Biology, University of Tours, France.

Structural colours are widely prevalent in nature. Some cuts of meat display iridescence too, due to the periodic arrangement of the muscular fibres. Groups of bacteria of a certain shape, and when arranged in a certain way, are iridescent. There are also certain types of viruses, called iridoviruses, which cause "optical infections", meaning they impart a bright blue or purple iridescent colour to the organisms they infect. The colours are due to patterns of packed protein crystals.

Photos courtesy: Frank Vassen/Wikimedia Commons (top); Richard Prum (bottom)

The brilliant green and blue eye wattles of the male velvet Asity (Philepitta castanea) *are produced by light scattering from hexagonal collagen nanostructures (right). In the dense Madagascar rainforests, the bright colour contrasts beautifully with their pitch-black coats and helps attract mates*

Despite the multitude of ways in which structural colour occurs in nature, research on the topic is sparse. Many researchers now focus more on fabricating structural colour for human use rather than understanding its function in nature. We know only little about why certain organisms use structural colour over pigments (and vice versa) and what molecular factors control structural colour. For example, we know that iridescence helps with ecological behaviours like camouflage, but we are not entirely sure how this differs from pigment-based camouflage.

The main reason is that fabricating structural colours in the lab to understand their natural functions is hard – experiments mandate replicability, and repeatedly fabricating similar structural colours can be tricky and costly. Modern techniques are still not quite able to faithfully replicate the nuances of structural colour found in nature. “You would imagine that there have been a lot of people studying peacock feathers, but there are very few,” says Renee M Borges, Professor at the Centre for Ecological Sciences (CES), IISc. “People have modified the number of eyes in the peacock’s tail feathers artificially, either by painting them out or attaching new feathers, but haven’t actually manipulated the structure.”

Modern techniques are still not quite able to faithfully replicate the nuances of structural colour found in nature

Undeterred, some scientists are exploring the causes and consequences of structural colour out in the wild. Though it requires more complex tools, it lets them peek directly at the natural phenomenon instead of struggling with an imperfect replica in the lab. They are now slowly uncovering the myriad mysteries of structural colour in the natural world.

Photos courtesy: Charles J Sharp/Wikimedia Commons (top); V Saranathan (bottom)

The moth Urania fulgens *produces iridescent green-and-gold colouration through microscopic wing scales (right: 10x magnification) that refract light. A day-flying moth, it cannot rely on camouflage for safety and uses bright colours to signal toxicity*

Costs and causes

Evolution and biology are all about cost versus benefit. Plants, for example, need colourful flowers to attract pollinators, but the energetic cost to achieve those colours can be high. There is a substantial body of work on the use of colour in animal and plant signalling. But we know little about the relative costs of colour achieved via pigments versus structural means.

A few studies have shown that there is a considerable difference in the energy that creatures have to invest in producing colour through pigments versus through structural colour, which could be one reason why pigments are more common in nature than structural colour. “Structural colour needs more material in general than colour just due to pigments. So, it could be like an additional resource investment to produce those fine structures, and they need to be finely regulated too,” ventures Humberto Herrera-Ubaldo, postdoctoral researcher in the lab of Beverley Glover at the University of Cambridge, England.

Preliminary studies of birds’ genes have revealed that non-iridescent (non-structural colour) feathers need genes which consume a lot of resources for protein production, like pigmentation, metabolic, and mitochondrial genes. On the other hand, iridescent feather development is associated with structural and cellular organisation genes, which may also require significant cellular resources. Once the structural colour material is produced, the cell then has to expend extra resources to arrange them into the final macrostructures. We don’t have a definitive answer on the energy expenditure differences between the two pathways.

Another interesting question is why structural colour adopts similar forms in insect scales and bird feathers from evolutionarily distant families, despite their mostly independent origins. Saranathan, who works on evolutionary photonics, studies this by comparing the structural colour manifestations across species. “Taking inspiration from D'Arcy Thompson [a 20th-century Scottish biologist], we study how one structure has evolved from another structure by understanding the molecular and physical forces that drive these transformations. For instance, we investigated how and why some leafbirds have evolved a space-age crystal structure called single gyroid in their feathers from ancestors that had random spaghetti-like networks – this is driven by female preferences for pure structural colours," he says.

His lab has also studied tarantulas and found that iridescence was lost in the species and then was regained. "There's no pattern to explain why," he says.

What controls structural colour? Is it a single gene? Researchers say probably not. "I think it's not really one gene because there are multiple ways to achieve the same structures or processes by altering different pathways," Humberto comments.

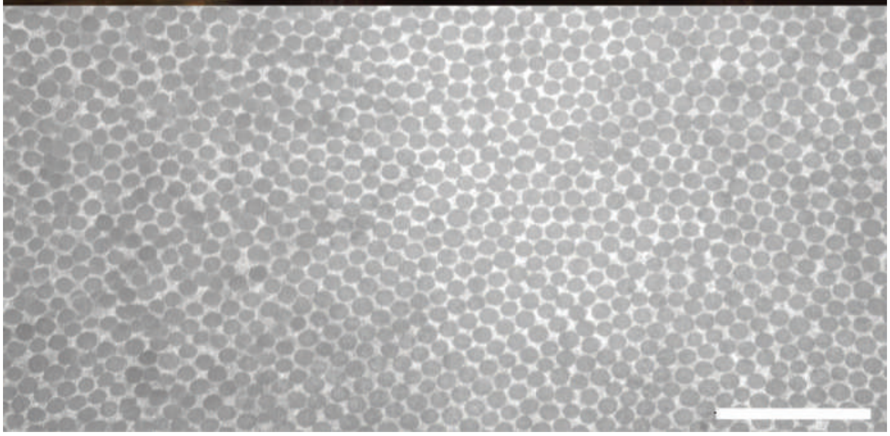
Preliminary molecular biology studies are now giving us hints about what goes on behind these brilliant physical phenomena. In buckeye butterflies, the thickness of laminae, a kind of nanostructure on the wings, is thought to be mediated by the *optix* patterning gene, which affects their colour.

In another species of butterflies, a gene called *cortex* controls the colour of the wing scales. Genomic analyses of species of bacteria whose colonies display structural colour indicate that the pterin (an organic compound) pathway is involved in the clustering of bacteria, which in turn is responsible for the colour. Hormones can impact the colour, too. Testosterone exposure in female common parakeets, for example, changed the colour of a structure on their beaks from brown to blue, the latter being the colour in male counterparts.

"A single gene or a factor for structural colour is virtually impossible," says Renee. "There are no genes for assembling complex structures, as far as we know. There are genes for making the materials, but there's no instruction guide for how those materials are actually laid down."

Selecting for colour

If structural colour is costly to produce, why do organisms still use it? "There are two things that influence the colour of an organism – what pigment molecules or nanostructures it can make, and what selection is acting on the colour of the species in the life of the animal: protect it from predators, attract mates, and so on," Richard remarks.



Photos courtesy: Matt Sabbath/Wikimedia Commons (top); Richard Prum (bottom)

*The striking blue facial skin on a male mandrill (*Mandrillus sphinx*) is created by coherent scattering of light off quasi-ordered collagen fibres (right). It is an indicator of a male's health and a tool for social signalling and mate attraction*

Just because an organism has structural colour doesn't mean that it needs structural colour to survive. Certain beetles, which burrow in the soil but can't really see, still display structural colour. The materials causing their colour are self-cleaning hydrophobic scales that prevent them from getting wet, an example of accidental colouration.

Structural colour is excellent for camouflage and can serve as a social or mating signal

In other cases, colour is due to natural selection – it provides certain fitness benefits to the organisms and helps them survive better. Structural colour is excellent for camouflage and can serve as a social or mating signal. Reef fish make use of it to blend in with colourful corals. Sometimes, only one sex of a species displays structural colours, and it plays a role in how animals choose their mates.

For example, the depth of blue structural colour on the testicles of a male vervet monkey indicates its degree of dominance within the troop!

Structural colour can work as a defence mechanism too; rapid changes in colour or brightness, and dangerous-looking colours can scare off predators by indicating toxicity. The surface of an insect can be such that even a small change in angle can dramatically alter the colour, which can scare predators like birds.

It can also act as a sign of health. "If an iridescent bird does not have a really striking colour, it means maybe it's an old bird, has been damaged, attacked, or it indicates health levels as well," remarks Humberto.

Compared to animals, there are relatively fewer instances of structural colour in plants. "Structural colours in animals are plausible because of the modification of surfaces; for instance, the surfaces of insects are made of chitin and that would allow the kind of easy deposition of layers of materials, which is fundamental for structural colouration. However, plants are made of other materials, and that might be a reason why," ventures Humberto.

There have been documented cases of structural colours emerging independently in several families of flowers; though we don't know the exact reason, researchers speculate that structural colour confers some benefits, such as attracting pollinators.

Structural colours are not only for visible light. If the nanostructures are small enough, they can have a similar effect on ultraviolet light, too. Plants make use of this form of structural colour to attract more pollinators. "It's like one more signal to pollinators to advertise, to come visit the flower," says Saranathan. In the Colorado blue spruce tree and the succulent plant Britton's dudleya, the materials that confer structural colour reflect shorter wavelengths of light, which leads to UV protection. In spikemosses as well, such materials enhance the reflection of blue light and absorb more red light – possibly for improved photosynthesis.

Hurdles in studying structures

Research on structural colours has so far focused more on their applications in daily life, such as in clothing, cosmetics like nail polish, printable structural-colour devices (like MorphoChrome), and anti-counterfeiting methods. "I think that one reason why structural colouration is studied more in the realm of physics and has not yet made its way into the biology (functional) kind of studies is because of the difficulty of accurate and consistent measurements," comments Renee.

Photos courtesy: Cambridge University Botanic Garden (top); Humberto Herrera-Ubaldo and Beverley J Glover (bottom)

The dark purple centre of the Hibiscus trionum *flower produces an iridescent sheen through structural colour. A cross-section of a petal epidermal cell (right) shows the wrinkled cuticles, which act as a diffraction grating that splits and bends light waves. This vibrant structural hue at the centre helps insects locate nectar (Scale bar: 2 micron)*

Pigments are relatively easier to study – scientists use a spectrophotometer to measure the absorption or reflectance spectrum, which gives us information about the properties of the molecules in the pigments. But with structural colour, the colour depends on the angle of view, making it difficult for labs across the world to measure and characterise colour accurately.

Pigments are also easier to fabricate and experiment with – it is easier to make different hues through formulations of different pigments than tweaking the parameters of structural colour. Generating colour cards or choices, which is what people do with pigments to study insects being attracted to flowers, is very difficult to do with structural colour.

Some of the techniques used in fabricating structural colour may not work when scaled up. Fine instrumental and human errors can lead to irregular colours, which defeats the purpose of replicability. Additionally, it takes a very long time to fabricate the fine variations in appearance that occur naturally; the studies would not be accurate until we can achieve this. Different organisms perceive different kinds of light, hence one has to be mindful to factor this difference into experiments.

Nevertheless, nature has countless hidden mysteries about structural colours that are waiting to be explored. It turns out that most blues in nature – like the brilliant blue of the morpho butterfly – are structural colours. "That is something quite interesting also to examine from an evolutionary perspective, as to why there are a lot of yellows and reds [in pigments] and why blue is mostly structural colour," remarks Renee.

Scientists are keen on exploring more of these ecological and molecular mysteries. "These are difficult areas, yes. But they are very interesting. We must always be looking for these different things that have not been worked on extensively," Renee adds.

Chandana Valaboju is a third year BSc (Research) student at IISc and a former science writing intern at the Office of Communications

(Edited by Rohini Subrahmanyam, Abinaya Kalyanasundaram)

Third Spaces for Science

- Rohini Subrahmanyam

How informal settings unlock new ways of thinking

Colloquially called an "adda", scientists gather to chat, ideate, and relax over coffee at the Department of Physics, IISc

Photo courtesy: IISc Photography Club

When he started working at IISc many years ago, Rishikesh Narayanan used to pull people from his lab to get coffee at Prakruthi, an outdoor campus cafeteria that closed down in 2020. “I am a coffee addict,” says Rishikesh, now Professor at the Molecular Biophysics Unit (MBU).

But it wasn’t just about the coffee. Between sips, their conversations traversed many topics, ranging from *Star Wars* and *Kung Fu Panda* to dinosaurs and physics. Inadvertently, these informal chats would meander towards interesting scientific ideas. “There are several instances where the fundamental ideas that came to define the PhD projects of several students came up at Prakruthi,” Rishikesh says.

‘The advantage of these informal discussion spaces is that it's very ‘no strings attached”

Many scientific discussions are structured and planned, held at labs, faculty offices, classrooms, or conference venues. But informal spaces – like canteens, common rooms, or sports grounds – can foster just as many scientific conversations. In fact, some campuses have deliberately designed such spaces by placing blackboards, benches with tables, and comfortable seating in common areas, where researchers can mingle outside of their labs.

Sometimes, these spontaneous chats lead to serendipitous publications or even a successful long-term collaboration. But even if nothing substantial comes out of such unstructured discussions, many scientists believe that they are essential to keep the spark of scientific curiosity alive.

“The advantage of these informal discussion spaces is that it's very ‘no strings attached,’” says Purvi Gupta, Associate Professor in the Department of Mathematics, IISc.

“Something tangible can come out of it, or it's just a nice conversation that is enriching in other ways – you can just enjoy the conversation.”

Spaces for spontaneity

If you walk through the Department of Mathematics at IISc, you will see many blackboards at the ends of corridors, on the terrace, and even in some small cut-away spaces with tables and chairs. When Purvi was a student at IISc more than a decade ago, these blackboards were fully out in the open, but monkeys would often disrupt the mathematicians trying to use them. Eventually, the department installed glass windows around the areas and grills in one of the terraces. “Even faculty members who have their own office spaces sometimes choose to have discussions with their students or with other collaborators in these spaces because they are a little bit more open,” says Purvi. “You can enjoy the greenery.”

Another plus point of these spaces is that they help researchers leave behind the clutter of their office desk and other pending work and focus entirely on the discussion, Purvi says. She has noticed students from other departments use the little nooks as well.

These little spaces were first conceived by Gadadhar Misra, former Chair of the department and presently Visiting Professor at IIT Gandhinagar. The push arose from a practical need – before the rooms were completed in 2011-12, there was not enough space in the department for people to meet, as the lecture halls would always fill up.

Gadadhar particularly likes the open terrace with the blackboard right at the top of the maths building. An office can make one feel more claustrophobic, he says, especially for intense mathematical discussions. “The fact that you can walk up and down brings a kind of feeling of freedom that you can let your thoughts not be restrained in any way,” he explains. “That openness basically allows you to feel free.” He likens it to how people writing poetry sometimes prefer sitting out in open, scenic spaces to observe nature as they write.

Some mathematicians like to convene at cafeterias over a cup of coffee, which then evolves into a much longer conversation. Gadadhar remembers this being very common in the USA from his PhD days. “There are many movie scenes where you take a napkin in a cafe and start scribbling on the back of a napkin,” he says. “And that often becomes an intense sort of discussion leading to very meaningful results that ordinarily you wouldn't have anticipated. You wouldn't have walked into that coffee place thinking that that's what you would be doing.”

Purvi also recalls seeing some colleagues working from the campus cafeteria the entire day, wherever such spaces exist on the IISc campus and elsewhere. “It's very strange that despite all the comforts in your office, it's sometimes actually nice to just go sit on a plastic chair and table near a cafeteria – somehow that is more conducive [for work],” she says. “As soon as you have some amount of seating, people flock to it, even if the food is terrible – it shows you how much need there is for such spaces.”

“I think a lot of scientific creativity and scientific activity often happens in an

Photo: Rohini Subrahmanyam

Terrace-like spaces surrounded by greenery at the Department of Mathematics, IISc, encourage scientific discussions outside of the confines of offices unstructured mode," says Rajesh Gopakumar, Director of the International Centre for Theoretical Sciences (ICTS-TIFR), Bengaluru. "The new things, at least the beginning of a new thing, often happen through a conversation over a coffee or lunch or something. And the spaces need to give that ability to have more of these serendipitous conversations or interactions."

'There is a subtle way in which I think architecture influences your thinking if you're in a closed room as opposed to a place with a lot of light'

The idea of keeping open discussion spaces was a major driving force in the initial design and layout of ICTS. "There's a sense that you can think big thoughts, so to say," Rajesh says. "There is a subtle way in which I think architecture influences your thinking if you're in a closed room as opposed to a place with a lot of light." The pleasant Bengaluru weather also makes it easy to have discussions out in the open.

There are many spots for faculty members and students to bump into each other for conversations at ICTS – be it an open space with tables and chairs, a small cafe/snacks counter called the Bhaskara square, the main cafeteria, or the various blackboards nestled in various nooks across the campus.

Some of these boards have various squiggly equations scribbled over them, some have chairs nearby for scientists to rest their feet even as they continue to wave their chalks about, discussing animatedly. And, as Rajesh says, they are all strategically placed in various open locations for one main purpose – encouraging the spontaneous expression of ideas. "[In] a lot of the maths, physics, theoretical areas, the thinking is often very much mediated by the blackboards," says Rajesh. "So, that's why they are spread all over in our institute, even in the cafeteria." He likes the informal, ephemeral nature of the boards – how one can just wipe them clean and start afresh.

Photo courtesy: Debdutta Paul

Outdoor spaces at the ICTS campus are dotted with many blackboards covered in scientific scribbles

Sometimes the blackboards turn into art displays. A former ICTS student, Manish Jain, had used the boards as a canvas for whimsical drawings, particularly a chalky version of Van Gogh's *Starry Night*. "I like it when it's used as a collective space, as a medium of self-expression in some ways," Rajesh says. "It's not only that you're expressing your research ideas and thoughts, but you share a joke, or you share some funny statement there. It gives a kind of feeling that this is a home for creative people."

The importance of informality

Outside spaces may physically feel more liberating and thus encourage casual, scientific conversations. But no matter where one has them, the informal, open-ended nature of these conversations in itself offers a sense of freedom. "You don't have constraints," says Suryanarayanan (Suri) Vaikuntanathan, Professor at the University of Chicago. "You can do what you want to do when you want to do [it]."

While at a conference at the Kavli Institute of Theoretical Physics (KITP) in Santa Barbara, California in June 2026, Suri and a colleague chatted about work over a run. Eventually, they took their conversation to a blackboard found on campus. This completely unstructured talk helped them iron out a problem that they were both stuck on, and Suri thinks that not having a specific agenda might help in finding new ideas. "You're not coming in and saying, 'I have a question that I want to answer,'" he says. "But you talk about what you have done, you let it seep, and then it nucleates something."

Such informal conversations help scientists get to know their colleagues or visitors better. KITP hosts many scientists at its multi-week conferences, which typically have only one or two scheduled talks per day. The rest of the day is deliberately left free for the scientists to mingle and chat.

Martina Dal Bello, Assistant Professor at Yale University who was involved in organising the KITP conference this year in May-June 2026, shares that even the residences where the visiting scientists stay have large common rooms with comfortable couches and open spaces with multiple blackboards. And as soon as dusk sets in, the barbecue grills in the residence grounds would immediately light up, serving as a casual space for the scientists to relax, unwind, and discuss science.

Photo courtesy: Debdutta Paul

Some ICTS blackboards have become canvases for chalk art, like this one depicting Vincent Van Gogh's Starry Night by former student Manish Jain

Rishikesh believes that casual conversations should also be encouraged amongst members of the same lab, as it can help build camaraderie. “Seniors help juniors and juniors have newer ideas, which are not confined by coursework,” he says. But for this, he adds, it is extremely important that supervisors not make themselves the centre of every informal conversation amongst the lab members. “It's important to have these subgroups, individuals talking to each other,” he says.

Spontaneous discussions “serve the purpose of creating a sort of connective tissue among group members, so that they feel like, ‘okay, we can be in an informal space and still talk about science’, and maybe it's less stressful than, ‘oh, we have to meet to discuss that with a laptop,’” Martina says.

Informal, open-ended chats can also help supervisors better understand the students’ deeper motivations and discuss any other issues that they are facing. In addition to creating a healthier work environment, such impromptu conversations can help students ideate and better define their projects.

Doing a PhD requires research, publishing papers, and graduating, says Rishikesh. But it is also an inward journey for students. “You are learning who you are, what you want, what motivates and interests you. [The PhD] just comes to define that stuff,” he says. “And such informal discussions allow you to have insights about yourself, dive deeper into who you are and what you want to do.”

Casual conversations

Whether or not there are dedicated campus spaces for scientists to hang out, researchers still find ways to talk to their colleagues or students in a casual setting. Martina, for example, likes to corral her entire group towards lunch together. “At a certain point in the day, everyone has to eat. My intent is to try to have at least this space during lunch where people can actually gather, and it's less formal than a group meeting,” she says.

Similarly, Rishikesh also likes taking his lab for coffee or whenever there is a reason to celebrate – like someone finishing their comprehensive exam successfully, or a paper getting accepted – they take a walk towards New BEL Road for a meal, which gives plenty of opportunity for the students to chat amongst themselves as well.

Even walking back towards home from the lab can provide space for a casual work-related chat, something Rishikesh recalls doing with one of his former graduate students, Pavithraa. As they paused to part ways near the Main Building, they chatted for many hours about a particularly sticky point in her project and ultimately made a breakthrough.

Purvi also makes it a point to visit the Faculty Club at IISc for lunch to meet and chat with colleagues outside of her field and recalls explaining her work to them over games of table tennis. “Often when you play with your colleagues, one of the first questions is ‘what do you work on?’ But talking to somebody across departments forces you to think about how to express your research to somebody in a different area. You try to connect it to what they do,” she says. “If I'm not meeting with them to play something, that conversation may never happen.”

There is no doubt that researchers across the IISc campus, including Rishikesh, would love to gather in a Prakruthi-like space on campus again. Even outside of its cafeterias, IISc has historically – sometimes unofficially – offered many informal spaces for scientific chats. Gadadhar fondly recalls sneaking onto campus back between 1995 and 1998, when he used to work at the Indian Statistical Institute, Bengaluru, to meet his physicist friend Cherian Varughese who was establishing his own startup at the time. They would sit and chat on some stone benches nestled in a formerly green area behind what is now the administrative block. They met regularly for about three years and finally ended up writing a couple of papers together based on what they discussed. “I'm very, very happy that IISc let us do that,” he says. “Having such a nice environment with trees, [the] library was right across, there were perhaps some coffee places that one could go to. It was very nice.”

What connects these casual conversations is that they are not initiated with the thought of, as Rishikesh puts it, “this is an informal space, I will go there and talk about science.” He likens it to transcendental meditation; “let it flow as it flows,” he says. “Many times, nothing happens; it's a conversation, if nothing else, at least it's stimulating. You get aware of some new things that are happening,” says Rajesh. “But at its best, it can maybe spark a collaboration or a very new idea.”

(Edited by Abinaya Kalyanasundaram)

Photo: Rohini Subrahmanyam

Apoorva Khare, Professor in the Department of Mathematics, likes to use the blackboard in the corridor to discuss maths with his students

Tracking Tiny Migrants

- *Kavi Bharathi R*

How insects traverse impossible distances

Photo courtesy: Jeevan Jose/Wikimedia Commons

The tiny globe skimmer dragonfly covers an astonishing 14,000-18,000 km migration circuit between India and Africa

Somewhere over the Indian Ocean, the globe skimmer (*Pantala flavescens*) flaps its delicate golden wings, beginning a remarkable relay journey covering up to 14,000-18,000 km between India and Africa. These small insect travellers measure about 4-5 cm in length and are no heavier than a paper clip, yet they hold one of the longest insect migration records.

The globe skimmer is one of the most common dragonfly species in the world. With their golden brown bodies, they are adept at travelling long distances, guided by innate cues. Even if they have never travelled to a location before, they know exactly where to go, displaying an incredible instinct for direction. Similarly, the painted lady butterfly travels over 7,000 km from Europe to South America, while the majestic monarch butterflies cover 5,000 km from Mexico to Canada.

These migrations are fascinating, but they aren't easy for scientists to study – the creatures are often too small to track and too fast to follow. Long-term field observations, novel tracking instruments, and drones – even scientists chasing them in aeroplanes – have helped to a large extent. Yet, many questions remain unanswered. How do creatures so small know when to leave? How do they find their way across landscapes that they have never seen before? And how do we track insects that can disappear into the sky?

These and similar mysteries continue to stump entomologists and researchers around the world.

The paradox of size

Patrick Guerra, a neuroecologist and independent researcher in the USA, is one of them.

"As a student, I wanted to become a police detective. Instead, I became a different kind of detective – one who investigates how insects navigate across continents," he says.

Patrick points out that people often ask him why he studies insects instead of more complex animals such as mammals. For him, the answer lies in the monarch butterfly's remarkable simplicity.

"The monarch has a brain the size of a pinhead, yet it still performs the same kind of computations and decision-making that humans use to get from A to B," he explains.

One might assume that because of their size, insects are less efficient at migration than larger animals, but this is not true. "Insects have well-developed navigation systems. For instance, bees and ants have splendid evolutionarily driven mechanisms to navigate, interpret environmental cues, and respond to factors like flower colours and distances," says Gerard Talavera, evolutionary biologist and entomologist at the Botanical Institute of Barcelona (CSIC), Spain.

Photo courtesy: Ryan Moehring/US Fish and Wildlife Service via Flickr

A tagged monarch butterfly at Quivira National Wildlife Refuge. Each tag weighs about 0.006g, approximately 1.2% of the mass of an average monarch

In recent years, scientists have started combining established tools with newer approaches to track insect movements and trace their flight routes. Vertical radars, for example, help entomologists precisely track the motion of an entire moving swarm of insects and follow their travel routes.

'As an engineer, to see that such migrations are actually possible seems almost like a fairy tale'

One of the earliest methods used to track insects in the 1950s and 1960s was the use of coded stickers. Canadian zoologist couple Norah and Fred Urquhart tracked monarch butterflies for decades by attaching tiny coded stickers to their wings. Each code marked the location where the butterfly had been tagged, allowing researchers to determine the origin if it was later recovered elsewhere.

Modern approaches use miniature radio transmitters that emit signals to nearby receivers, but these remain difficult to use on flying insects because the devices can alter their aerodynamics. Researchers are therefore developing lightweight tags that can be attached to the insect's thorax, says Patrick. These work better for larger, ground-dwelling insects such as beetles and mormon crickets, where additional weight has less impact on insect movement.

Researchers also rely on radar systems to monitor insect movements. "Ground radar can detect swarms and distinguish different groups of insects by their unique wingbeat frequencies," says Patrick. This allows scientists to identify whether passing migrants are butterflies, dragonflies, or other insects.

"Another way of looking at migrating insects is isotope labelling, which can provide an idea of the location where they emerge from," explains Sandeep Saha, Associate Professor at IIT Kharagpur. "By analysing the heavy water content in the wings, we can estimate the origin." Lakes and ponds that dragonflies emerge from have distinct levels of heavy water, allowing researchers to pinpoint the source.

Sandeep finds studying these tiny creatures quite rewarding. “As an engineer, to see that such migrations are actually possible seems almost like a fairy tale,” he adds.

Image: Abinaya Kalyanasundaram

Proposed migration route of the globe skimmer, which covers a roughly 14,000 km loop between India and East Africa. They begin in India around October, following the retreating monsoons in search of ephemeral pools to breed in. They may stop over in the Maldives and Seychelles, where they breed, and successive generations move to East Africa by November-December; the return crossing is in May-June, aided by strong tailwinds from the Somali Jet

Uber in the sky

Sandeep is currently studying the globe skimmer dragonfly migration across the Indian Ocean using a combination of computer simulations and experimental techniques. Drawing from insights into bird migration, they have estimated the energetics involved in insect flight by calculating the creatures’ energy reserves (the fat stored in the insect’s body). This allows them to assess how long the dragonflies can continue flying over long distances.

Sandeep and others have also found that insects can't reach their destination by flight alone. They simply don’t have enough energy. What, then, carries them across such vast distances?

It turns out that wind plays a large role in shaping migration, ferrying insects to their locations like taxicabs.

“Many migratory insects are so tiny that they are not going to fly thousands of kilometres; instead, they fly up, and then are transported by wind,” says Saskya van Nouhuys, Associate Professor at the Centre for Ecological Sciences (CES), IISc. “Seasonally, the wind directions change, so once the insects go up in an updraft, they also travel in different directions seasonally. Lots of really tiny insects like plant hoppers move like this.”

To understand how wind shapes migration, Sandeep’s team performs Earth-scale simulations and uses graph theory to predict routes that insects are most likely to take. These computational models are then validated in a wind tunnel experiment, where insects are flown under carefully controlled wind conditions. "We try to see if what we learned from our theory and simulations matches what we find in the experiment," says Sandeep.

The need to move

Like other animals, insects migrate primarily in response to seasonal changes that affect temperature, rainfall, availability of food, and breeding habitats. “While the exact triggers are still not fully understood, scientists believe that migration is initiated by a combination of environmental cues such as day length, temperature, wind conditions, and resource availability. Different species then rely on different navigational cues, such as wind, the Sun or Earth's magnetic field, to reach their destinations,” says Vishwesha Guttal, Professor at CES.

‘Many migratory insects are so tiny that they are not going to fly thousands of kilometres; instead, they fly up, and then are transported by wind’

The monarch butterfly is often called the king of butterflies. Unlike migratory birds, these orange and black-veined flyers navigate using a combination of external and internal cues. They primarily use the Sun as a compass along with an internal circadian clock to adjust their orientation.

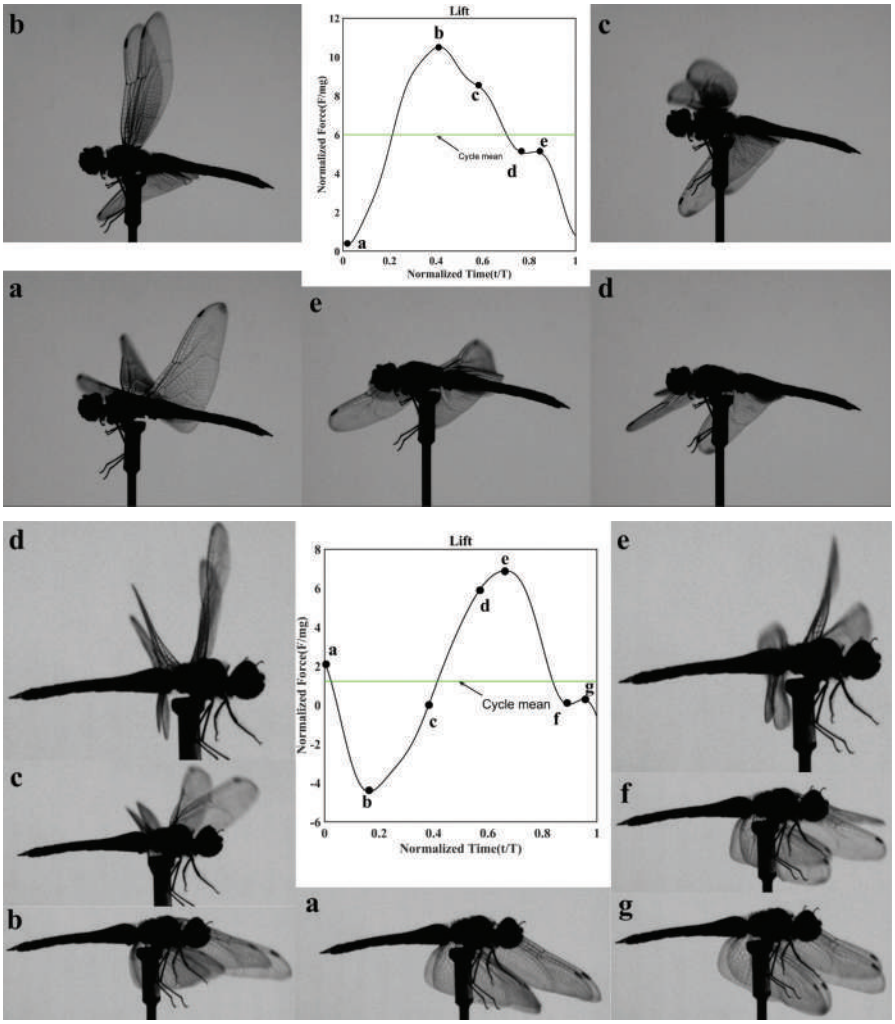
Nocturnal migrants use similar strategies related to the position of the Moon or stars. Studies also suggest that migrating animals like monarchs might use local environmental cues such as wind speed and direction, and visual cues like land, vegetation, and smell. However, these mechanisms remain under investigation, says Patrick.

To understand how the monarchs use their magnetic compass, his team tried to recreate their migration under controlled laboratory conditions.

The butterflies are first tethered inside a small treadmill-like flight simulator, allowing them to fly while remaining in place. The simulator is then surrounded by Helmholtz coils that generate an artificial magnetic field system replicating conditions from various locations around the globe. To remove the Sun as a directional cue, the flight simulators are covered with a diffuser that blocks the solar disc while still allowing normal daylight and ultraviolet light to reach them. Under these conditions, the only directional information available is the artificial magnetic field, enabling researchers to isolate and study the butterflies’ magnetic navigation system. These experiments showed that, in the absence of visual cues from the Sun – under an overcast sky, for example – monarchs can stay on course by switching to the Earth’s magnetic field as a backup navigation system.

But understanding how insects orient themselves is only one challenge. Another is retracing the routes that they have taken.

Images: Sandeep Saha



Snapshots from the wind-tunnel experiment where dragonflies are flown under controlled wind conditions to assess their flight during headwind (right) and tailwinds (left)

Following invisible clues

Gerard's team studies the migration of painted lady butterflies (*Vanessa cardui*). The orange and brown-winged butterflies are found in many parts of the world and are long-distance travellers, known for making trans-Saharan flights from Europe to Africa.

In 2013, when Gerard heard about rare sightings of these butterflies in South America, he decided to travel to French Guiana, eager to catch a glimpse of them.

"It was a risky expedition in the sense that I was most likely not going to find the butterflies because they are not supposed to be there," Gerard says. "But I was lucky, and one day I could find about 10 butterflies standing on the beach early in the morning, in a very bad condition – very worn and exhausted. They were lying on the sand of the beach just a few metres from the water, which is a very strange place for a butterfly to be, especially at dawn. So, it was clear to me that they were migrants," he adds. Gerard suspected that they had arrived after an extraordinary journey. He wanted to trace their origin, but no single technique could provide the answer. He collected three specimens and used a combination of techniques to study them, such as pollen metabarcoding, ecological niche modelling, wind trajectories, stable isotopes and genetics.

As butterflies visit flowers along their journey, pollen grains stick to their bodies. By identifying the DNA in these pollen grains, researchers can determine which plant species the butterflies visited. If a butterfly collected in one region carries pollen from plants found hundreds or thousands of kilometres away, it provides evidence of its migratory route, and the possible place of origin can be identified using pollen metabarcoding – a DNA-based technique to trace insect movements.

In spatiotemporal ecological niche modelling, researchers combine records of breeding populations with environmental data to predict where a species can survive and reproduce throughout the year. By modelling suitable habitats across space and time, they can identify likely breeding areas and reconstruct migratory pathways, even when direct observations are unavailable.

Each method contributed a clue, and together, with all these pieces of evidence, Gerard's team was able to document one of the longest recorded migrations – the painted lady butterflies had travelled 4,200 km across the Atlantic Ocean from West Africa to South America. The overall journey – from Europe to Africa to South America – would have been a whopping 7,000 km.

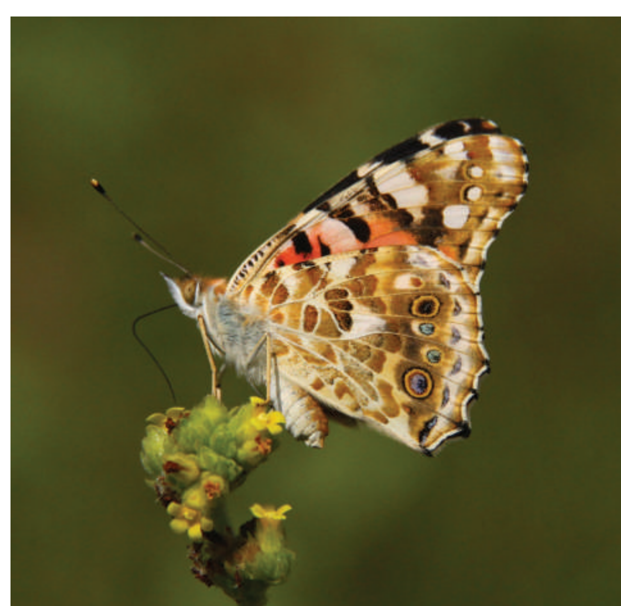


Photo courtesy: Gerard Talavera

A painted lady butterfly, Vanessa cardui*, feeding on a flower in Africa*

Clues in the genes

Where does the innate ability to carry out such extraordinary expeditions come from? Going back to the globe skimmer, for example, how are generations of this insect species able to travel to places they have probably never been to before?

Monarch butterflies, too, undertake their first and only migration without guidance from parents or experienced individuals. "[This is] unlike other animals where older individuals teach younger individuals how and where to fly, or where there's mimicry – when young birds just fly where the older birds are going. That's intriguing," says Patrick. "Unlike birds, there is no clear evidence of learning or cultural transmission. Instead, in insects like monarchs, the instructions for migration appear to be genetically determined or hardwired."

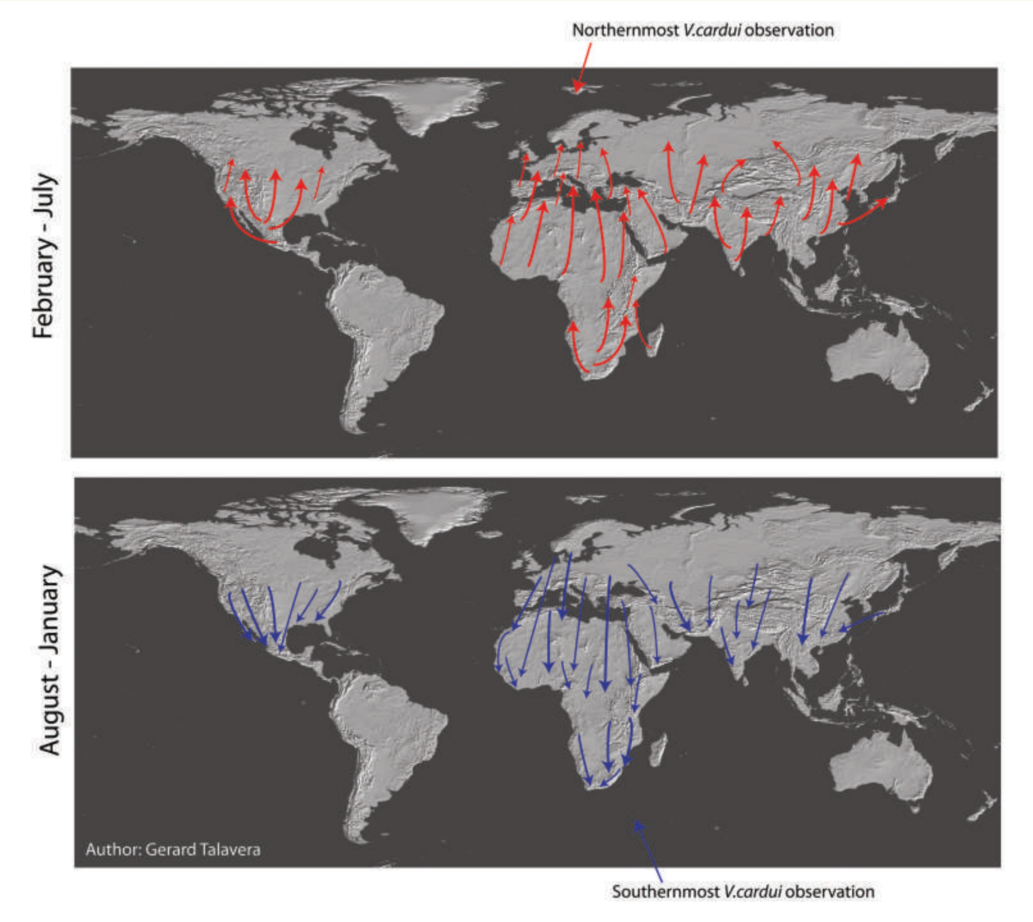


Image courtesy: Gerard Talavera

Painted lady butterflies migrate south from Europe to sub-Saharan Africa during autumn, to escape freezing winters and exploit rich breeding grounds fueled by seasonal rains. In the spring, the next generations migrate back north toward the Mediterranean and mainland Europe to follow emerging vegetation and avoid the scorching tropical summer

If migration is almost instinctive, is it written into an insect's DNA? According to Gerard, the answer is yes, but not in the way people often imagine. It is not as simple as one gene controlling migration. The control is pleiotropic – the insects' behaviour arises from a package of interacting genes and regulatory elements that determine how, when, and where an insect migrates.

Migration happens in three main stages. First is the onset of migration, during development. Next is the actual migration – where the insect maintains direction and navigates over long distances. Finally, the termination of migration, when the insect settles down to reproduce. Each stage is likely regulated by different sets of genes responding to environmental cues, researchers say.

Recently, Gerard's team discovered a chromosomal rearrangement in painted lady butterflies that differs between the northern and southern hemisphere populations. This rearrangement appears to affect genes linked to migratory behaviour. These genetic changes could be involved in how the butterflies interpret environmental cues important for orientation and navigation, like the Sun's position. While researchers are still working on the details, their findings suggest that subtle changes in genome architecture can impact large-scale migratory patterns like direction and geographical range of migration.

'In insects like monarch butterflies, the instructions for migration appear to be genetically determined or hardwired'

"By linking genomic patterns with ecological observations, researchers are beginning to understand not only how insects migrate, but also how evolution has worked to shape migrations," he explains.

Gerard's team is now developing Artificial Intelligence (AI)-powered automated traps equipped with UV light for continuous, year-round monitoring of nocturnal insect activity. "We keep recording them, and this data is processed; AI identifies and processes the data in a way that we know more of what is happening every night for the whole year," he explains. By linking multiple automated traps, they hope to detect waves of migratory insects and better understand which species migrate and under what conditions.

Even with radar, isotopes, atmospheric models, and AI-powered automated systems, scientists are still only beginning to understand the hidden lives of migratory insects.

"It is surprising that despite centuries of observing and studying insect migration, we have only scratched the surface of what we know," says Patrick. "There are many unanswered questions about their behaviour."

(Edited by Ranjini Raghunath)

‘It requires a peculiar type of personality to groove on chemistry'

- Interview by Sandeep Menon

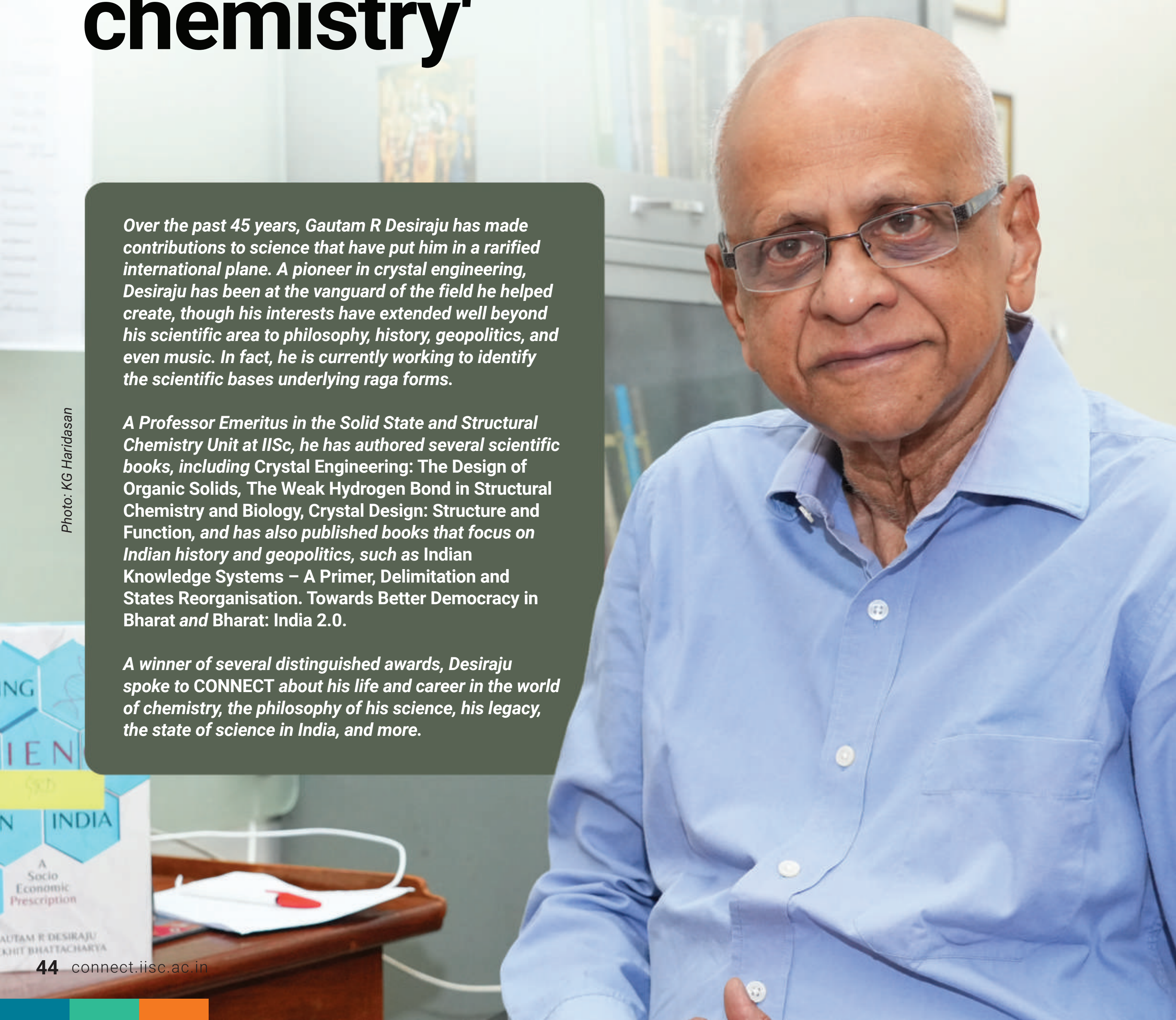


Photo: KG Haridasan

Over the past 45 years, Gautam R Desiraju has made contributions to science that have put him in a rarified international plane. A pioneer in crystal engineering, Desiraju has been at the vanguard of the field he helped create, though his interests have extended well beyond his scientific area to philosophy, history, geopolitics, and even music. In fact, he is currently working to identify the scientific bases underlying raga forms.

A Professor Emeritus in the Solid State and Structural Chemistry Unit at IISc, he has authored several scientific books, including **Crystal Engineering: The Design of Organic Solids, The Weak Hydrogen Bond in Structural Chemistry and Biology, Crystal Design: Structure and Function*****, and has also published books that focus on Indian history and geopolitics, such as*** **Indian Knowledge Systems – A Primer, Delimitation and States Reorganisation. Towards Better Democracy in Bharat** ***and*** **Bharat: India 2.0.**

A winner of several distinguished awards, Desiraju spoke to **CONNECT** ***about his life and career in the world of chemistry, the philosophy of his science, his legacy, the state of science in India, and more.***

How did you get interested in science? Was there an academic bent through your family background, obviously, with Dr Radhakrishnan being your grandfather?

It's ironic that you talk about my maternal grandfather; not many of his children or grandchildren took to academics. My maternal uncle was an academic, a well-known historian in his time, but family members, at least on my mother's side, were either doctors or civil servants and things like that. My grandfather wrote a lot about science, however.

When I was in Class 8, I liked history, geography, and science. It was a great regret of mine that when I entered Class 9, I had to choose between the science and humanities streams. Although I liked history a lot, I liked chemistry too much.

My fascination with history and geography never left me; some of the recent things that I've been writing have been on geostrategy. When I travel abroad and see some unusual places and things, I often think about them from the point of view of Mackinder (Sir Halford Mackinder's Heartland Theory relates global dominance with control of the central landmass of Eurasia). I really wish I had a chance to get some more formal training in history and geography. But chemistry was nice enough.

Why did chemistry hold your fancy?

Chemistry is a very unusual mixture of the qualitative and the quantitative. Physics is very much towards the quantitative side, and large portions of biology are towards the qualitative. I call chemistry the "Middle Kingdom" – there are certain parts where one needs to be quantitative, and other parts where, unless you are qualitative, you really cannot make any headway.

Without a good memory, I don't think anybody should get into doing serious chemistry because you simply need to know the facts. That is the qualitative side. When you take these facts and then try to find a pattern, that's where you get into the quantitative side. This leads to an important thing about chemistry, that there are a small number of rules and many exceptions to these rules. The rule is the quantitative part, and the exceptions are the qualitative part. That is chemistry. You have got to know when, where, and why the rule is not followed.

What happens in chemistry is very beautiful; today's exceptions become tomorrow's rules. Gradually, the exceptions become so many that they form a pattern of their own, and then they form a new rule, and sometimes rules that were held to be inviolate have been found to be broken. So, chemistry, that way, is a very surprising subject. It requires a peculiar type of personality to groove on chemistry.

You have spoken about the relationship between knowledge systems and chemistry. Can you elaborate on that?

This whole idea is about a holistic way of thinking versus a reductionist way of thinking. If you look at ancient civilisations, they were all holistic. Then humankind went into reductionist thinking, that is, logic, cause and effect. When you go into this, your thought process becomes more quantitative, because that is the essence of reductionism. Astronomy, (Isaac) Newton, (Robert) Boyle and (John) Dalton ... the great German chemists of the 19th century; you find it is the triumph of reductionist thinking.

In the last 50-100 years, it became clear that the reductionist way of thinking could solve some problems up to some levels, and in certain problems, it could do very well. But there were other problems that refused to be solved, chiefly in the areas of medicines, drugs, and materials. The essence of reductionism is that the properties of something can be completely derived from the properties of the constituents. The whole is equal to the sum of the parts. In the holistic paradigm, the whole is more than the sum of its parts. Also, the whole is different from the sum of the parts.

Has this influenced your work with supramolecular synthons?

The supramolecular synthon is one of the ways in which I was trying to express these ideas. If you take a molecular crystal, instead of saying A+B will give you C, I say I have C, and C must be derived from A+B. I am putting the product before the reactant. Why is this kind of thinking important? Because chemistry, and all sciences, in the end must do useful things. If you can identify some material, molecule, crystal, or whatever, and identify that it has a good property, you will identify that substance C. To put it in another way, you go from property to a particular structure. This is the essential difference between reductionist thinking and holistic thinking.

So, a supramolecular synthon is that bit in a crystal that confers the property that you want. The synthon is the core or kernel of a crystal structure. It is a useful part. If you were to use a word from our shastras, it is the *Bindu*, a single point of convergence. My method of defining a supramolecular synthon essentially is that it was a method of simplifying something big, like a crystal structure, into the essential and not simplifying it so much that you lose the essential detail.

If you take the synthon and then try to simplify it further, like some people have tried to do, then you lose everything, so it is a balance. Everything can be broken down into finally atoms and subatomic particles. But that's not going to help me to get a crystal of metformin, which is used to treat Type 2 diabetes.

Are synthons then a balance between holistic and reductionist?

Right, because it is holistic enough that you can go from the synthon and reconstruct the whole crystal. It is reductionist enough that, given the synthon, I will be able to find out the stuff

Photo courtesy: Gautam R Desiraju

Gautam R Desiraju (left) receives the TWAS award for chemistry in 2000 from Murli Manohar Joshi, the then Minister of Human Resource Development that you need to put in to get that synthon.

Can you talk about your work in crystal engineering and co-crystals?

Co-crystals are an interesting way of looking at crystallography. The subject, which I sort of defined with many other people, mostly in the 1990s and early 2000s, is called crystal engineering. It starts from a crystallography stream – symmetry of crystals, how molecules are put together – but then it comes from a chemistry stream also – which molecules to put together and when to put them together, how do they do a handshake? To answer those questions, crystallography will help you a little bit, but mostly it comes from the chemistry side. There are certain crystals we have done a lot of work with, which are soft crystals. They will bend.

The scope of crystallography and chemistry is changing. These two are intersecting in certain very novel ways. A simple example: put a stable crystal in a computer, remove the molecules, and ask the computer to bring them back. Only in 60-70% of the cases will the computer put the molecules back in the way they were originally. That means we do not understand how these molecules come together. [Though] I would say this problem might not be that bad of late because Artificial Intelligence may be the key to solving this problem.

What about co-crystals?

The most useful place for co-crystals is in practical applications in the pharmaceutical sense. You have got drugs; they are called Active Pharmaceutical Ingredients (API). Usually, most medicines are sold in solid foundations (forms) – tablets, ointments, powders, and so on. Some have good medicinal effects but are not water-soluble. We might have to take too much of the drug to dissolve a small amount to have some medicinal effect. People found my synthon theory helpful because it is a way of expressing how molecules aggregate together. Suppose I take two different molecules. One is the drug, and one is something which is quite soluble. Suppose you make it stick together, then the soluble part, which we call the co-former, will literally drag the insoluble drug into a water solution. So, it becomes soluble enough for tissues to absorb and experience the medicinal effect. What is the soluble molecule that will stick to the drug? That is the synthon. The heart or core of that drug is that synthon, which we call heterosynthon, simply because the two molecules that are being put together are different.

You worked in the field of hydrogen bonding. Why is this area so fascinating?

Hydrogen bonding has been around for 100 years, and a great name in chemistry, Linus Pauling, is associated with it. Before Pauling, the Germans were there; they are always there in chemistry before anybody else (*laughs*). They called it a hydrogen bridge. Pauling said that hydrogen bonds are strong. Early in my career, in the early 1980s, I started noticing some crystal structures that seemed to defy Pauling's ideas.

So, you were already doing crystal engineering?

I used the word crystal engineering for the first time in 1983. People tell me that I am one of the first people to use that word as the title of a paper when the subject itself was not known very clearly.

Photo courtesy: Gautam R Desiraju

Gautam R Desiraju (centre) alongside Arunanchalam Ramanan (right) and Jagadese J Vittal (former PhD students at IISc), co-authors of Crystal Engineering: A Textbook published in 2011

When I was looking at a crystal structure, I saw that some interactions between molecules were not strong but had a resemblance to Pauling's strong hydrogen bonds. To form Pauling's strong hydrogen bonds, you need atoms like nitrogen and oxygen. I found that things like C-H…O (we weren't calling them hydrogen bonds in the early 1980s) had certain features of Pauling's strong O-H…O and N-H…O hydrogen bonds. But C-H…O, every chemist will tell you, is weak, not strong. So, how can a weak thing have certain hydrogen-bond-like properties? Then the question is, how weak can it go before it stops being a hydrogen bond? We found that you could go quite far into the weak domain, and it still showed properties of hydrogen bonds.

I wrote a book (*The Weak Hydrogen Bond, In Structural Chemistry and Biology*) with Austrian Thomas Steiner in 1999 about weak hydrogen bonds in structural chemistry and biology. This biology part is very significant because biology is really where you take the rules of chemistry and apply them to systems in which interactions are weak.

Molecular biology looks at protein structures. They found that the combination of many weak bonds is more potent and useful than a few strong bonds. If you take Pauling's strong hydrogen bonds, once it's there, it is there; you can't do anything with it. But suppose you get molecules put together with many weak interactions, suppose when the molecules are coming together, there are some mistakes in the way that they recognise each other. Because the interactions are weak, a few of them can get loose again. So, it has the ability to correct mistakes. That is why it is very important in biological mechanisms.

From hydrogen bond, you moved to halogen bonding?

The thing is that the hydrogen bond itself is what we call a complex interaction. There are at least four different aspects that come into hydrogen bonding like electrostatics, polarisation, charge transfer, and so on. In halogen bonding, the importance of these four components starts changing. Today, there is chalcogen bonding and others like these. Anytime you have an electrophilic thing, you get these sorts of things. The hydrogen bond is a parent.

Do you think about the legacy you have left behind in your career?

Many scientists feel themselves lucky to be associated with a particular thing. I would say I am doubly lucky because synthon is one thing I am associated with, and hydrogen bond is another.

Normally, there are two levels of success for a scientist. The first stage is when they start associating a name with a particular area. The second stage is that you mention an area, and a name is associated to it. For both areas of crystal engineering and hydrogen bond, more so for the former, I would say my name will come up. I have done something to bring these two ideas to some level of maturity. Not that my work is the last word; scientists can never have the last word. What a scientist can do, which is what I think I have done, is sometimes to say the first word.

Interestingly, I came across a third higher level of recognition in my case. When I went to the Calgary Congress of the International Union of Crystallography in August, I was apprehensive as to how scientists 50 years younger than me would react to my physical presence in the meeting; what I mean to say is that I really didn't know these young people, and I don't know how they react today to anything. A colleague in my age group said that the whole idea of crystal engineering is so well known that they don't even associate the name Desiraju with it anymore and that it would do the youngsters some good to see that I am a real person. This is life.

Where is science in India right now, in relation to other countries, as well as from where we were in the past?

In the last 10 years or so, I realised that there are many things wrong with the way science is done in India. The reasons why Indian science is not as good as it should be are not scientific in nature. The problems are economic and social. Fifty years ago, when I was coming up, science was at a primitive level because India had no money. CV Raman won the Nobel Prize. He got a grant to buy a spectrometer from GD Birla, and if you convert the money into today's rupees, you get something like Rs 6 crore. How many people are willing to give Rs 6 crore to do an experiment today?

Raman had a very well-paying job in the Indian Audits and Accounts Service. He surrendered that job to do freelance research at the Indian Association for Cultivation of Science. I am sure Birla was impressed by this young man who gave up a job to do science. He took a leap of faith. Without good money, you cannot do good science. Not that everybody who gets good money will do good science.

World over, investment in science has come down, correct?

World over, it has come down, but there is a big difference. The USA, the UK, and Germany are all scientific giants; the buffering capacity of their scientific systems is so great that tomorrow they will make money somewhere else and put it back. We are still at subcritical. Part of the problem is that we have never been able to put science, technology, engineering, manufacturing, and public good into different silos.

In an earlier interview, you suggested focusing on undergraduates rather than further up.

China did that almost 25 years ago; they started investing heavily in integrated laboratories. Because I think chemistry, even physics, is an experimental subject. Unless you go to the lab, sit down, make the compound, have the compound blow up in your face, hear that compound exploding ... it's a very earthy subject. Chemistry is synthesis. Synthesis is chemistry. Chemistry creates its object. It's the only subject where we have that privilege. If you want to study something, you can go and make it and then study it. It requires a very funny kind of person to do well in this subject. It can be very baffling sometimes.

In addition to science, you also write a lot about geopolitics. Does science inform geopolitics, or does geopolitics inform science?

Science originally started informing geopolitics. But today, geopolitics may inform science because it may tell the chemist what to do. We have extremely good coal in India, and it is not a particularly difficult technique to make it into natural gas. China has already overcome a great deal of its dependence (on outside countries) by making its own natural gas. Knowing about something is not the same as doing it.

You have won several awards – the TWAS award, Alexander von Humboldt Forschungspreis, ISA Medal for Science, and now the Ewald Prize. How do you feel about getting these recognitions?

Photo courtesy: Gautam R Desiraju

Gautam R Desiraju (right) accepting the Alexander von Humboldt award from the foundation president Wolfgang Frühwald in Germany, in 2002

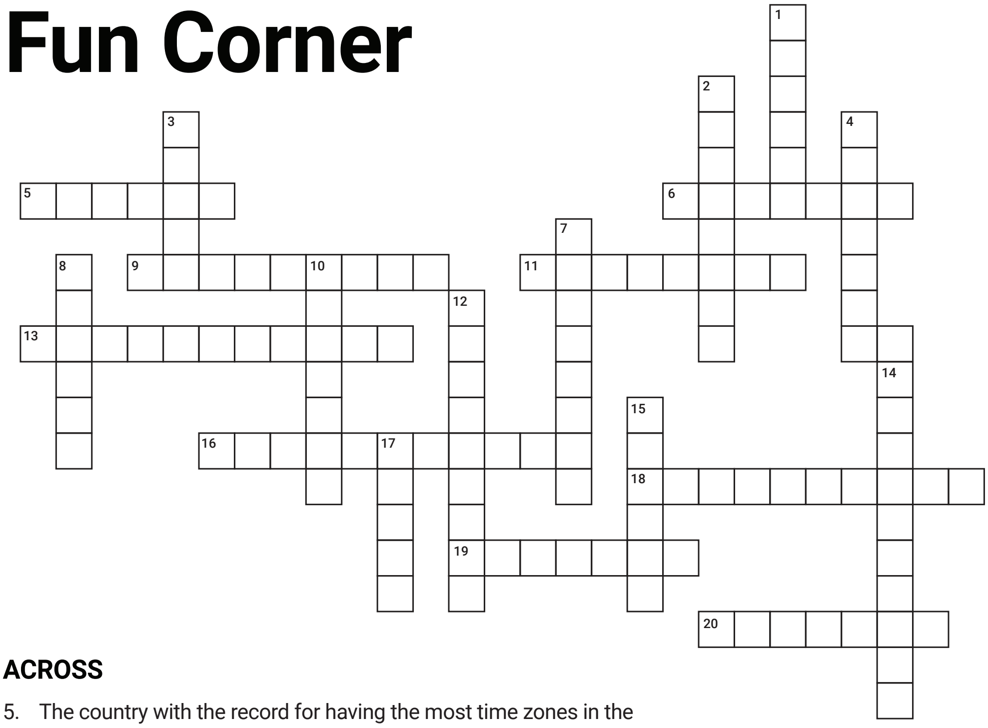
I am suitably honoured. The previous 13 Ewald Prize awardees are people I have held in very high regard. And the fact that my scientific peers have chosen me to get this award is why I really feel happy.

I always tell youngsters, the first thing you should do is write full papers for specialist journals. If you are doing serious work, the only people who should really be able to understand it are those in your own subject. Many today, including those from IISc, send their papers to generalist journals. We have a journal from the American Chemical Society called *Crystal Growth and Design*. The impact factor is hovering somewhere around 3.0, but you can be sure that everybody who reads it knows the subject of crystal engineering through and through. So, if you can get a full paper there, that means your immediate scientific peers think that you are doing well. Once you build upon that foundation, then you can go to generalist journals because then your work will get maturity and outreach. This is where we are really losing the forest for the trees.

We don't know how to fix many things about science in India today. We have committed sins of both omission and commission – plenty of both. All this calls for a serious rethinking and reappraisal which we are incapable of, so fond are we of the status quo. In the present situation, I am not hopeful about the future of science in India, at least as it concerns improvements in chemistry as is being done currently in academic departments such as in IISc. I say things that others don't like. But more often than not, I have been proved right. This is why I have received an award like the Ewald Prize.

(Edited by Abinaya Kalyanasundaram)

Fun Corner



CONNECT CROSSWORD

Send your completed puzzles to **connect.ooc@iisc.ac.in**

The winner will be announced in the next issue!

ACROSS

5. The country with the record for having the most time zones in the world, largely due to its various overseas territories and departments
6. Migrating butterfly species in the USA
9. Which grassland-inhabiting ungulate is the fastest running animal in India, once the main prey of the Asiatic cheetah
11. A network of deep-ocean research moorings deployed across the equatorial Pacific Ocean to monitor climate patterns
13. The shifting of hues when viewed from different angles, a hallmark of structural colour
16. A Karnataka town known for its vibrant, GI-tagged wooden toys, coloured using eco-friendly vegetable dyes
18. Winds that weaken or reverse during an El Niño event
19. A hypothetical particle that travels faster than light
20. Protein structure that forms the basic framework of chromosomes

DOWN

1. Cosmic cloud of gas and dust where stars are born
2. The era known as the Age of the Mammals
3. A tiny spherical cluster of molecules that forms when a substance with water-loving and water-fearing parts is mixed in water
4. Greek mythological character with one eye
7. The organ in the body which produces insulin
8. A bright blue butterfly that produces its colour through nanostructures on its wings, and not pigments
10. The primary carbon ring that serves as the backbone for a majority of conventional pharmaceutical drugs
12. A molecular property where a molecule cannot be superposed on its mirror image
14. Invented Non-Covalent Derivatisation, a photograph development technique without toxic heavy metals
15. Unit measuring the depth of water
17. A ring-shaped coral reef enclosing a lagoon

Last Issue's Answers

Guess the Spot
The unique doorknob is seen inside the Main building, IISc

LAST ISSUE'S WINNERS!

Crossword
Chirag Panigrahi, PhD student, Dept. of Biochemistry, IISc

Guess the Spot
Himanshu Gupta, PhD student, Dept. of Aerospace Engineering, IISc

GUESS THE SPOT!

Can you guess where this photo was taken on campus?

Email your answer to **connect.ooc@iisc.ac.in**
The winners will be announced in the next issue!

Abstracts | Hridesh Gupta


EXIT
(10S–0N) averaged Temperature (degC) anomaly from
20
60
100
140
180
220
260
300
45°E
55°E
65°E
75°E
Jul-2026
Monthly variation of Dipole Mode Index
Nino 4
Historical Nino 3.4 Sea Surface Temperature Anomaly
Mid-Aug 2026
CCSR/IRI Model-
Based Probabili
ENSO Foreca