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Mechanical Engineering
Celebrating 75 years

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The story of SlipDIISc

Memories of Satish
An enduring presence

INDIAN INSTITUTE OF SCIENCE
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IN THIS ISSUE

Editorial

The Department of Mechanical Engineering (ME) at IISc is celebrating 75 years of existence. In this special issue, we bring you several stories from its past and present. From its beginnings in internal combustion and power engineering to its significant contributions to industrial acoustics, and to the critical roles it played in the formation of several departments and centres at IISc, these stories capture ME's far-reaching influence and impact.

As we continue to face the pandemic, read about IISc scientists' ongoing efforts against COVID-19. We also look at the thorny ethical issues that scientists deal with. Players from IISc's Ultimate Frisbee club share their trials and tribulations. An enthusiastic group of people from different fields seek to bring Indian archives together.
K Nagarathna, who has been at the Institute for more than four decades, talks about her experiences working alongside trailblazing scientists.

And on Satish Dhawan's birth centenary, his daughter revisits her childhood on campus, and her father's persisting influence on her own research as a cell biologist.

Happy reading!

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Making Things Work:
75 years of Mechanical Engineering

- *Ranjini Raghunath*

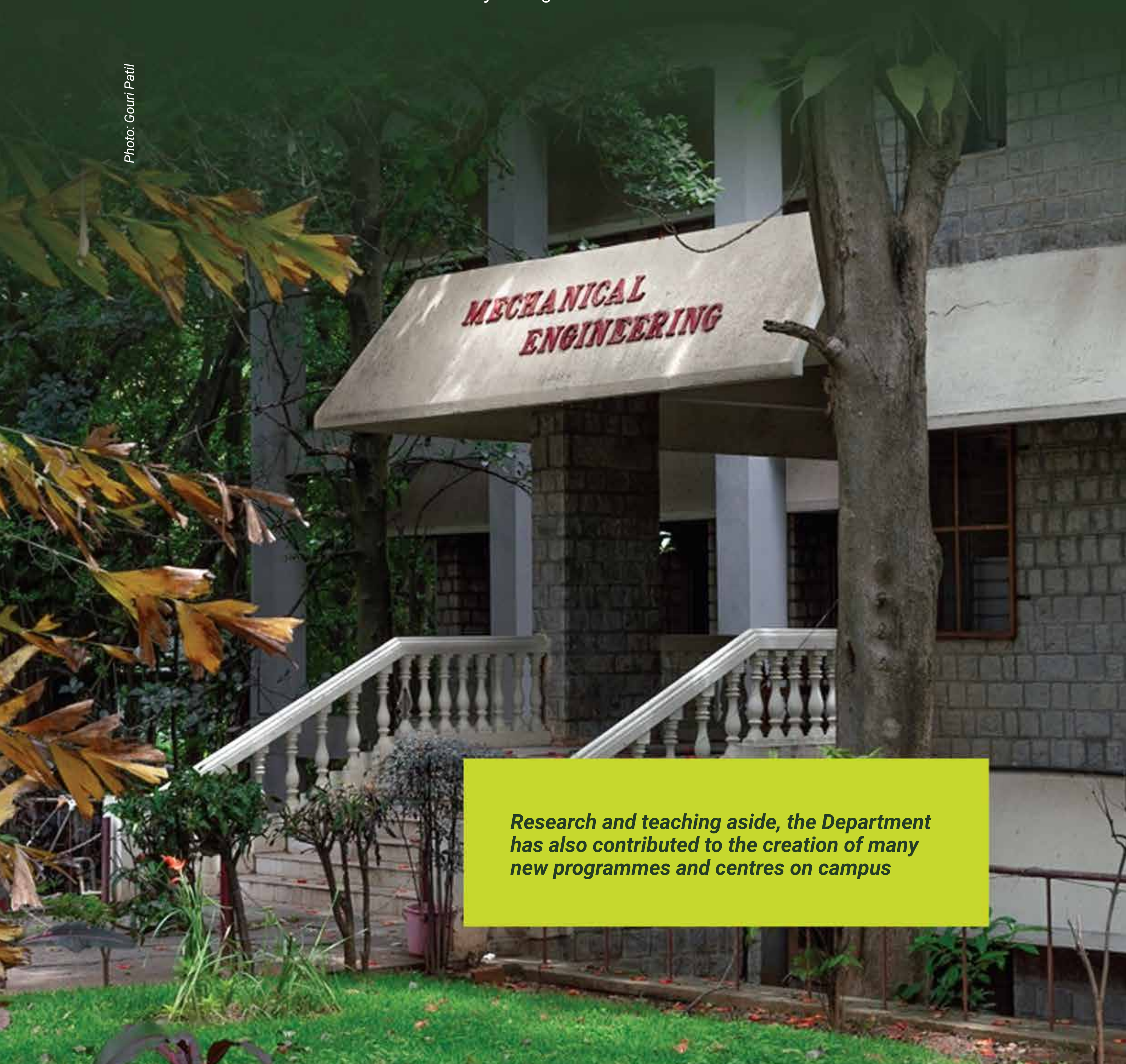


Photo: Gouri Patil

Research and teaching aside, the Department has also contributed to the creation of many new programmes and centres on campus

Times were tough for IISc in the 1930s. It faced a serious cash crunch – income from both the Mysore Government and JN Tata's Bombay properties had dwindled. World War II was looming on the horizon. Criticism was growing that the Institute was focusing too much on "pure sciences" like physics and biochemistry, and doing too little of the applied research that Tata had originally wanted. Courses in engineering other than electrical engineering were "completely ignored in the early life of the Institute," according to Sir M Visvesvaraya, former president of IISc's Court.

To rectify this neglect, a Joint Committee of the Council and Court members was set up in 1940. This committee recommended, among other things, the establishment of a central workshop that would deal with "problems of design and construction of industrial plants for various manufacturing processes." It also suggested that "as soon as funds become available, a Department of Mechanical Engineering be established at the Institute."

> ***ICE and PE – the latter had a separate Mechanical Engineering section – merged into what is now the Department of Mechanical Engineering***

But the Department wasn't set up right away – even though related courses like applied mechanics and hydraulics, and heat engines were taught to students as early as in the 1930s. Its forerunners were the departments of Internal Combustion Engineering (ICE) and Power Engineering (PE) – the latter had a separate Mechanical Engineering section – established around 1945-46. These two merged into what is now the Department of Mechanical Engineering (ME) during the 1970s.

Over the past 75 years, research at ME has spanned a wide range of areas, from engines, foundry and heat transfer to more recent interdisciplinary explorations such as robotics and biomechanics. Its faculty members have led and participated in national and international initiatives related to energy, acoustics and design. At home, they have also helped establish many of IISc's departments and centres, including Sustainable Technologies, Product Design and Manufacturing, Nano Science and Engineering, Energy Research, BioSystems Science and Engineering, Continuing Education, Industrial and Scientific Consultancy, even the JN Tata auditorium, points out GK Ananthasuresh, faculty member and until recently the Chair of the Department.

"Our department has been a quiet force, but I would also call it quite a force," he says. "It has had a tremendous impact on the campus."

Engines and energy

The impact of World War II on the Institute was enormous. "The War that is going on," Visvesvaraya once announced to the IISc Court, "is a mechanical engineer's war." Industry-relevant research got a shot in the arm, and new courses on aerospace engineering and metallurgy were added. A new Department of Internal Combustion Engineering (ICE) was also set up in 1945, in the building that now houses the Society for Innovation and Development, and Major BC Carter was appointed to head both ICE and the central workshop.

During the early years, ICE researchers extensively tested and designed various types of engines and their components, working together with industry partners on collaborative projects nurtured by the newly formed Council of Scientific and Industrial Research (CSIR).

Around the same time that ICE was set up, a new Department of Power Engineering (PE) was also established, to support the electrical power projects that mushroomed across the country after the war. Its foundation stone was laid in 1947 by former Cabinet Minister Syama Prasad Mukherjee, and the building was inaugurated by Rajendra Prasad, the then President of India, in 1951. MS Thacker, who would go on to become IISc's Director, was appointed its first head. A few years later, it was bifurcated into an Electrical Engineering and a Mechanical Engineering section.

Photo courtesy: IISc Archives

Former President Rajendra Prasad inaugurating the Power Engineering building in 1951

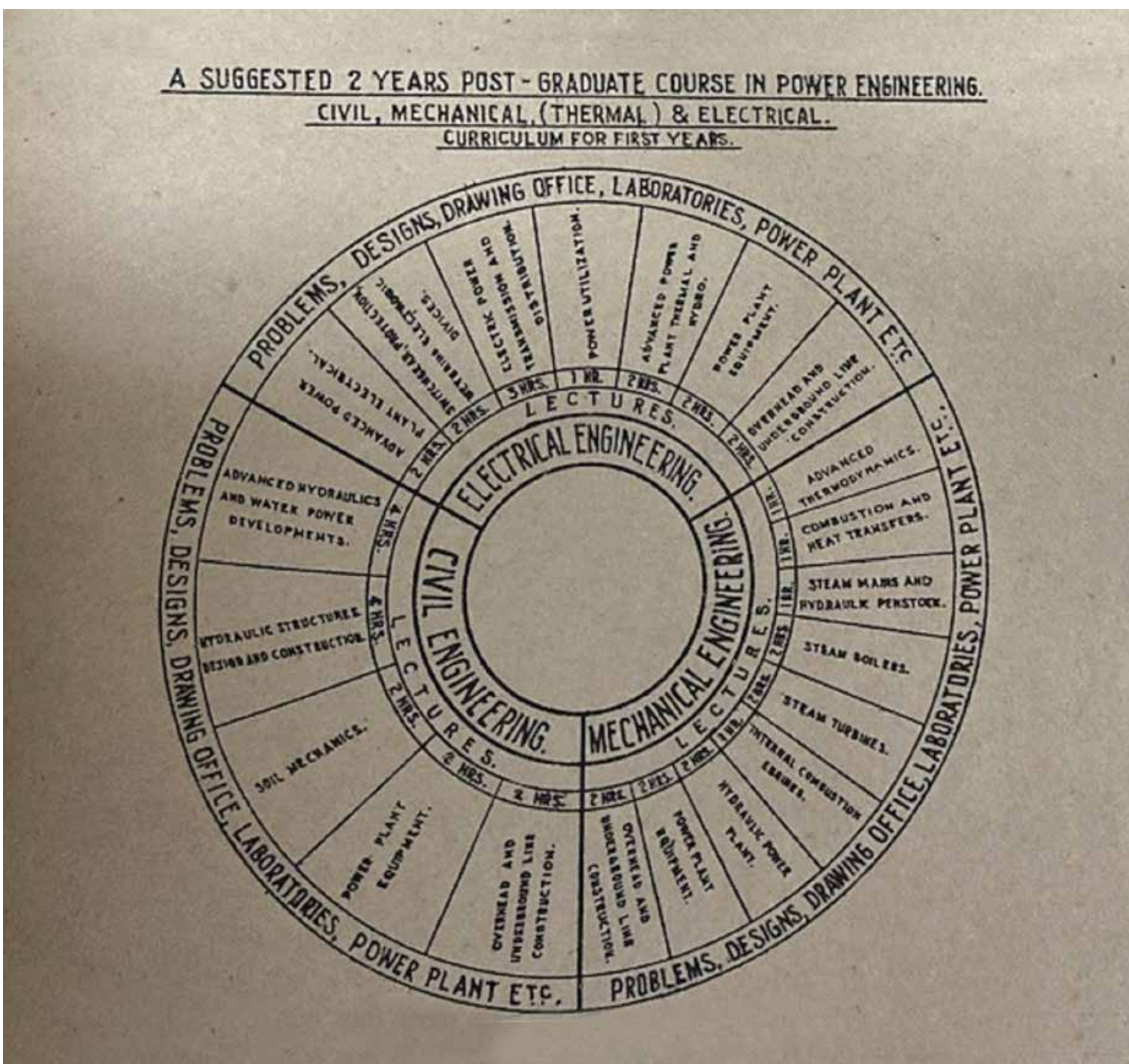
From the early days, the emphasis on hands-on learning was heavy. Students built equipment and machines that they needed for their projects on their own in the workshop. A full-fledged thermal power station was also set up on campus to train students in operating and maintaining it round the clock.

In 1950, Arcot Ramachandran joined IISc as an assistant professor, and later became the head of the Mechanical Engineering section. By all accounts, he was a trailblazer. He kick-started research on heat transfer and thermal sciences, which helped spawn major programmes on energy research across the country. He was also an exceptional administrator who is said to have introduced many new programmes and courses like nuclear engineering and machine design.

"The Department owes a lot to Arcot Ramachandran," says J Gururaja, a former student who also worked with Ramachandran in later years. "He was always looking beyond the current state of affairs at that time: What new branches can there be? What new areas can we start? Who were the competent people available?" Ramachandran was even tipped to become IISc's Director – Satish Dhawan was eventually appointed – before moving on to head IIT Madras, and later the Government of India's newly established Department of Science and Technology (DST).

To this day, heat transfer and energy research – which Ramachandran pioneered – continue to be an important part of the Department's focus. More recent research has focused on thermo-chemical storage, combustion and spray research, refrigeration technologies and heat management in spacecraft systems. Many ME faculty members also helped establish and continue to be associated with the Interdisciplinary Centre for Energy Research at IISc, which is pursuing innovative research on solar power, supercritical carbon dioxide-based power generation, and clean coal technologies.

Image: IISc Archives/1945 memorandum on proposal to establish PE



Proposed curriculum for first year students in a two-year post-graduate course in Power Engineering

Changing directions

A few years after Ramachandran left IISc, the Department's focus shifted. In the early 1970s, Dhawan brought LS Srinath, the head of the Mechanical Engineering Department at IIT Kanpur, to IISc and tasked him with merging ICE and the ME section into a single Department of Mechanical Engineering. "He [Srinath] was interested in creating an integrated approach to mechanical science. That is how the division [of mechanical sciences] was founded and he became the first Chairman," says Gururaja.

Soon after the merger, the Department became involved in a crucial social experiment. In the early 1970s, science and technology institutes in the country were severely criticised for not doing enough to address rural problems, and for focusing solely on urban challenges. Faculty members at IISc, including many from ME, lobbied the Institute administration, and as a result of their efforts, the Cell for the Application of Science and Technology to Rural Areas (ASTRA) was set up in 1974. It mobilised the development of many rural technologies – biogas plants, low-carbon housing, and small-scale fertiliser industries, to name a few. Several extension centres were also set up in villages near Bangalore to train local people to become self-reliant. Many of ASTRA's early initiatives were assigned as ME student projects. ASTRA later evolved into the Centre for Sustainable Technologies, which continues to work on rural development.

> ***Faculty members at IISc, including many from ME, lobbied the Institute administration, and as a result of their efforts, ASTRA was set up***

Similar to ASTRA, another initiative called SuTRA (Sustainable Transformation of Rural Areas) was led by former faculty member Udipi Shrinivasa in the 1990s. It was created as an independent programme unit under IISc's Society for Innovation and Development. The aim was to implement developmental projects in a set of villages surrounding ASTRA's extension centre in Ungra village, Tumkur district. An important outcome from SuTRA was the development of biodiesel from non-edible seeds including *Pongamia*. Other projects involved building rainwater harvesting structures, using satellite maps to spot locations for drilling borewells and preserving perishable agro products by dehydration.

Yet another socially-relevant initiative that ME researchers were involved in was the development of microhydel power generators which use turbines to generate electricity. An ultra-low head propeller turbine ideal for flat terrains was developed and installed near Mandya, Karnataka. Several cross flow turbines were also installed in various parts of the country, including Kedarnath and Arunachal Pradesh.

ME also made critical contributions to industry in two key areas. One was the development of cast-iron crankshafts to replace forged crankshafts in automobiles in order to reduce production cost by 30-40%. Another was work on industrial acoustics, particularly on mufflers and silencers to reduce noise in vehicle exhaust, an area pioneered by faculty member Manohar Munjal. He and others in the Department worked on several industry projects related to noise control and vibration, even stealth technologies for Indian Navy submarines and silencers for limiting cockpit noise in a fighter aircraft. Manohar has also advised the government on defining noise control norms and policies, and was instrumental in setting up a research hub called the Facility for Research in Technical Acoustics (FRITA) at ME in 1998. "He defined technical acoustics for the country," says Ananthasuresh.

Photo: KG Haridasan/IISc Archives

A small-scale model of the micro-hydel generator developed by ME researchers

New designs

Back in the 1930s, as the Institute was struggling to strengthen its financial situation, one of the cost-cutting measures proposed was the setting up of a central workshop "to avoid unnecessary duplication of staff and equipment." Over time, this facility became especially indispensable for ME students. Many of them would spend hours each day toiling away at the workshop, designing and assembling parts and equipment that they needed for their projects. Manufacturing and design continued to remain an important part of ME, and in 1996-97, the Department started a two-year Master's in Design programme. This led to the transformation of the central workshop into the Centre for Product Design and Manufacturing (CPDM) with former faculty member TS Mruthyunjaya as its first Chair. CPDM is now deeply involved in developing futuristic manufacturing technologies, including India's first smart factory platform.

Around the same time that CPDM was launched, IISc also joined hands with Tata Consultancy Services (TCS) to start a first-of-its-kind for-profit venture called Advanced Product Design and Prototyping (APDAP) to provide design services for a slew of industry clients, including BHEL, TVS, GM India and DRDO. Its goal was to take a product from the drawing board all the way up to prototyping, and tying up with industry partners for large-scale manufacture. The initiative was largely driven by faculty members from ME.

Towards the close of the century, research on robotics and autonomous systems also picked up steam. Snake-like robots useful in search and rescue, and surgery; crawling robots to inspect pipes in hazardous conditions, and more recently, touch-based tools to cut tissue and carry out surgical procedures have all been developed. A start-up called Mimyk with roots in ME has also developed an ingenious endoscopy simulator to train medical students and doctors without using human subjects.

Photo courtesy: Mimyk

An endoscopy simulator developed by Mimyk

In 2004, with funding from DST, DRDO and the Ministry of Mines, the Department set up a National Facility for Semisolid Forming (NFSSF). A few years later, researchers working in this facility made a breakthrough: they developed an indigenous version of a process called thixocasting. In thixocasting, a metal is heated until it becomes partially liquid and injected under pressure; this makes it less viscous and improves the quality of the parts made from it. The technology has proved tremendously useful for manufacturing light-weight vehicle components, including parts for two-wheelers manufactured by TVS Motors.

In the past few decades, research at ME has become more interdisciplinary. One person who exemplified this spirit was former faculty member Sanjay Biswas. Although originally known for his contributions to tribology, he also pursued research in areas as diverse as chemistry, nanoscience and bioengineering. "Biswas was also an able administrator who knew how to excite people around him to take new initiatives, and then step aside when things were on the right track, only to move on to another initiative," his colleagues recounted after his passing in 2013.

In later years, he developed a keen interest in healthcare and began studying the mechanics of cell wall movement and cancer cell adhesion. He wanted to bring about a "radical change" in bioengineering and biodesign in the country. Biswas was among the first to start a bioengineering group at the Institute, bringing together IISc faculty members and medical doctors. His efforts played a pivotal role in the establishment of the Centre for BioSystems Science and Engineering (BSSE) at IISc.

Looking ahead

What does the future hold for ME? "We have a fairly long list," says Ananthasuresh.

In 2019, as part of an international peer review, ME was asked to assess its strengths and weaknesses, and identify areas where it needed to work on. It became clear that large-scale collaborative efforts anchored by the Department were lacking, more faculty members had to be recruited in core areas, Master's programmes needed to become more attractive, and industry networks had to be strengthened.

> ***"We hope to see more women coming into the Department as students as well as faculty members"***

Ananthasuresh also points out several new research areas where the Department wants to break new ground: simulation technologies, food storage and transportation, automated agriculture, mobility engineering, space robotics and underwater exploration. New and exciting technologies are also on the horizon, he says. "Now we have cell and tissue mechanics, and biomedical devices, but we would like to go beyond that – artificial limbs, for example, that gel well with the nervous and muscular systems, and can integrate with the body."

Encouraging more women students and faculty members to join what has traditionally been a male-dominated field will also be important. "Right now, I am happy that we have three women faculty members in the Department," says Ananthasuresh. He points out that the field is "getting redefined in many ways," and moving beyond the misconception that mechanical engineers only "lift heavy weights and work with heavy machinery." "Traditional areas like refrigeration and air conditioning, power and heavy machinery have now become more R&D than fundamental research. Newer areas are emerging and more emphasis is being laid on computational modelling. So, we hope to see more women coming into the Department as students as well as faculty members."

A Quiet(er) Place

- *Samira Agnihotri*

Manohar Munjal with different types of silencers and ducts in his lab at IISc

Photo: KG Haridasan

A closer look at how industrial acoustics and noise control research began at the Institute

In 1896, Henry Ford drove his first experimental automobile down the streets of Detroit in the United States. "My gasoline buggy … was considered something of a nuisance, for it made a racket and scared horses," he wrote in his autobiography. Soon after, Milton Reeves, another pioneer of the automobile industry, patented a muffler to reduce the noise and fumes emitted by these vehicles. Since then, reducing noise in automobiles has been an important issue that engineers have grappled with. However, this was not the case in India even in the 1970s when the automobile industry was booming.

A few years earlier, in 1968, Manohar Munjal, an ME student in his fourth semester at the Department of Internal Combustion Engineering (which eventually became the Department of Mechanical Engineering) at IISc, was assigned his thesis topic: Analysis and design of exhaust mufflers for automobiles. This was a peculiar situation for him, as the subject had never been part of his syllabus. His friends, worried that this would harm his career, and risk his position as the class topper, urged him to go to the Department Chair and request that he be given a different topic.

But Manohar prided himself on taking up challenges and was not deterred. "After dinner, I went to the library, and in the catalogue, there was a journal called *Engineering*. In the index, I looked for the keywords "muffler" and "silencer". That's how I started. During this process, I also came to know that practically nothing had been done on muffler acoustics," he recalls.

> ***Manohar came up with general design criteria for silencers, which did not exist back then ... this was considered a breakthrough***

When Manohar looked through the references cited in the papers, he found that the name of one book kept turning up: *Fundamentals of Acoustics* by Lawrence Kinsler and Austin Frey. Fortunately for him, he found two copies of it in the Department of Electrical Communication Engineering (ECE). "In 15 days, I studied the entire book, solved all the exercises in it, and that is how I taught myself acoustics. But it still didn't tell me what happens with sound waves travelling in a silencer," he says.

Manohar therefore came up with general design criteria for silencers, which did not exist back then. He developed an algebraic algorithm for describing the acoustics of tubular mufflers using problem solving techniques such as transfer matrix multiplication and mathematical induction, in an age that predated not just computers but also calculators. This was considered a breakthrough in the field of automobile acoustics.

Manohar soon developed a niche for himself in the field. After he graduated, he continued as a lecturer at IISc, and became an Assistant Professor in 1973. Currently an Emeritus Professor, AICTE Distinguished Chair and INSA Honorary Scientist, his work kickstarted research on the acoustics of silencers and ducts in India.

Mufflers

Manohar explains why automobiles and commercial generators need mufflers. "In an engine, the piston is sucking in air and pushing it out very rapidly; this sends out very strong pressure waves into the system, and this produces a lot of noise." There are two types of mufflers – absorptive and reflective. In the first type, the acoustic waves pass through an absorptive material and lose energy. This energy is converted to heat, resulting in a silencing effect.

The reflective muffler is also known as an impedance mismatch muffler. Impedance refers to the interference in the passage of sound waves due to obstructions or differences in the medium. Most of the sound gets reflected in such situations. "If someone is drowning and I shout, they won't be able to hear me, as the characteristic impedances of water and air are very different. Sound travels at different speeds in the two media, and there is a strong mismatch," Manohar adds. Reflective mufflers use this phenomenon by including a series of structures within them that result in multiple impedance mismatches. In such mufflers, some of the sound is reflected back at every step, resulting in a loss of energy and the required dampening of sound.

A joint quest for quietness

One of Manohar's colleagues at IISc, BS Ramakrishna, a professor at ECE, was renowned for his work on electrical and architectural acoustics. Ramakrishna was like a guardian figure for DN Raju, who in the 1970s and 80s was exploring the uses of vermiculite, a mineral that expands at high temperatures, and could therefore be used as an insulator. One of the goals of his company, Vermiculite India Private Limited, was to investigate the mineral's applications in industrial noise and heat control. Ramakrishna put Manohar in touch with Raju. "That was how our association began – to see if vermiculite could be used in silencers," says Raju, whose work impressed Manohar. "Raju was very creative and gave shape to our ideas. I was a theoretician, and once I told him what I needed, he would come back in some time with beautiful sketches for fabrication," Manohar says. Having grown up on campus, under Ramakrishna's wing, Raju explains that he has been exposed to acoustics since he was a toddler. "From the first meeting itself, we [Manohar and I] worked on the same wavelength," he adds.

Photo courtesy: DN Raju

From left: Manohar Munjal, Jasjit Ahluvalia of IAC Acoustics and DN Raju during the US leg of the study tour for setting up FRITA, 1996

One of the landmark projects that they worked on together was with Tata Motors. "It was the first of its kind for the country to make a large anechoic chamber where even a truck could enter. The chamber was fully designed by FRITA, and the acoustic wedges required for it were also designed and tested at the FRITA facility. It was made fire-proof using vermiculite based coating, and is in use even to this day at Tata Motors," says Raju. Anechoic chambers are experimental rooms where sound cannot escape, and external noise cannot come in. This allows for accurate measurements of the acoustics of any device. Most anechoic chambers are made by installing a thick layer of an absorptive material like glass wool, mineral wool, ceramic wool or a special sponge-like material known as acoustic foam. Raju and his company have since designed and installed several such chambers for various departments at IISc.

During the 1990s, when Manohar was a member of the Science and Engineering Research Council (SERC) at the Government of India's Department of Science and Technology (DST), he gave a talk about quieter technologies and the importance of acoustics in engineering and machine design. This was an eye-opener for DST, and they sanctioned Rs 1.25 crore to set up a Centre for Excellence in Technical Acoustics at IISc. They had one condition though – a minimum of 15% of the total cost should come from industry. And so, the Facility for Research in Technical Acoustics (FRITA) was born, in collaboration with Raju as the industry partner. "We needed a model for FRITA. With my own money, I travelled with Prof Munjal to dozens of acoustic labs all over the world. Without copying a single thing, we designed our own set-up," he adds. In June 2000, Raju's company, Noise and Heat Control Systems Private Limited, entered into a renewable, 15-year joint venture contract with IISc and FRITA, to work on projects dealing with industrial noise control. "This association led to a lot of indigenisation of technology, at a time when many heavy industries like automotives were dependent on know-how from abroad at exorbitant costs," adds Raju.

Another memorable project was with the Central Pollution Control Board (CPCB). In the 1980s and 90s, diesel generators were commonly used in commercial establishments as there were frequent power cuts. But these generators were very noisy and produced a lot of fumes, and the onus to find a solution to these issues was on the user. In 2001, CPCB contacted IISc to find a permanent solution to this problem. After many iterations, Manohar and Raju made a novel prototype of a generic acoustic enclosure for generators that did not affect the wattage, had ventilation for the combustion, and also reduced the noise. It took them almost one-and-a-half years to convince genset manufacturers – including big names such as Birla Yamaha, Honda and Ashok Leyland – to adopt the technology. Raju recounts, "Finally, one day, before a meeting called by the CPCB and in the presence of government and industry representatives, we switched on the generator with our enclosure design. After the meeting was over, they said, 'Okay, let's start the generator and see if it works.' We told them that all this time it has been sitting next door and has been working! The impact on the others in the meeting remains unknown, but the CPCB representative was duly impressed." The report that the representative submitted to the government eventually led to new noise limits being set for gensets, and made the use of acoustic enclosures mandatory for the manufacturers of all diesel generators.

Silencers under the sea

Manohar's algorithms for the design of mufflers have had other applications too. One of these was in reducing breakout noise through ducts, such as those in air conditioning and ventilation systems. Over the years, he has been teaching architects about breakout noise through these ducts, and how it can be used for industrial snooping.

When the Indian Navy was looking for ways to reduce the sound of underwater propellers, so that it couldn't be picked up by enemy sonar, they contacted Manohar through Ramakrishna. In collaboration with former ME faculty member Vijay Arakeri, Manohar worked on the noise characteristics of marine propellers and self-noise of underwater bodies. Later, Manohar was asked to work on acoustic propagation across lined hulls. "I did not know anything about submarines or underwater acoustics," he recounts. But he took up this challenge too, and developed indigenous and cost-effective stealth linings for submarines that could absorb the sonar pings of enemy ships. "Visible light and electromagnetic waves cannot move far underwater. Detection and stealth under the sea is all through the use of acoustic waves. In association with my research student Satya Narayana Panigrahi, I was able to do some pioneering work in this field for the country."

Noise control

Noise is measured as the sound pressure level in decibels (dB). The relative loudness of sounds in the air as perceived by the human ear is expressed as A-weighted decibels or dBA. Normal human speech is typically around 55 to 60 dBA – a shout is 75 to 80 dBA – while the sound from an automobile without a silencer is 120 dBA. "At 130 to 135 dBA, you will feel as if someone is piercing a needle through your ear, and 155 dBA can render you permanently deaf," says Manohar. He describes their very first project in noise control, in response to an enquiry by the Fertiliser Corporation of India's branch in Sindri, in erstwhile Bihar. The plant used air at very high pressures for the chemical reactions to make fertilisers. The noise when this air was released through the exhaust vent was unbearable, enough to damage the ear drums. Even though these vents were placed at a height of 20 metres, the din was still too much. "When we went there, we found that there was not a single bird in the entire area. They had either died or flown away. That day, I realised how our human actions can be so cruel, knowingly or unknowingly, to the creatures around us." Manohar's silencer designs, which brought about a reduction of 50-55 dB in the noise generated, are being used by those factories even today.

Photo courtesy: Manohar Munjal

Manohar Munjal and DN Raju after signing the contract for FRITA, 2000

There are other ways in which sound waves can affect living beings. Human ears can hear sounds at frequencies between 20 to 20,000 Hertz (Hz). “At frequencies lower than 20 Hz, known as infrasound, I may not be able to hear anything, but my body can feel it. The resonant frequencies of my chest, arms and thighs are around 6 to 8 Hz,” explains Manohar. He recalls a scary incident when he was a consultant to the National Aeronautics Laboratory (NAL). On entering the control room of a wind tunnel, he felt as if he had been kicked in the chest, and somehow made it out before he collapsed. He was wearing earmuffs, and realised only later on what had happened. “There was peak noise at 8 Hz, so I couldn’t hear it, but it affected my body.” Similarly, animals such as bats that can pick up ultrasound over 20,000 Hz might be affected by machine-generated noise that is beyond human hearing.

As the long-term Chair of the National Committee for Noise Pollution Control, Manohar was also instrumental in setting up guidelines for the noise limits that vehicles can produce

As the long-term Chair of the National Committee for Noise Pollution Control, Manohar was also instrumental in setting up guidelines for the noise limits that vehicles can produce. Any new vehicle that produces a pass-by noise of more than 74 dB cannot get a road-worthiness certificate. Ironically, Manohar has also been involved in the resolution of Public Interest Litigations (PILs) against noise created by tampered silencers. “The slightest damage to reflective or impedance mismatch silencers results in it making more noise than before. These days, after buying a new vehicle, just for a kick, some people go to unscrupulous mechanics who will make one or two holes in the silencer at the ‘right’ places, and the result will be like an ‘anti-baansuri’ [anti-flute]!” says Manohar. After several complaints were made to the National Green Tribunal about these deliberately tampered silencers, and other sources of noise like loud pneumatic horns, the Karnataka State Pollution Control Board was called upon to respond, and Manohar was once again roped in as the expert. Also in attendance were the Bangalore Development Authority, the Bruhat Bengaluru Mahanagara Palike and other public agencies. A report based on these discussions was released in July 2021.

Challenges

It hasn’t always been an easy road for Manohar and Raju. “For India, noise was celebratory. For a country which says ‘Horn, OK please’, any function which is quiet is not a successful one,” says Raju. Getting people to take noise control seriously was a challenge, especially in the early years. Raju recalls an instance when they went to a sheet metal shop. “The manager sat peacefully amidst the continuous din of metal being pounded. When he was asked how he could work in the noise, he said, ‘Sir, if we don’t hear that, our heart fails, because the noise is money for us. It means that production is going on.’ He couldn’t fathom the fact that there could be a way to see the work happening, and block out the noise as well.”

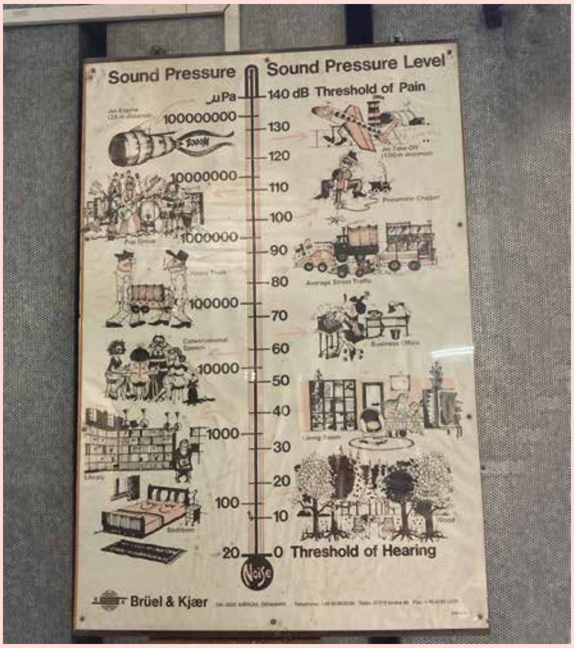


Photo: KG Haridasan

A guide to sound pressure and its levels displayed in Manohar Munjal’s lab

Manohar also had similar experiences. Once, Kirloskar Oil Engines Limited had asked his team to design a new muffler. Later, when Manohar met their Chief Engineer at a conference, and asked him how the new mufflers were performing, the latter couldn’t recall their design. “When I said it was 7 dB quieter than the others, he remembered and said that they couldn’t use our mufflers as they were 8 annas costlier than others,” says Manohar. “Noise reduction was absolutely immaterial … insignificant at that time.”

Things, however, have come a long way since then, and acoustics and noise control are now held in high esteem by the industry. “Reduction in noise means longer-lasting and better machines. Other benefits [of quieter technologies] on the quality of life and on aural health are perhaps not as tangible, but equally important. Prof Munjal took it upon himself to go to every industry and talk to their engineers,” says Raju. “We must have reduced thousands and thousands of dB together, for the country.”

Remembering Arcot Ramach

- Ranjini Raghunath

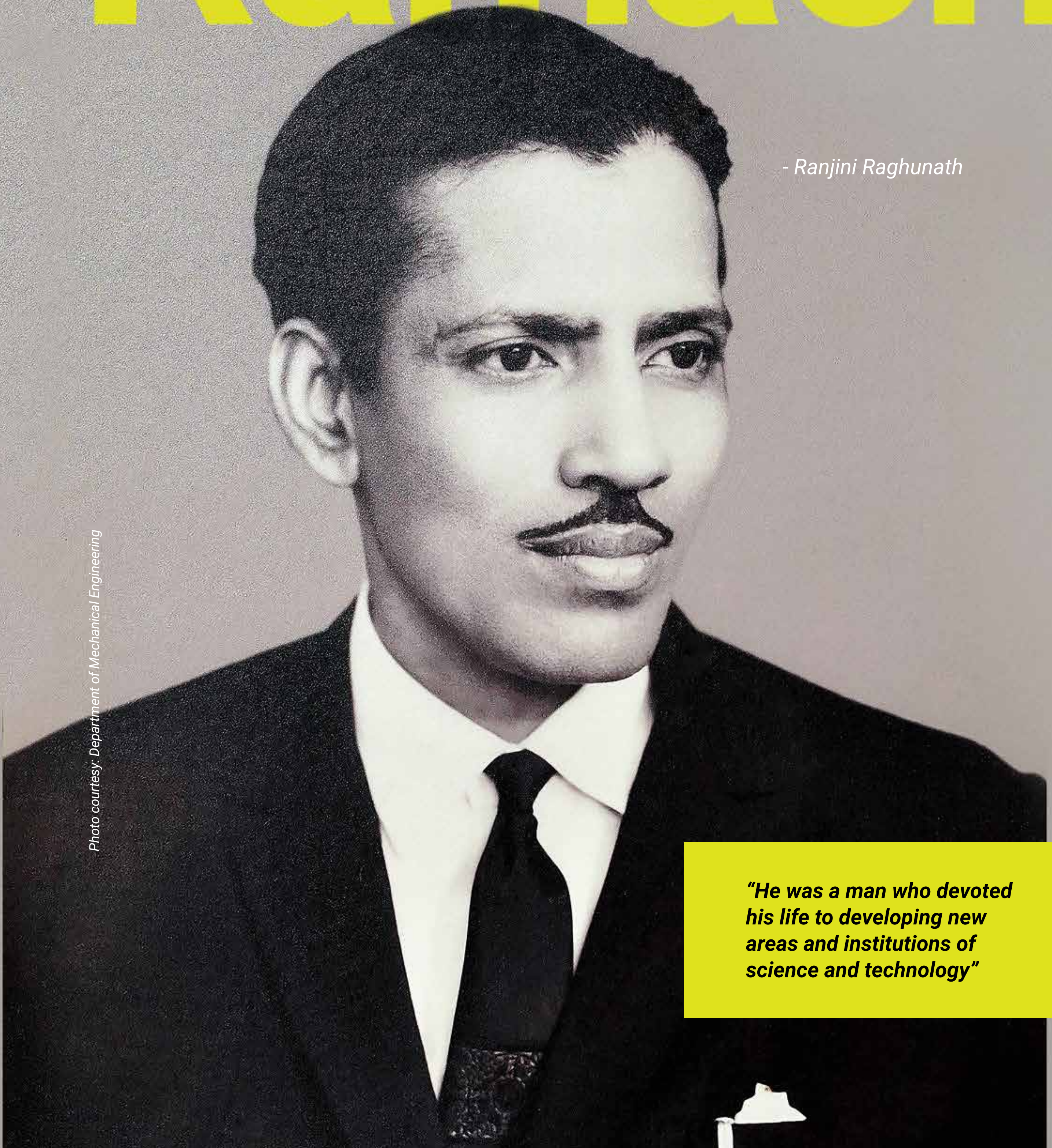


Photo courtesy: Department of Mechanical Engineering

"He was a man who devoted his life to developing new areas and institutions of science and technology"

andran

In 1966, when Arkal Shenoy travelled to the US to join a PhD programme at the Georgia Institute of Technology, after completing his Master's in Mechanical Engineering (ME) at IISc, he didn't have his degree certificate with him. "In those days, you would get your degree certificate in the mail after six months," he says. But to his dismay, the Registrar at Georgia Tech refused to let him join the programme without it. Arkal was 9,000 miles away from home, at a time when there were no mobile phones or the internet, and had been banking on his promised PhD scholarship. "The Registrar then asked me to join their undergraduate senior year and complete one semester, by which time I would get my degree certificate. But I couldn't afford to stay there; I didn't have any money."

Arkal then met with the Dean of Graduate Studies and explained his dilemma. The only documents he had were his course lists and marksheets, a letter from Satish Dhawan, the then Director of IISc, and a letter from Arcot Ramachandran, the head of ME under whom he had studied. To his surprise and relief, the Dean recognised Ramachandran right away, having worked at Purdue University around the same time Ramachandran had done his PhD there. "From that point on, there was no discussion about my degree certificate. He said to me, 'If you are one of Ram's students, I don't need any degree certificate,'" says Arkal. "It gives you a flavour for how well-respected he [Ramachandran] was."

A towering figure in the field of heat transfer, Ramachandran played a key role in shaping ME in its early years. During his time at IISc, he started important lines of research on heat transfer and thermodynamics, and introduced new courses of relevance to the industry.

Former students of Ramachandran also remember him as someone who went out of his way to help and mentor them, and efficiently juggled his research and administrative responsibilities. He was passionate about building new institutions and programmes. After he left IISc in 1967, he went on to lead IIT Madras, the Government of India's Department of Science and Technology (DST) and the United Nations Centre for Human Settlements, where his ideas birthed new policies, centres and ministries.

"He was always deeply committed to his work, an exceptionally capable person, a good administrator, and a good academic," says J Gururaja, a former student.

Ramachandran as a researcher

Ramachandran was born in Madras (now Chennai) in 1923. His father, Arcot Lakshmanaswami Mudaliar and uncle, Arcot Ramaswami Mudaliar – identical twins – were both highly accomplished. The former was a renowned gynaecologist and the longest-serving Vice Chancellor of Madras University, while the latter was a reputed lawyer, politician and the last Dewan of Mysore.

After completing a bachelor's degree from Madras University in 1943, Ramachandran went to Purdue University to pursue his Master's and PhD, and subsequently a postdoctoral stint at Columbia University. In 1950, he came to IISc and joined the ME section of the Department of Power Engineering as an assistant professor. He was soon promoted to its head.

One of the first things that Ramachandran did was set up a heat transfer lab – the first in the country, according to a souvenir publication commemorating the ME Golden Jubilee in 1995. "At that time … very little research work was being done in India in the field of heat transfer," writes former student and faculty member MV Krishna Murthy in *Current Science*.

Ramachandran's early research focused on problems such as measuring the temperature of hot gas streams and studying the influence of vibrating and rotating surfaces on heat transfer. A wind tunnel was built fromscratch in the central workshop and used for investigations of heat transfer between plane surfaces and flowing air. Foundry engineering was another area of interest; he collaborated with former faculty member MR Seshadri to study the influence of mould materials on the mechanical properties and microstructure of metals. He was also keenly interested in the application of heat transfer in nuclear power production; he introduced a course on nuclear engineering at ME and invited experts to give lectures on campus.

"He conducted extensive research on heat transfer problems related to production technology such as solidification, and thermal properties and characteristics of metals and non-metals as well, which helped him gain international recognition," Krishna Murthy writes.

Teacher and mentor

Ramachandran had many distinguishing qualities that endeared him to his students.

"His classes were very enjoyable," says former student and faculty member TS Mruthyunjaya. Ramachandran was quite well-versed in the subjects and could teach them without referring to a book or notes, Mruthyunjaya adds. "He would move around the class, addressing each student by name and asking them questions. Nobody could doze off."

Ramachandran was also decisive, Gururaja points out. When he was admitted to IISc, Gururaja was undecided about which branch to select: aeronautics or mechanical. After hearing about Ramachandran's approachable nature, he walked into the head's office directly and told him that he was planning to join ME only if he received a scholarship. Ramachandran immediately replied that he would definitely get a scholarship, and asked him to join the very next day. "That was his style. He was very quick at making up his mind."

Every day, Gururaja recalls, Ramachandran's wife would drive him down to the campus and drop him off at ME. "He had a very fast stride. He would come to the lab first, not go to his office. If there was any researcher working on something, he would sit down with them, talk to them and try to find out what and how they were doing."

Ramachandran also took pains to remember his students' names. "When we applied to the department, we had to submit our photographs. I was told that he used to keep those photographs with him and link the face to the name. And as soon as you entered his chamber, he would shout out your name. We would be amazed," recalls Mruthyunjaya.

Over the years he spent at ME, Ramachandran cultivated extensive connections that helped him procure vital equipment and facilities for the Department. In one instance, S Kasturi, another former student, needed some stainless steel sheets to manufacture trapezoidal ducts for experiments on laminar and turbulent fluid flow. "They were not available at that time in the whole of India, except at HAL," Kasturi recalls. "Prof Ramachandran was very helpful; he contacted the Director of HAL and procured all the material."

Kasturi recounts how Ramachandran gave students complete freedom to pick their own research topics and pursue them. He would also ask students pointed questions to nudge them in the right direction, according to Arkal. "His way of teaching was not to tell you, but to ask you: Why are you doing this? How are you going about doing this? What are the applications of the work that you are doing?"

It was during Ramachandran's tenure that a full-fledged thermal power station was set up on campus – on a "war footing", according to the souvenir – to give ME students real-life experience in operating and maintaining a power plant. He was also keen on setting up a similar small-scale nuclear reactor on campus, adds Gururaja, but that did not materialise.

Apart from serving as the head of ME, Ramachandran was also appointed the Dean of the Engineering Faculty in 1961 and later the professor-in-charge of a newly established Department of Industrial Management in 1965. His leadership skills made him well-respected across campus, his students say.

Photo courtesy: J Gururaja

Arcot Ramachandran (circled in red) with ME students in 1961

"We were thinking that he might become the Director of the Institute," says Gururaja. However, Satish Dhawan, who was a Professor in the Department of Aeronautical Engineering, was appointed instead. His appointment wasn't without controversy; some senior faculty members allegedly protested that he was too young and inexperienced. "Dr Dhawan was an exceptionally capable person, articulate, charismatic," says Gururaja. "So whatever rumbling was there, it sort of [died] down very quickly."

Ramachandran, for his part, remained neutral to these rumblings. "I knew that he would go higher up one day ... that his services would be called upon for bigger things," adds Gururaja.

Within a few years, Ramachandran was called away to become the next Director of IIT Madras, and left IISc in 1967.

Building institutions

During the five years that Ramachandran spent at IIT Madras, he was "directly responsible for its growth as a leading research institution," writes Krishna Murthy. "In the field of heat transfer, a new school of research was established by him at IIT-M. This school is now a recognised centre of excellence for research in heat transfer problems related to food processing, fluidised bed combustion, and passive and active solar thermal systems." Ramachandran was also instrumental in helping IIT Madras secure an IBM 370, one of the most powerful computers in the country at that time.

Photo: C Gourishankar/IIT Madras Heritage Centre

Arcot Ramachandran takes over charge as Director of IIT Madras from B Sengupto in the presence of CV Sethunathan, the Registrar, and S Sampath, Professor in the Department of Electrical Engineering

In 1973, the Government of India decided to establish a new Department of Science and Technology (DST) and tapped him as its first Secretary. He also served as the Director General of the Council of Scientific and Industrial Research (CSIR).

At DST, Ramachandran was tasked with chalking out the country's first Science and Technology plan. He played a key role in constituting the National Committee on Science and Technology and in bringing out the National Technology Policy Statement. He also launched national R&D initiatives related to the environment, ocean science and technology, biotechnology and remote sensing. His long-term interest in energy led him to institute a national R&D programme in new energy sources. "These activities and the programmes that he created blossomed into departments and ministries," says Gururaja, who was recruited by Ramachandran to DST and became the first director of the renewable energy programme.

Ramachandran was particularly interested in solar energy. "Under his leadership, solar energy research, demonstration and application became the mantra of the new energy sources programme of DST," says Gururaja. "His personal interest in energy research and development played a catalytic role in mobilising the active participation of academic institutions, CSIR national laboratories and public sector industries to combine their efforts and harness solar energy in a major way for the benefit of the country." During his tenure, a major conference called the International Solar Energy Congress was held in Delhi in 1978, which was attended by participants from about 63 countries. "This placed India as a prominent player on the world solar energy map," Gururaja adds.

Ramachandran did not stay at DST for very long; he soon had a higher calling. In 1978, he became the Under-Secretary General and Executive Director of the newly established United Nations Centre for Human Settlements, headquartered in Nairobi. There, he proposed the idea of a World Habitat Day to raise awareness about affordable and adequate shelter. A Sustainable Cities Programme and a Global Strategy for Shelter were also launched.

At the UN, Ramachandran advocated an integrated approach to human settlements, using indigenous natural resources for construction, and involving local residents in building shelters. In a recorded interview from 1991, for example, he explains that governments must not fixate on building houses for all citizens by themselves. "They must become enablers and facilitate people to help themselves. This means a change of attitude of public sector officials and local authorities to involve the people, community-based groups and NGOs in the implementation of projects."

Wherever he went – IIT, DST or the UN – he would handpick competent people, take them along with him to the new place and give them full freedom to build and develop things, says Gururaja.

Ramachandran retired from the UN in 1993 and returned to Bangalore. In 2003, the Government of India conferred on him the Padma Bhushan, India's third highest civilian award. In 2013, a new auditorium in ME named after him was inaugurated. He passed away at his home on 17 May 2018.

"He was a man who devoted his life to developing new areas and institutions of science and technology, and encouraging young people to really come out with their best talent," says Gururaja. "He was a builder of people, institutions and programmes. That is his legacy."

With input from Connect Staff

Engines at IISc

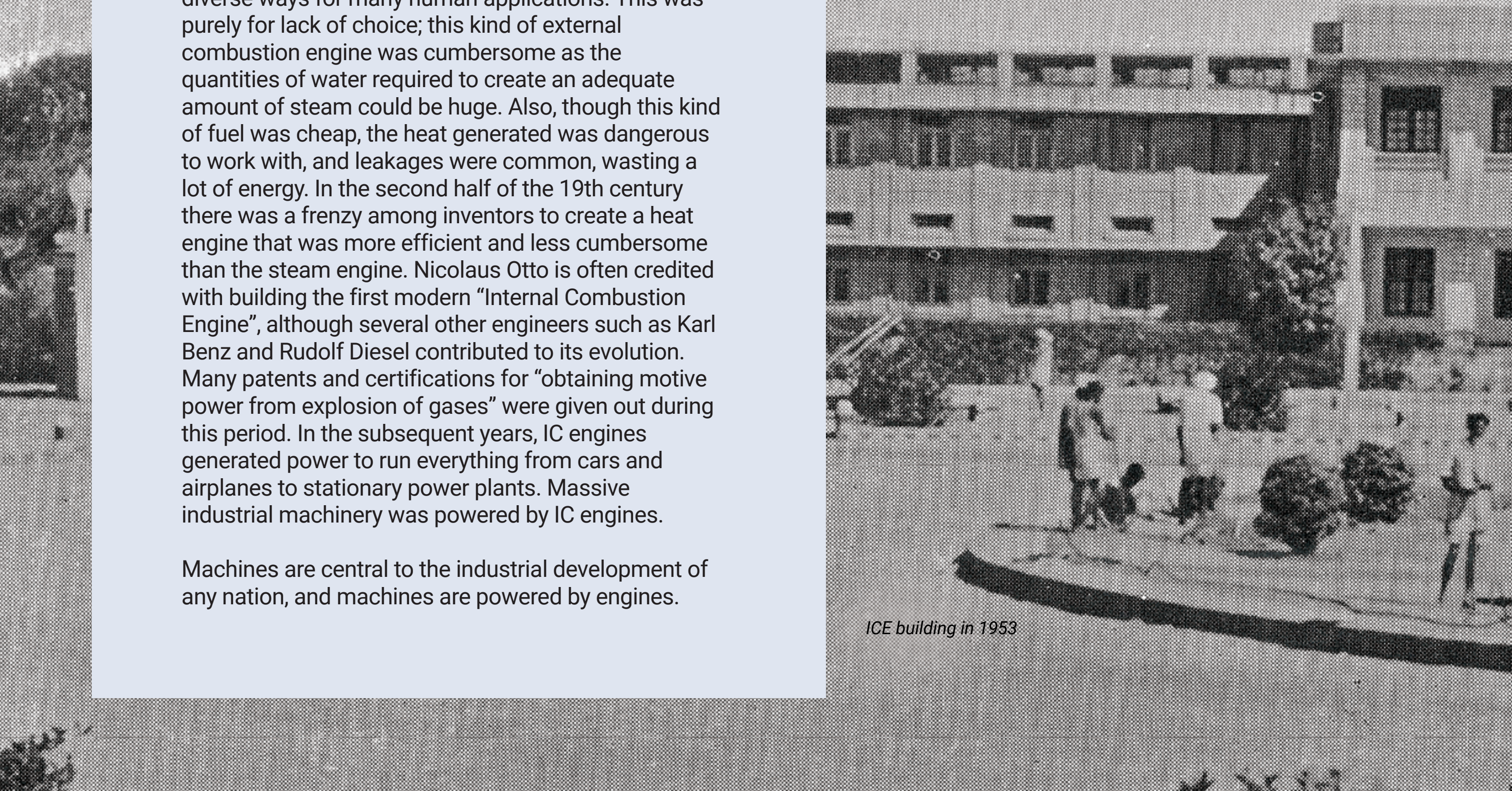
- *Narmada Khare*

The erstwhile ICE Department contributed to indigenous engine technology in the early years of India's industrial development

There once was a particularly popular department at IISc called the Department of Internal Combustion Engineering (ICE), and for close to a quarter of a century, the engineers there designed, constructed and tested a plethora of engines and engine accessories.

Since its initial use in driving water pumps in the late 17th century, the steam engine has been used in diverse ways for many human applications. This was purely for lack of choice; this kind of external combustion engine was cumbersome as the quantities of water required to create an adequate amount of steam could be huge. Also, though this kind of fuel was cheap, the heat generated was dangerous to work with, and leakages were common, wasting a lot of energy. In the second half of the 19th century there was a frenzy among inventors to create a heat engine that was more efficient and less cumbersome than the steam engine. Nicolaus Otto is often credited with building the first modern "Internal Combustion Engine", although several other engineers such as Karl Benz and Rudolf Diesel contributed to its evolution. Many patents and certifications for "obtaining motive power from explosion of gases" were given out during this period. In the subsequent years, IC engines generated power to run everything from cars and airplanes to stationary power plants. Massive industrial machinery was powered by IC engines.

Machines are central to the industrial development of any nation, and machines are powered by engines.



ICE building in 1953

To appreciate the complexity of IC engine research, it is useful to get an idea of how an engine works. In its most basic form, an IC engine constitutes a chamber in which a mixture of air and fuel is injected. A piston plunges inward into the chamber to create very high pressure, causing the mixture to explode. This sudden explosion drives the piston back, initiating a chain of events: a crankshaft attached to the other end of the piston rotates, leading to the movement of gears, pulleys or hammers; essentially using the energy from the heat to move things. The shapes and sizes of each of these parts, the materials they are made of, the fuel used, the force with which it is injected into the chamber, the pressure imparted by the piston, the number of chambers, the number of explosions – all these factors (and more) contribute to the efficiency with which an engine generates power and moves a machine. There can be literally hundreds of moving parts in a machine. And when you turn an engine on, you start a chain reaction that eventually ends up turning the wheels of a car, or lifting the mechanical arm of a crane, or drawing oil out from deep seas.

ICE at IISc

IISc did not enter the field of engine research until almost the end of World War II. In 1945, a new Department of Internal Combustion Engineering (ICE) was set up. It soon occupied the grey stone building at the southern entrance to the campus, which is now the Society for Innovation and Development.

The 1944-45 Annual Reports record two developments that played a significant role in the establishment of the ICE Department. The first was the journey of Sir JC Ghosh (Director of IISc at that time) to England as a member of the Indian Scientific Mission. There, he discussed with experts from around the world about the need for new areas of research at the Institute. Upon their recommendations, he appointed Major BC Carter to teach the students at the Department of Aeronautical Engineering "the working of Internal Combustion Engines," thus sowing the seeds of a new department. The second was the decision of the Institute to start post-graduate programmes in Heavy Engineering, Power Engineering, Designing of Machinery, and Chemical Engineering, "in view of the post-war plans for the proper development of the resources of the country." Steps were taken to raise a generation of well-trained, confident engineers who could stand up with the best in the world.

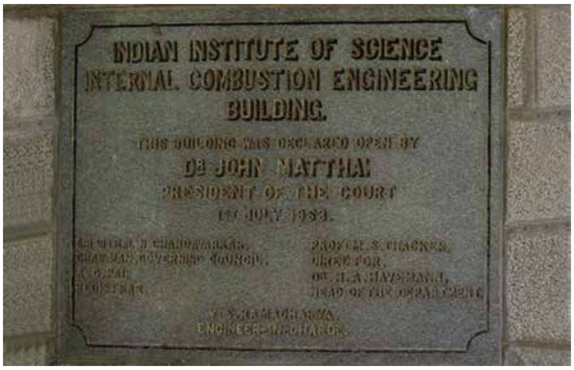


Photo: Gouri Patil

A plaque commemorating the inauguration of the Internal Combustion Engineering building by John Matthai in 1953

Photo courtesy: ICE brochure, 1953

From the get-go, researchers at ICE worked actively with their industry counterparts, testing and designing various types of engines and their components, housing them in a large hangar in the west wing, according to former faculty member V Kuppu Rao. One of these, he notes, was a Derwent Mark V engine that originally powered fighter planes in World War II, which was given to the Department by Rolls Royce. Its "howl", he says, could shatter the calm over the entire campus and the then relatively quiet streets of Malleswaram.

Many collaborative projects were carried out by ICE under the aegis of the fledgling Council of Scientific and Industrial Research (CSIR). One of these – led by MA Havemann, who succeeded Carter as the Department head, and VM Ghatage, Chief Engineer of Hindustan Aeronautics Limited (HAL) – focused on developing a fully indigenous six-cylinder engine for the HT2, India's first aircraft used to train air force pilots. Another of Havemann's projects centered on an engine using hot air as the working medium, which could prove useful in rural areas where organic fuels like firewood or charcoal were more abundant than gasoline or diesel.

For the next 20-25 years, engineers at ICE invested efforts to indigenise foreign engines, to develop new engines using local material and indigenous fuels, and attempted to reduce the pollution that was always associated with the use of engines.

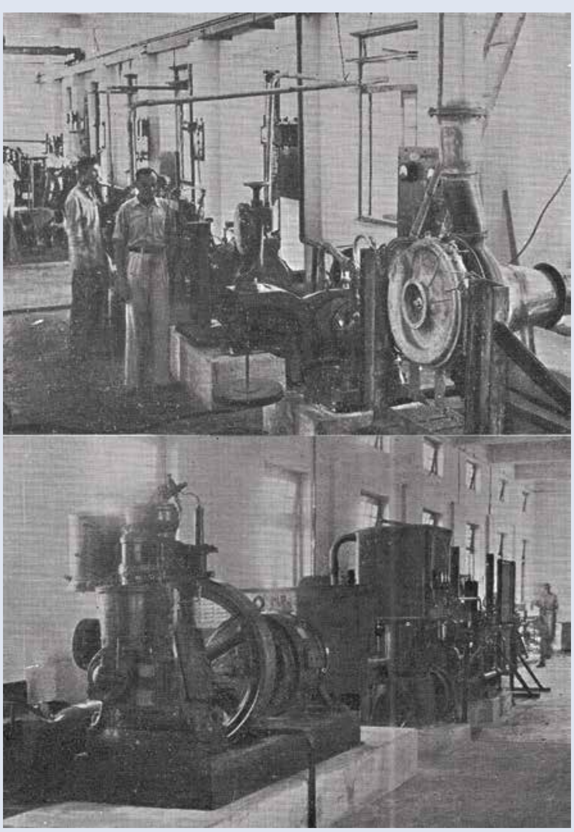


Image: ICE brochure, 1953

The ICE laboratory in 1953

Examples of activities reported in the 1952-53 Annual Report give an idea of the diversity of the work carried out in the ICE laboratory: Testing of two Kirloskar engines for the effect of chromium plating on the piston ring, tests conducted on 'horizontal single cylinder engines' from Messrs Cooper Engineering Ltd to improve the geometry of the combustion chamber, development of 'twin fuel Diesel engines' to accept indigenous fuel and the installation and testing of a Derwent Mark V turbo-jet engine.

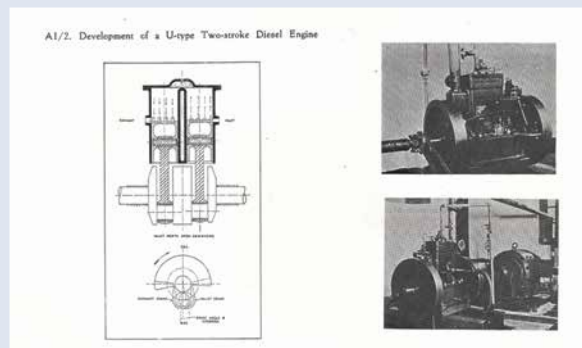


Image: ICE brochure, 1953

Design and development of a U-type two-stroke diesel engine

Indian industry at that time was rudimentary at best. Most engines and fuel were imported and expensive. The Department often received engines from outside sources for testing and analysis of parts. The Annual Reports describe how the stands on which engines were hoisted for testing often required significant realignment to accommodate foreign-made engines.

The engineers at ICE strove to create engines suited to Indian conditions. Indigenous fuels, vegetable oils and alcohol were tried out as cheaper replacements to imported mineral oil. Innovative techniques for manufacturing crankshafts were tried. Several observers have reported that in innovation and discovery, ICE researchers were at par with their counterparts in countries like Japan and Germany.

Less noise, more efficiency

Work in one area that considerably advanced the field was efforts to reduce the air and noise pollution caused by engines. N Raman, who joined the Department in the late 1960s and retired as a Principal Research Scientist in 2003, remembers how loud many of these engines were. "There are so many IC engines," he says. "A gas turbine is also an IC engine. We had a gas turbine section. It made a tremendous noise. It could be heard everywhere, even outside the campus. Finally, it had to be discontinued." Raman calls faculty member Manohar Munjal "one of the best in the world" in the field of acoustics; his research played a major role in reducing noise pollution. Raman himself studied tribology, the science of friction and lubricants. He worked with MV Narasimhan, a professor at ICE, on two-stroke engines that were "powerful, but very dirty." Their project to reduce air pollution and to increase fuel efficiency of the two-stroke engines was sponsored by the Department of Science and Technology, Government of India, and later the concept was handed over to TVS India.

Photo: Gouri Patil

A model of the 2-stroke engine that was handed over to TVS India

Another important contribution of the Department was developing cast-iron crankshafts – the rotating parts that form the backbone of an IC engine – to replace forged crankshafts in automobiles, which were expected to cut down production cost by 30-40%. S Seshan, Professor Emeritus and former Chair of the Department of Mechanical Engineering (ME), who has worked at IISc for 36 years, explains, "The crankshaft is a critical component of any automobile, and mandates premium properties. It is a fairly intricate steel component, and is complicated and expensive to manufacture. Ever since the advent of automobiles (such as the Ford models), crankshafts were invariably produced, all over the world, through the hot forging process. Our department ventured into developing 'cast crankshafts', with the aim of reducing the weight as well as the cost, without compromising on the property standards. The availability of ductile iron and Austempered ductile iron served as yet another incentive for such an endeavour."

Manohar, in the ME Department's Golden Jubilee souvenir, recalls a lab accident that turned into a fortuitous discovery. When an engine using the cast-iron crankshaft was being tested, a sudden power fluctuation made the engine race to "abnormal" speeds. But the crankshaft didn't suffer any damage, proving that it was quite durable. "It was [re]assuring that cast crankshafts had gone through a test condition totally unanticipated." These engines were later tested in taxis in Bombay and in vehicles plying on different terrains, he adds. "There was not even a single case of failure." Despite the promise offered by cast-iron crankshafts, for reasons that are lost to time, they did not end up in commercial use.

Winding down

Although ICE and the Department of Mechanical Engineering merged much later in the 1970s, ICE seems to have struggled to acquire funding for several years before. As a 1953 brochure states, "It may be stressed, however, that other countries are spending a far greater amount on similar work, and unless sufficient help is forthcoming, both from the Government and private enterprises, it may not be possible to solve the numerous problems connected with and arising from, the quest for an indigenous IC Engines Industry in India."

The Annual Reports in the 1960s mention several collaborative projects between ICE and the ME section, until the merger. LS Srinath from IIT Kanpur's Mechanical Engineering Department was put in charge of this merger by Satish Dhawan. J Srinivasan, a former faculty member at the ME Department, says that the merger was recommended by an international review committee that didn't completely appreciate how rudimentary the Indian automobile industry was at that time. According to him, India still needed an academic department to study ICE. Seshan indicates that ICE was comparatively smaller in size and hence the growth potential (in terms of the number of students and faculty, and lab facilities) became somewhat constrained. Plus, many aspects were common in the curricula and courses of the departments of ME and ICE. Added to this was the slow development of the Indian automobile industry and inadequate career challenges for IC engineers. All the above lead to the merger of the two departments, for more effective common academic activities.

But the transition wasn't smooth. "That was a period of churn and change of direction," says J Gururaja, former ME student and faculty member who later led the renewable energy programme at the Department of Science and Technology, Government of India. "Srinath wanted to shut down work on IC engines; he felt that the work of testing and certifying them for industry on the score that it also involved development research was nevertheless too 'low-grade' for IISc, and that the Institute should focus its work on more fundamental research in newer areas."

However, those turbulent times are long gone, and the ICE Department's legacy lives on in the labs of current faculty members RV Ravikrishna, who studies combustion and flow dynamics and develops technology for using biofuels, and RT Naik, who focuses on renewable energy, biofuels and emission control in ICEs. Himabindu M, a senior scientific officer, is also involved in developing alternative biofuels and thermoelectric generators for hybrid vehicles.

With input from Connect Staff and ME students

The Mechanics of Life

Photo courtesy: Namrata Gundiah lab

Namrata Gundiah and her doctoral student Anshul Shrivastava studying hydrogels

- Karthik Ramaswamy

Scientists from IISc are addressing questions about the biological world using their engineering skills

Most mechanical engineers do what we think they do – design and fabricate aircraft, machines, and other such human-made objects. But it turns out that some members of their tribe are also curious about how living things work.

One of them is Namrata Gundiah, Professor in the Department of Mechanical Engineering, who has taken on the challenge of addressing problems in biology using her training in mechanics.

Elastin and collagen

When Namrata began her PhD at the University of California, Berkeley, she was drawn to a class of rubber-like proteins secreted by cells in certain tissues that allow them to undergo large and cyclic deformations. Elastin is one such protein responsible for the "stretchiness" of tissues.

This led Namrata to investigate what happens to elastic tissues in the human cardiovascular system – specifically arteries and the heart – when they are damaged during disease. "When I, in collaboration with a cardiac surgeon, saw how damaged tissues adapt following injury, I was fascinated with how the cellular processes could contribute to changes in the tissue properties. Exploring changes to tissue properties after disease then became the subject for my postdoc for a two-year period."

Namrata decided that if she were to study how tissue properties change during disease (and how to design engineering solutions to handle disease), then she would have to use a "mechanobiology approach." This emerging field of science, which brings together physics, engineering and biology, attempts to understand how mechanical properties affect the fates of cells and development of tissues. Today, mechanobiology has become an integral part of her research. The questions Namrata's lab is addressing in the realm of cell-based mechanics are how cells adhere to the substrate, how they respond to mechanical cues, and how they migrate.

Another important focus of research for Namrata is aortic aneurysm, in which the walls of the aorta, the largest blood vessel in the body, become weak and bulge when blood flows under high pressure. This may cause the aorta to rupture. One of the primary drivers of this disease is the disruption in the balance between collagen, the main structural protein found in human beings and other mammals, and elastin, the rubber-like protein that she had studied earlier. "There's an imbalance between the two proteins – not having enough elastin and the deposition of collagen of poor quality," she says. She and her team created a disease model by changing the relative composition of the two proteins, and quantified the mechanical properties of the tissues. The ideas were tested using human aortic samples obtained from Narayana Hrudayalaya (now Narayana Health City) in Bangalore.

Hydrogels

Namrata also uses tissue engineering, a discipline that aims to restore or replace damaged tissues in the human body. Here, scaffolds of a specific material are engineered, and tissues are grown on them in a laboratory. Among the more popular tissue engineering scaffolds are hydrogels. Hydrogels are made up of large molecules or polymers that have a unique combination of properties: they do not dissolve in water, are absorbent, and are structurally sound.

In the future, hydrogels could have significant applications as biomaterials. For instance, the cornea, which is the clear, protective outer layer of the eye, is similar to a hydrogel. Like many other parts of the human body, the cornea contains the protein collagen. When collagen degrades, it damages the cornea. Namrata's lab is interested in synthesising hydrogels that are tougher so that they can be used to help corneal wounds heal. "If we are looking to the next generation of biomaterials, we need materials that are tough, can support cell growth and can serve as replacements for tissues," she explains.

Another important reason why bioengineers are interested in hydrogels is the way they rupture. "They can undergo large deformations and when they fail, they are brittle and rupture not unlike jelly, the dessert made from gelatin. Jelly has a lot of water, and can undergo large deformations, but when you break it, it has a very clean rupture surface. It breaks like glass," Namrata explains. She says that understanding the mechanics behind hydrogel failure may provide insights into tissue engineering applications.

Insect biology

When Namrata decided to set up her lab at IISc, she remembered what one of her mentors from her graduate school had told her: "When you set up your lab, you should have your bread-butter projects which will give you the moolah for your research. But always have a hobby project which you do purely for the joy of science." She took his advice seriously and decided that her hobby project was going to be insect biomechanics. She began with resilin, one of the best known rubber-like proteins, found in the appendages of insects and other arthropods.

Namrata's insect biology research has thrown up many surprises. For instance, her lab has shown that the female parasitic fig wasp inserts her ovipositor (the appendage used for egg-laying) inside the fruit with the help of a microscopic drill enriched with zinc. Her team has also shown that mandibles of the larvae of the coffee white stem borer beetles are strengthened by zinc too. They use their mandibles to tunnel their way through wood until they find a safe place to pupate. "My student wanted to call it "cutting-edge" research, while I call it "boring" research," she says in jest.

Swimming fish

Jaywant H Arakeri, Professor, and Namrata's colleague at the Department of Mechanical Engineering, is also an engineer who has a passion for the biological world. One of the problems that this fluid mechanist studies, along with RN Govardhan, also a Professor in the Department, is how fish and other aquatic animals glide through water.

When an object moves forward under water at high speeds, the forward forces, or thrust, need to balance the forces that push it back. These forces, called drag, are the result of friction and pressure exerted by water on the moving body.

"If you look at a submarine, it has a propeller whose rotation helps it overcome the drag on it. The blades of propellers are rigid. But if you look at a fish, it's body and tail are flexible," says Jaywant. The other difference between a human-made propeller and the tail of a swimming fish is the unsteady nature of movement in the latter. "Unlike a propeller which moves at a constant speed, the fish tail constantly moves back and forth, with its speed periodically varying from zero to a maximum value." Jaywant's lab is studying how these factors – the flexibility of the body and tail of the fish and the flapping of its tail – contribute to both thrust and drag.

Jaywant's team is also addressing another related question: how efficiently do fish swim when compared to human-made objects? "There is no clear definition of efficiency. But one way of thinking about it is how much energy is expended," he says. The energy expended shows up as disturbance in the wake, the region of disturbed flow of water around a body, which can be measured. "Many people believe that the wake of a fish is quieter than that of human-made objects."

Jaywant's experiments are done in a water tunnel or in a glass tank containing water. An airfoil having a flexible flap is connected to a motor that produces oscillatory motion. "This makes it behave like a fish and we are able to measure the forces it experiences. It tells us about the thrust being generated. We can also measure the torque [rotational force]," he explains. The torque reveals how efficiently the thrust is generated.

And in order to visualise flow, a fluorescein dye is used. By shining a sheet of laser light perpendicular to the foil, researchers can see the wakes and vortices (a vortex is a whirling mass of water produced by the movement of the swimming object) that are formed. His team also makes quantitative measurements of the velocity around a "swimming" foil. "For this, we use a technique called particle image velocimetry where you put really minute tracer particles of the order of 10-20 microns in water and shine a laser. And with a high-speed camera, we can measure the displacement of these particles," he elaborates.

Agriculture

Jaywant comes from a family of agriculturists. "My father was an agricultural scientist, and many of my family members are into farming. So it was natural that we started looking at fluid mechanics issues related to agriculture," he says.

The first agricultural problem that Jaywant tackled was how temperature could be regulated in a polyhouse, a kind of a greenhouse protected by a polythene mesh. Polyhouses, commonly used for growing vegetables and flowers, are of two kinds: one with a fan pad system which reduces temperature by evaporation of water constantly dripping from a wet pad. The other is a naturally-ventilated polyhouse, in which temperatures can go up substantially, especially in a tropical country like India.

To make polyhouses more energy-efficient, Jaywant has collaborated with MS Bobji (Professor, Department of Mechanical Engineering), M Uday Kumar (Professor, University of Agricultural Sciences, Bangalore), and KR Sreenivas (Professor, Jawaharlal Nehru Centre for Advanced Scientific Research) on projects funded by the Robert Bosch Centre for Cyber Physical Systems at IISc and the Indian Council of Agricultural Research. As part of one of the projects, they developed a design for

Photo: Jaywant Arakeri Lab

M Udayakumar, Jaywant H Arakeri and other scientists inside a polyhouse at UAS, Bangalore

a naturally-ventilated polyhouse that incorporates a solar chimney. The chimney uses the convection of air heated by solar energy. "We wanted to see if evaporation could be built into the system, while also being energy-efficient."

Yet another agricultural project was to create optimal conditions in aeroponics chambers used to grow potato tubers for seed production. Aeroponics is a method of cultivation where the roots, hanging in the air, absorb moisture and nutrients from tiny droplets that are continually sprayed on to them. "We came up with cost effective and energy efficient techniques to keep temperatures low, at both the root and shoot levels, by using fluid mechanics and heat transfer principles in the design," says Jaywant. His team has also investigated how supplemental LED lighting can be used to increase tuber production.

Jaywant's research interests in agriculture do not end there. "My students and I have come up with a small device to rapidly measure evaporation rates at the leaf level." This, he says, will tell us how much water is required by plants – and when – as we move towards precision agriculture.

Jaywant has also collaborated with Namrata to study arterial flows to understand flow-induced stresses that are believed to be responsible for several cardiovascular diseases, including atherosclerosis.

Jaywant's and Namrata's curiosities about living organisms have inspired them to make intellectually exciting journeys from the world humans have built to the biological world. And in the process, the mechanical engineers have provided us with a unique perspective of nature.

Designing a legacy

- *Sidrat Tasawoor Kanth*

Cotton harvesting machine being tested in a field in Gujarat

A glimpse into the origins and evolution of product design at IISc

In a cotton field in Gujarat, the pickers have a delicate and labour-intensive task before them. That task is now less tiresome than earlier because they are trying out a light-weight, battery-powered device which makes their job faster and easier. These are prototypes of a cotton picking machine designed by Sickle Innovations, a farming solutions company co-founded by IISc alumni. It is projects like these that bring out the entrepreneur in a student, as they step into a realm full of innovation and enterprise – product design. A key requirement for creating such impactful innovations is an environment that incubates and encourages out-of-the-box thinking. Which is exactly what the Department of Mechanical Engineering (ME) at IISc has been providing for the last 75 years – long before terms like 'innovation incubator' were in vogue. The Department has pioneered teaching and research in design way ahead of its time, and also contributed to developing other related interdisciplinary centres at IISc.

Sowing the seeds

The ME Department offers one of the longest running courses in design, called Design of Engineering Systems, which was initiated back in 1963 by MR Raghavan (who retired from IISc in 1988). The course has continued in one form or the other over the years. Today, it is being offered as Creative Engineering Design by Amaresh Chakrabarti (Professor and Chair of the Center for Product Design and Manufacturing or CPDM), himself an alumnus of ME. One of Raghavan's students was TS Mruthyunjaya, who joined the Master's programme at ME when only two faculty members were working on design research – MR Raghavan and P Srinivasan. Within a few years, he became part of a growing pool of faculty researchers in

ME, dabbling in the field of Mechanisms, which is the study of the construction of devices that rely on mechanical movements to perform their functions. Mruthyunjaya, who first taught the subject at ME, says, "[The] ME Department in IISc became a centre of research activity in India in the field of Mechanisms." This tradition is now being continued by his own student, Dibakar Sen, who is now a professor at CPDM and ME, and teaches a course on Mechanism Design. Mruthyunjaya laughs while remembering his first time teaching the subject, saying that he was "very, very disappointed" with his performance as a teacher, and that it motivated him to delve deeper and sparked a life-long career in the subject.

Over the years, the ME design community kept assimilating expertise across subjects and backgrounds. In the early 1970s, LS Srinath came from IIT Kanpur and strengthened the Department's research in Solid Mechanics. With the merger of the Department of Internal Combustion Engineering (ICE) with ME in 1971, areas like noise control and acoustics, nurtured by faculty member Manohar Munjal, began to influence design research in ME.

At the turn of the century, newer research areas were developed by B Gurumoorthy, R Narasimhan, Ashitava Ghosal and others. They established groups specialising in Computer Aided Design (CAD), Finite Element Analysis (FEA), and nanotechnology and robotics, which are the core strengths of design research anywhere in the world. Their labs continue to attract student talent to IISc. As Gurumoorthy says, "The best products of the department are the students themselves."

Setting up of CPDM

ME has been a nursery for several interdisciplinary centers in IISc, one of them being CPDM. Mruthyunjaya was instrumental in its establishment. He recounts how he became deeply interested in creative engineering design through the lectures of Bernard Roth, a visiting professor from Stanford University, in 1984. A couple of years later, during his sabbatical as Visiting Professor at Ohio State University, he utilised the opportunity to study design methodology in depth and eventually took over the ME Department's engineering design course in 1988. A final push towards the creation of CPDM came during the ME Department's golden jubilee year in 1995 when it was hosting the International Conference on Advances in Mechanical Engineering (ICAME). In a panel discussion, Mruthyunjaya realised the potential of a programme exclusively tailored for studying product design. With inputs from colleagues at the Centre for Electronics Design and Technology (CEDT, now known as the Department of Electronic Systems Engineering), a Master's programme in product design was launched in 1997. A year later, this led to the formation of CPDM, which is one of IISc's most sought-after departments today.

"I envisioned CPDM as a unit where we can train students from diverse backgrounds … because uniformity is not good for creative efforts," says Mruthyunjaya. He led the centre from 1998 till his retirement in 2003, with a vision to combine engineering and industrial design and make products that balance functionality, usability and aesthetics – a need that was not being met at any premier institute in India. Gurumoorthy also credits the interdisciplinary nature of the centre to giving an impetus to students' creativity. CPDM continues to be true to its mission, with faculty members' and students' backgrounds ranging from architecture to metallurgy. "Mechanical Engineering can be justifiably proud of its offshoot – CPDM," Mruthyunjaya adds.

Real world applications

Taking their expertise to the field has been a long-standing practice at the ME Department. In this regard, former faculty member S Soundranayagam's contributions to turbomachinery are hailed by many, including Abdul Kareem A, a technical assistant who joined the Department 38 years ago. Abdul remembers their efforts to set up a mini hydroelectric power plant in a village in Mandya district, working with the Karnataka Power Corporation Limited (KPCL), and also their visit to Vishakhapatnam where they worked on torpedo propeller designs for the Naval Science and Technology Laboratory (NSTL).

Photo courtesy: IISc Photography Club

Students at CPDM

In recent years, students of ME and CPDM have put their creative minds to focus on issues of agriculture, mobility and healthcare. These choices are a "testament to the students themselves," as Gurumoorthy puts it. "Students were not so keen on designing lifestyle products; they were more keen on solving problems of the people around us."

One of the labs working on design optimisation with a focus on biomedical devices is that of GK Ananthasuresh, who was the Chair of ME until recently. His students have developed compliant mechanisms that enable the study of the mechanical properties of cells. Compliant mechanisms are joint-less, flexible structures that can transmit forces. This technology is being commercialised by a Bangalore-based startup, BendFlex, founded by the lab's alumni. Virtual reality-based products from the lab have led to the establishment of another startup – Mimyk. His students are also collaborating with geriatric specialists to design comfortable and adaptable seating solutions for the elderly.

Biomedical devices are also the focus of the Applied Geometry and Mechanisms lab led by Dibakar Sen, where students work on prosthetic limbs, among other areas. One of their projects led to the founding of a company called Grasp Bionics, which is pushing boundaries in rehabilitating amputees. Another product designed here is a chair to make the dialysis process more comfortable for patients.

At the lab run by Ashitava Ghosal, another faculty member at ME, robotics technology is being applied to design tools that help surgeons perform minimally invasive surgeries. Manish Arora, a faculty member at CPDM heads the Universal Technology Solutions for Accessible and Affordable Healthcare (UTSAAH) laboratory, where the focus is primarily on providing efficient design solutions to make healthcare universal and accessible. Their projects range from developing better insulin pumps to rehabilitation solutions for children who are hearing impaired.

To bring these ideas to life, the ME department has continuously fostered collaboration between academia and industry. When computers became essential for designers but were still prohibitively expensive, ME started a one-of-a-kind design service for the industry where the expertise and computing resources of the ME research groups would be available to solve practical issues faced by the industry. Udipi Shrinivasa, who retired from ME as a professor in 2012, recounts how novel this scheme was back then. "People laughed at us," he says. But they went ahead and collaborated with Tata Consultancy Services (TCS) to develop the Advanced Product Design and Prototyping (APDAP) initiative. In 1995, rapid prototyping was introduced to produce quick and efficient prototypes for companies that would usually have to wait for several months for their designs to be manufactured abroad. The success of APDAP triggered engagement with Micro and Small Medium Enterprises (MSMEs), which eventually led to the birth of the Society for Innovation and Development (SID), currently headed by Gurumoorthy. "What SID has brought to the table is the comfort with which faculty can engage with the industry," he says. SID not only acts as a bridge between industry and researchers, but also incubates startups, a few of which are founded by alumni from ME and CPDM.

Photo: Gouri Patil

The new ME auditorium, dedicated to Arcot Ramachandran

Future directions

With its diverse expertise in biomedical systems, ME is uniquely poised to contribute to this field. Future directions also include generative design – through which optimised design solutions can be generated on a computer and then fine-tuned by the user. Foundational work in this field is already being done by Gurumoorthy, Ananthasuresh and others. Another exciting area is the design of next-generation materials, such as those for building structures in space, which is being investigated by Aloke Kumar, a faculty member at ME. Taking inspiration from nature, his lab is experimenting with a special class of materials called 'soft matter'. Another group adapting design principles from nature is the Biomechanics Lab run by Namrata Gundiah, also a faculty member at ME.

Balancing these technological advances is the emerging spotlight on sustainability. With increasing consciousness about sustainable design, it is only a matter of time before the designers at IISc make it the focus of their products. These ideas have already begun to take shape, as is visible within the ME Department building itself. In 2013, a new auditorium was inaugurated. It does not have a gleaming exterior or a swanky interior, not even air conditioning. It doesn't need to, since the design makes the most of its surroundings and the mild Bangalore weather. Strategically placed windows and ventilation keep it comfortable, while specially selected and locally crafted wall tiles give it the best acoustic experience. It is engineered to maximise functionality and usability while minimising maintenance.

The design of the auditorium is a reflection of the inward-outward balance that the Department has achieved over the years. While their products are at the cutting edge of technology, they are grounded in context, application and relevance – whether it is the turbine designs of the eighties, or the biomedical devices of today.

With input from Connect staff

Sidrat Tasawoor Kanth is a PhD student at the IISc Mathematics Initiative (IMI) and a science writing intern at the Office of Communications

Out of the lab, into the world beyond

- Sukriti Kapoor

How ME research aims to make a difference in clean energy, manufacturing, healthcare and more

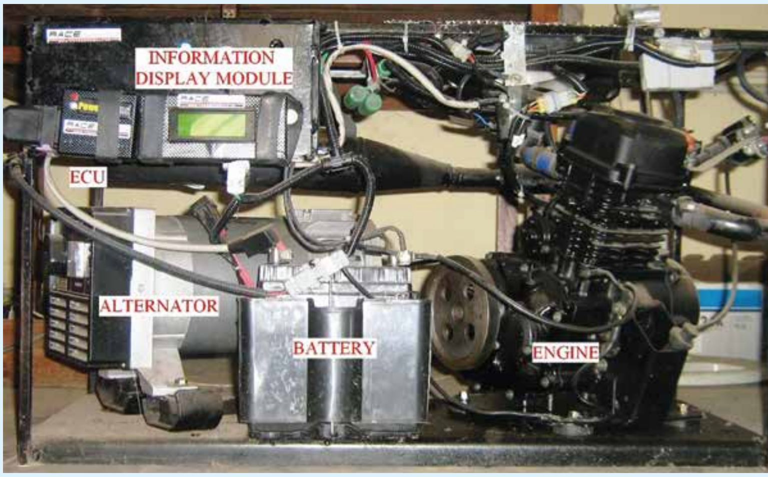
JN Tata, IISc's founder, strongly believed that scientific research played a role in social and economic transformation. The Department of Mechanical Engineering (ME), one of the largest in IISc and currently celebrating its 75th year, has had a history of conducting research aimed at having an impact on industry and society, a tradition that continues today.

A particular focus has been on translating technology in the area of energy. According to a souvenir published during the Department's Golden Jubilee, the turbomachines group at ME pioneered the design of microhydel power generators, which were used to power coffee estates in Coorg and small townships in Kedarnath and Arunachal Pradesh. In collaboration with the Department of Electrical Engineering, former ME faculty member S Soundranayagam and his team developed a prototype for low-cost microhydel crossflow turbines that could exploit energy from small drops in height at irrigation canals. In a DST-funded project in Nagaland, he and his team trained personnel in the use, design and installation of these turbines. Based on his design, the Science and Technology Council of Nagaland has funded the installation of two additional projects that have the potential to meet the energy demands of several villages with a cumulative population of more than 12,000.

Another important energy-related application has been the use of biofuels. In 1999, Udipi Shrinivasa, a former Professor at ME and also the Head of the Sustainable Transformation of Rural Areas Programme (SuTRA), explored the use of *Pongamia* seed oil as a cheaper and economic alternative to kerosene or diesel, as part of a project funded by the Ministry of Non-Renewable Sources. Based on his findings, the company Dandeli Ferroalloys converted their diesel engines to biofuel-based ones. Under the Karnataka Rural Development and Panchayat Raj Department, biofuel-run water pumps were established in seven villages around Kagganahalli in Kolar district, which had earlier no stored source of water apart from rainwater.

During 2006-2011, as part of two successive projects funded by the Ministry of New and Renewable Energy (MNRE), RV Ravikrishna, Professor at ME, and his team successfully developed a prototype of a small and efficient biogas-fueled 1 kW generator, suitable for powering small households. It was after this project, says Ravikrishna, that "[we] realised that there was a need to do fundamental research into other biofuels such as biodiesels, which was not available at that time." They were able to perform fundamental characterisation of biodiesels using a unique test facility built in the lab, which could help visualise the fuel spray, droplet formation and atomisation using high speed cameras and laser-based techniques.

Photo courtesy: RV Ravikrishna



Biogas Genset with push button start and advanced features such as port fuel injection and electronic control unit to maximise efficiency. It generates electricity in the sub 1kW range, sufficient to power a household and can be connected to any biogas storage tank

The primary focus was on biodiesels derived from vegetable oils, such as those from *Jatropha* and *Pongamia* trees. The data generated was helpful for designing engines that could accommodate biofuels with high efficiency. Such research is vital, Ravikrishna believes, because of the impact of biofuels on the environment as well as the enormous role that energy and transportation play in our economy.

At present, Ravikrishna's lab is working on ethanol and bio-methanol as cleaner and cheaper alternatives to crude oil. Their fundamental research on biofuels and fuel injection technologies for engines goes far beyond the laboratory. The team worked with TVS Motors on small two-wheeler engines and with Ashok Leyland on large heavy-duty engines, and reported that methanol-based engines had higher efficiencies than petrol-based and CNG-based engines, respectively.

Their work with Ashok Leyland is "the first indigenous effort to convert heavy-duty engines to methanol-based engines," he says.

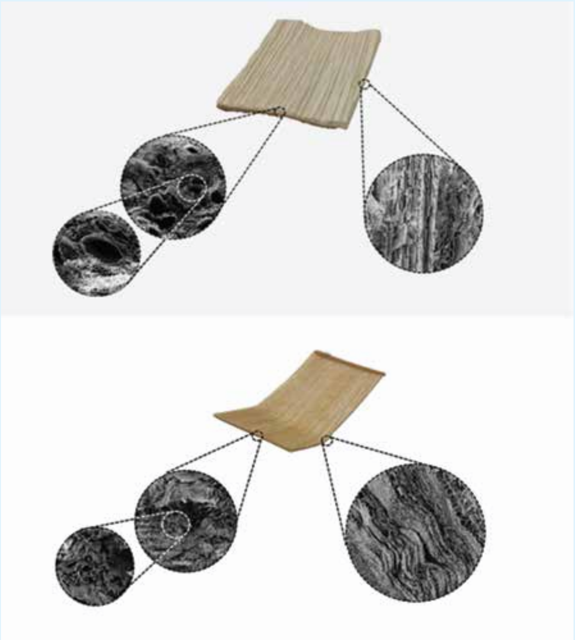
The group is set to initiate vehicle trials for methanol-based engines, as part of a recent academia-industry collaboration funded by the Department of Science and Technology, which was led by his group. The team also recently conducted a study on the life-cycle of automotive fuels from their source to vehicular emissions, on behalf of the Office of the Principal Scientific Adviser to the Government of India. This was a comprehensive study comparing various fuels including hydrogen, and powertrains such as electric and hybrid in addition to the conventional, evaluating both energy use and greenhouse gas emissions. This study is intended to aid the government's policy decisions in the energy and transportation sector.

Yet another important development in energy research has been the establishment of an experimental supercritical CO_2 Brayton cycle test loop facility in 2014, led by ME faculty members Pramod Kumar and Pradip Dutta, as part of an Indo-US clean energy project. This facility aims to develop power plants run on supercritical CO_2 (s-CO_2) that could replace conventional steam-run thermal power plants. Supercritical describes the state of CO_2 at a specific critical temperature and pressure which could yield more energy than steam. Coupled with a solar energy source, s-CO_2 run power plants could significantly reduce our carbon footprint.

Green manufacturing

A fitting complement to research on clean energy is research on clean and sustainable manufacturing. The Laboratory of Advanced Manufacturing and Finishing Processes (LAMFiP), led by Koushik Viswanathan, Assistant Professor at ME, works on 'green manufacturing' – production practices that are less polluting and that minimise waste. The manufacturing process for single-use plastics has a huge carbon footprint, in addition to the large burden that plastics place on the environment. At LAMFiP, research is being conducted on manufacturing processes for producing sustainable, biodegradable, and eco-friendly plant-based food wares and containers.

In a recent study, the research group studied deformation-microstructure relationships in areca sheath (the protective covering of areca nuts) using micro-computed tomography, scanning electron microscopy and mechanical testing, to understand its formability (the ability to be moulded into shapes such as those required for making cups and plates). Areca, a member of the palm tree family, is native to India and Southeast Asia and is a well-known alternative to plastic, but several issues prevent it from overtaking plastic, Koushik explains. At present, the team is developing solutions to make Areca sheath more stretchable – enabling the manufacture of food/beverage containers in more varied shapes – and less porous in order to delay fluid penetration and seepage, a prerequisite for making food delivery in areca containers possible.



Images: Harish Dhami and LAMFiP

Top: Scanning electron microscopy image of unprocessed natural areca sheath, showing microstructure along transverse and longitudinal directions. Bottom: Corresponding sections in the pressed plate reveal significant pore collapse and thinning

Healthcare

Research at ME has also contributed to healthcare in India, through the development of biomedical devices. Work at the Multidisciplinary and Multiscale Design and Device (M2D2) laboratory, led by GK Ananthasuresh – Professor at ME and Dean of Mechanical Sciences – has resulted in products designed to assist in medical procedures or improve one's quality of life. Among them is a simulator to train medical personnel in endoscopy procedures and an all-mechanical assistive chair to allow the elderly to rise from a chair with minimal effort.

One unconventional application of ME research is in the field of infertility treatment, driven by Santosh Bhargav and Ramnath Babu TJ, former students of the M2D2 lab and co-founders of the startup SpOvum.
Intra-Cytoplasmic Sperm Injection (ICSI) is a type of infertility treatment which, as the name suggests, involves injecting the sperm into the egg in the lab or clinic using specialised microneedles. For the injection, the egg is

"held" in place by applying a small suction pressure on one side of the egg with the help of a micropipette. As an alternative to the current suction pressure-based method of holding the egg, Santosh and his team have developed a mechanical gripper they call RoboICSI. This product was welcomed positively by the IVF community and has received recognition from the UK Government's Department of International Trade; the company is currently in the process of getting an international certification for the product, Santosh says.

Santosh also explains that they are the first company in the world to try and investigate the mechanical properties of the oocytes (immature eggs) during injections, which may be an important predictor for the success rate of the fertility treatment. In addition, the research team at his company has created a comprehensive machine learning model which can predict the success rate of the pregnancy based on several non-clinical and clinical parameters such as age, BMI, sperm quality, and the medical condition of the couple. Santosh credits the research experience and the exposure he received at M2D2 with shaping his thoughts and helping him plunge into entrepreneurship.

While the study of aerosols and fluid mechanics falls squarely in traditional areas of mechanical engineering, Saptarshi Basu, Professor at ME, has translated his expertise in these subjects to modelling the spread of COVID-19 infection. Saptarshi's work has helped explain how the virus spreads more efficiently in humid and cold conditions compared to a dry and hot environment. "We were the first to show how the droplet vaporisation and aerodynamics contribute to the spread of the pandemic," he says. On the urgent need for developing a more integrated, holistic model from first principles, he says, "You need to have such a model in place so that you can take decisions quickly. If you can advise the government quickly, then you can save lives and the economy." In another first, a study published in *Science Advances* by his group showed that aerosols – which carry a greater risk of disease transmission – can be contained more efficiently when using triple-layered and N95 masks rather than single- or double-layered ones.

Based on his lab's work on COVID-19, Dr Abhijit Sinha Roy at the Narayana Nethralaya Foundation approached Saptarshi through a colleague to conduct a COVID-19 risk assessment for doctors and hospital staff performing eye surgeries, such as glaucoma, cataract (phacoemulsification), and LASIK. "This was one area which was not normally looked at in the time of the pandemic," says Saptarshi. Aerosol generation and their trajectories were studied using cadaver eyes with techniques such as high-speed imaging and shadowgraphy. Based on the outcome of these findings, the hospital staff posted informational videos on YouTube, and a standardised protocol was devised which was shared with ophthalmologists across the nation. Suggestions made for changes in surgery protocol include the use of proper personal protective equipment (PPE), flushing the air at regular intervals, sanitising the room at regular intervals, and inhibiting the use of air conditioners. Currently, nine papers published from Saptarshi's lab, including the studies on the use of masks, modelling of aerosols, and risk assessment of eye surgeries, have been included in the WHO database for COVID-19 related research.

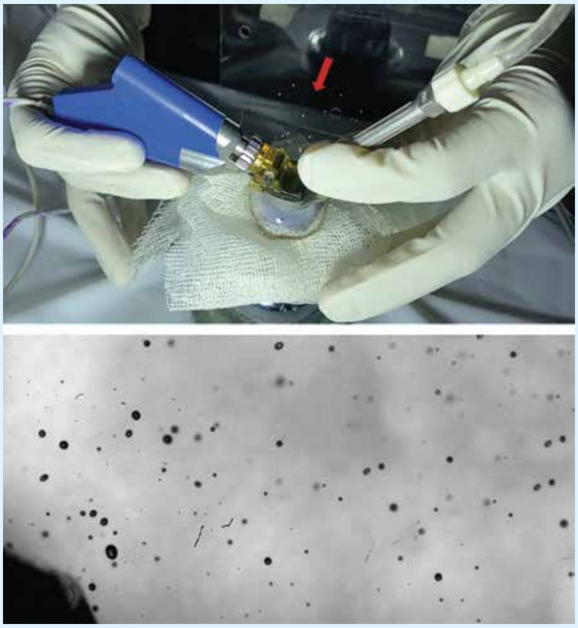


Photo courtesy: Narayana Nethralaya Foundation

Tracking aerosols generated while using a microkeratome for LASIK surgery

Science outreach

In addition to core research and industrial ventures, the Department also takes a keen interest in the education sector – an aspect that has deep roots in its past. In 1975, LS Srinath, former Chair of ME, established the Centre for Continuing Education (CCE) which continues to offer several short-term courses and workshops that are open to the public in new and upcoming areas of engineering and scientific methodology, grants for textbook writing, course material development and short-term visitor programmes.

Students of ME are likewise actively engaged in science outreach activities. In 2016, a few of them set up the Science for Rural India (SFRI) group, which organises weekend science classes for high school students based in rural areas of Karnataka, online seminars from distinguished scientists across India, and science magic shows to help kids understand key concepts and engage in the process of science.

Sukriti Kapoor is a PhD student in the Department of Microbiology and Cell Biology at IISc and a science writing intern at the Office of Communications

Building a testament to ME history

These photographs by Gouri Patil, a PhD student at IISc, capture the different physical locations that the department has inhabited

1 2 3

Mechanical Engineering first took formal shape at IISc in the form of the Department of Power Engineering. The "PE building", as it is still referred to today, was inaugurated in 1951 by President Rajendra Prasad. Today, it houses labs and offices of the departments of Electrical Engineering, Computer Science and Automation, and Mechanical Engineering.

4 5

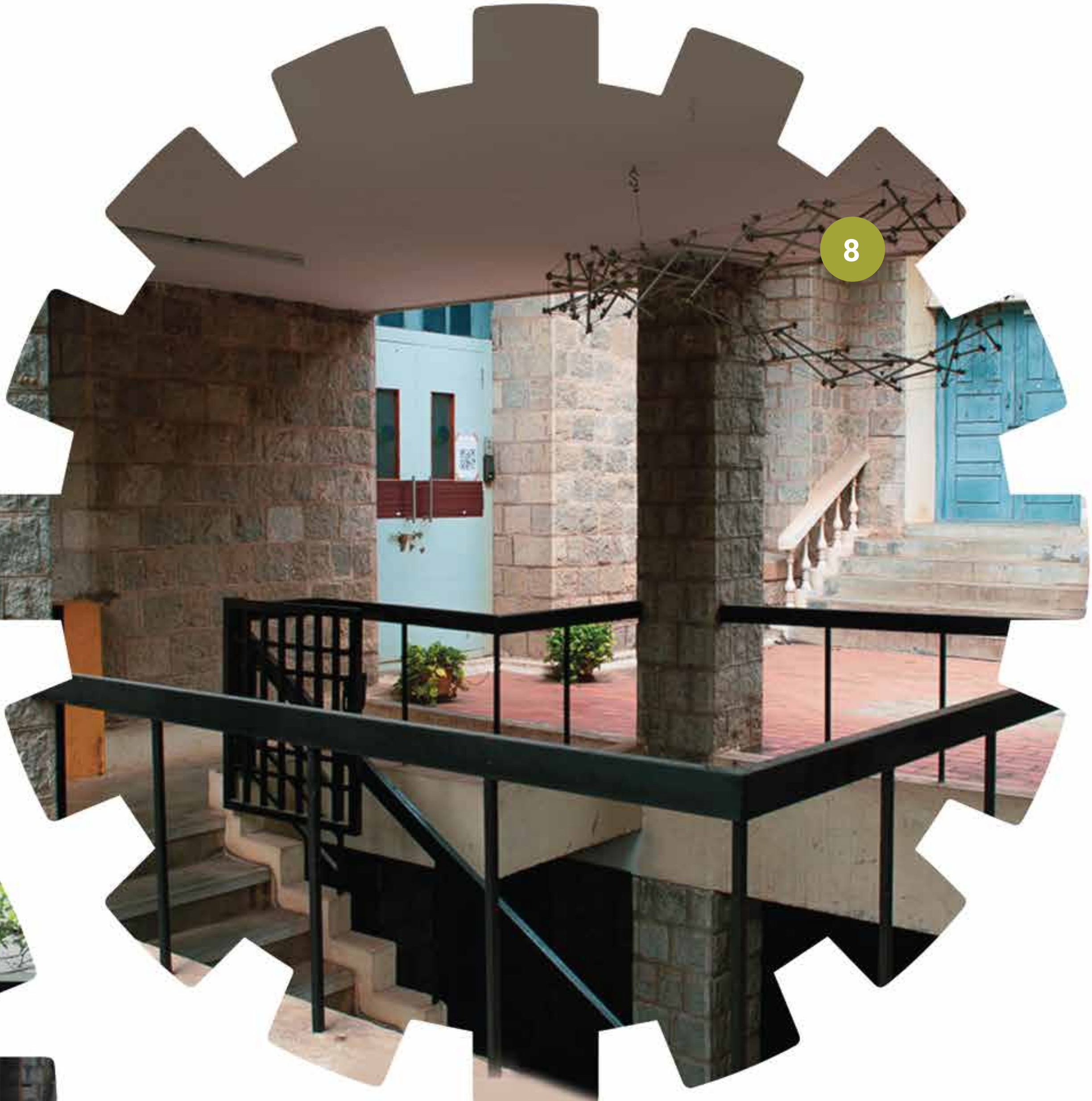
The Department of Internal Combustion Engineering was formally inaugurated in 1953. The old department building was located near Maramma Circle, and students would look out onto the street and try to identify cars passing by in the 1950s. Today, the building houses the Society for Innovation and Development.

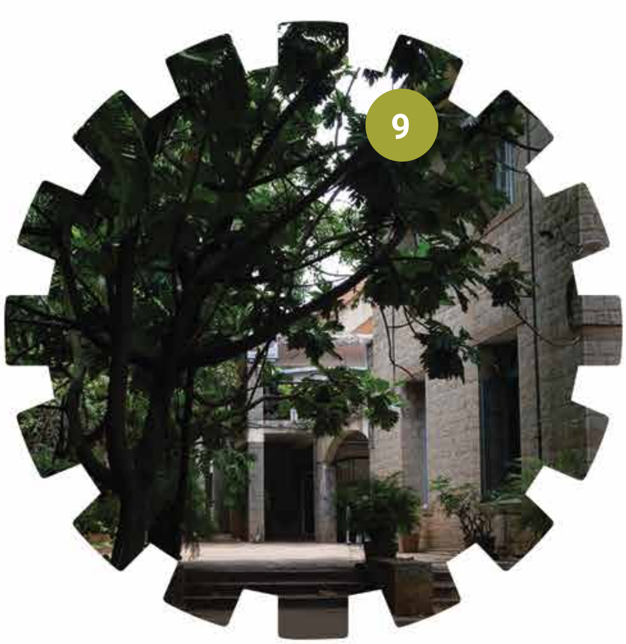
6

The Central Workshop was set up during World War II, and though it catered to multiple departments on campus, it was largely used for mechanical engineering and internal combustion engineering work. In 1996, it was converted to the Centre for Product Design and Manufacturing (CPDM).

7

The main Mechanical Engineering building, was opened in 1995, at the Department's golden jubilee. The uniquely designed Arcot Ramachandran auditorium is located here.





8 9

The department once had its very own thermal power station, set up in the 1950s, which was meant to give students practical experience in how to run it. Located right opposite the entrance to the main ME department building, it is home to multiple laboratories in entirely new fields!

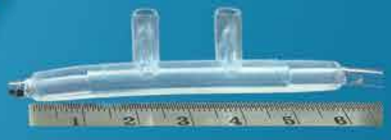
Battling COVID-19,
wave after wave

Developing COVID-19 solutions hasn't been easy for researchers working since the pandemic began, as well as for those who jumped into the foray recently

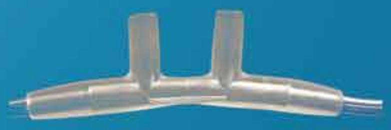
Photo: KG Haridasan

The nasal cannula developed by the IISc team

IISc Design



Regular Design



When the country was rocked by the second wave of the COVID-19 pandemic in early 2021, oxygen conservation became a prime concern. As hospitals designated for COVID-19 became swamped, patients struggled to find oxygenated beds and started pouring into smaller private hospitals seeking care, according to a physician at the ESIC Medical College and PGIMSR, Bangalore.

To tackle this issue, a team of doctors from the Rajiv Gandhi University of Health Sciences (RGUHS) approached a research team at IISc led by Pramod Kumar and Srisha Rao, associate faculty members at the Interdisciplinary Centre for Energy Research. They asked the IISc team if it would be possible to come up with an innovative device that would reduce the consumption of oxygen, without affecting the patients' need. They zeroed in on a nasal cannula, a tube-like structure that is inserted inside the nostrils to help deliver oxygen. A patient on oxygen support needs a lot more oxygen while breathing in than out. The team, therefore, came up with an idea to develop a nozzle that would be combined with the regular cannula, and vary the oxygen supply during inhalation and exhalation. Pramod explains, "When a person inhales, there is a pressure drop, so more oxygen will enter the cannula and thus the nose. Exhaling would be against the flow of oxygen from the cannula, so the flow would actually reduce. This would reduce the oxygen wastage during exhalation, which can be as high as 30%."

To make it comfortable for patients to use, the team decided to develop a secondary nozzle out of medical-grade silicone, as small as a fingernail, which was flexible and could fit the nostril shape. They studied samples of a silicone-based cannula used in neonatal care to re-engineer it. But it wasn't easy. The nozzle is so small that it cannot be added as a separate piece to the nasal cannula as the pressure from breathing could dislodge it, making it a medical hazard. It had to be bonded to the regular nasal cannula. The lockdown during the second wave didn't help either. They faced trouble transporting samples back and forth from the hospital. "The doctors were able to send us samples through Swiggy, Dunzo and such delivery services," recalls Pramod. The nasal cannula they finally developed is now undergoing academic clinical trials at three medical colleges – ESIC Medical College and PGIMSR, Bangalore Medical College and Research Institute, and Sparsh Hospital. The researchers say that the preliminary results have been encouraging, with the subjects preferring the newly developed cannula as compared to the existing design.

Although the nasal cannula is a recent example, there are many such solutions that IISc researchers have been working on since the start of the pandemic. And many have faced similar challenges.

Entering the COVID-19 arena

The pandemic pushed a lot of researchers into new arenas, forcing them to explore out-of-the-box solutions. Two teams, for example, started developing indigenous ventilators from scratch – a daunting prospect. Sushobhan Avasthi, Associate Professor at the Centre for Nano Science and Engineering (CeNSE), who currently leads one of them, recalls how they hit upon the idea. CeNSE mainly works in semiconductor research and one of the areas they cover is building equipment, often involving pneumatic systems which use pressurised gas or air to move mechanical parts. "When the pandemic started last year, everyone realised that ventilators would be required, and we got into the field because it would require a pneumatic system," he says.

Building critical care devices that demand high accuracy and reliability poses several issues, Sushobhan points out. "We realised it was more complicated than we thought. A ventilator needs to have alarms to see if valves and sensors are working or if the pressure is too high or low, and needs to detect when the patient is trying to breathe on their own. [Also], lungs come in different sizes and pathologies, so the ventilator should work well for a wide range of lung types." After working on it for more than a year, they managed to develop a full-fledged, microcontroller and microprocessor-run system which is very close to what a standard ventilator looks like. The device has been tested and approved by an external agency, and is now on its way to large-scale manufacture.

Photo courtesy: Navakanta Bhat

Electrochemical immunosensing test developed by PathShodh

Other research groups also had to adapt or expand the scope of their ongoing work. For example, PathShodh, a start-up founded by Navakanta Bhat, Professor at CeNSE and Vinay Kumar, an alumnus, changed direction from non-infectious diseases like diabetes to the infectious COVID-19. Earlier, they had designed a novel testing device using technology called electrochemical biosensing. Their "Lab-on-Palm" is a handheld device that can be used to check for and monitor various non-communicable diseases like diabetes on a single platform. When the pandemic broke out, there was a huge demand for efficient diagnostic tools for COVID-19, so they decided to develop one using their existing platform.

Currently, there are two types of serological tests available in the market. One is a lateral flow ELISA where a small drop of blood and reagent are put on the test strip; if a coloured line appears after a few minutes, it indicates that the person has COVID-19 antibodies. This test, however, is not very accurate and will not show the actual concentration of the antibodies. There are also lab-based serology tests, where large optical analysers estimate the exact antibody concentration, which is more accurate. Bhat elucidates that their electrochemical immunosensing test combines the best of the two – the former's simplicity and the latter's accuracy – and can therefore be taken even to remote corners of the country. Since it indicates one's immunity level against the virus, such a test could also help policymakers decide when a booster vaccine dose would be required.

The oxygen concentrator and the IISc team behind its development. From left: Kumaran G, Praveen C Ramamurthy, Raghavan S, Vijay S, Bhaskar K, Ashika

Waxing and waning interest

For some projects that started last year, another issue was that interest from industry and the general public waxed and waned with the two waves. For example, an indigenous high-performance oxygen concentrator developed by a team led by Praveen C Ramamurthy, Professor in the Department of Materials Engineering, and Bhaskar Krishnaswamy was ready in August 2020 itself. However, during the first wave, there wasn't much commercial interest since there were many imported oxygen concentrator systems in the market. Praveen says that this has changed over the last few months, triggered by the country-wide oxygen shortage. "On interacting with doctors over the last three to four months, we were told that many of the imported concentrators in the market were able to produce 90% oxygen concentration only at 1 litre per minute (LPM). When the oxygen flow rate of these systems is increased to even 4 LPM, the oxygen concentration drops to as low as 35-40%, which makes it difficult to use. The systems end up providing only air, not oxygen, which will do more harm than good."

The concentrator developed at IISc continues to provide oxygen at high concentration (95%) even at a flow rate of 10 LPM. It was also clinically tested and validated at the Bangalore Medical College Research Institute (BMCRI). Now the technology has been transferred to 24 companies and a few of them have already started producing the system; one of them, Reveron Industries, founded by a former PhD student from the same department, has distributed about 35 units to various hospitals in the Tumkuru district. Recently, the Government of Karnataka's Department of Health and Family Welfare has issued an expression of demand to procure about 5,000 units for all primary health centres, Praveen points out.

Like the concentrator, an oxygen generation system was also developed last year itself by an IISc team led by S Dasappa, Professor at the Centre for Sustainable Technologies. The team used their prior expertise in multi-species gas separation to conceptualise the design. The first plant built using this design was established recently at the Pobbathi Medical Centre, Bangalore, where it is expected to generate oxygen at 50 LPM with about 93% purity.

Photo courtesy: Praveen C Ramamurthy

A similar trend was seen even in the development of a COVID-19 vaccine by researchers in the Molecular Biophysics Unit led by Raghavan Varadarajan and IISc-incubated start-up Mynvax. Raghavan points out that after the first wave, people thought that the severity of the pandemic would reduce. Additionally, the general attitude was that vaccines would be easily available since large manufacturers were involved. However, this turned out to be untrue; vaccine shortage became a burning issue during the second wave. "We were able to raise significant investment from private investors only after the severity of the second wave," Raghavan says.

Overcoming challenges

Raghavan also points out how logistical issues have persisted from the first wave to the second, compounded by the multiple lockdowns. Movement of lab supplies and import of materials were restricted. Essential steps like gene synthesis were slowed down. Sameer Kumar Malladi, a PhD student in his lab, adds that there were delays in shipping and getting approvals for many essential materials such as culture media and antibodies, which are used to produce and test vaccine candidates. However, these problems reduced during the second wave, once cargo flights started running.

Supply chain problems also affected the researchers at PathShodh; sometimes delivery of even lab consumables like pipette tips was delayed. "However, the situation has mostly improved now, since the companies which supply raw materials now have a system in place. Even the earlier problems of getting clearance for imported raw materials at customs have been resolved after we explained that they were needed immediately for diagnostics," explains Vinay.

They also had to go through many stages of sensor development while validating the test since the chemistry with actual blood samples was quite different from the standard spiked samples. After suitable optimisation and modifications, the test was fully validated at an ICMR-approved laboratory, and the manufacturing license was issued by CDSCO. PathShodh has now started manufacturing the tests in their own ISO-certified facility.

The lockdowns also posed problems for the other ventilator project, PRAANA. Duvvuri Subrahmanyam, Assistant Professor in the Department of Aerospace Engineering, who was a part of the project, recollects how they practically lived in the lab during the first wave. They also faced difficulties in procuring components. "It was a challenge to get parts from even another part of the city, but we got a lot of help from IISc, the Karnataka government and the Bengaluru police. They issued us emergency passes [to carry out the research] during the lockdown," he recollects. "There were times when we had to go to a distributor's house with a police escort, pick him up and go to his godown, where he would open his shop and give us the components we needed."

The CeNSE team working on the ventilator, for their part, tackled the unavailability of components in-house. "When some components like flow sensors weren't available, our team designed and 3D printed them to integrate with the system. When we did not have access to calibrated oxygen sensors, one of my colleagues, a postdoctoral scholar, calibrated the one we had using their own gas calibration system," he explains.

> ***Despite all these challenges, the researchers say that their motivation to contribute has remained high***

Despite all these challenges, the researchers say that their motivation to contribute has remained high. Some had their own 'Eureka' moments. Sameer recollects that when they were testing molecules for vaccine candidates, they found that one of them could stay stable at 100°C, a huge breakthrough for the 'warm' vaccine. "It was a breathtaking surprise."

Even people who were not directly working on the projects were keen to help out in their own ways. Pramod points out how some local manufacturers agreed to make prototypes of their nasal cannula at minimum cost, and how the doctors they worked with showed continued enthusiasm and support. "We were able to set up meetings, often late in the evenings with them, within half an hour despite their being so busy," he says.

Praveen also highlights the support they received from various quarters – particularly from the Society for Innovation and Development at IISc – to procure components, reach out to companies, raise funding, and license their technology. He recalls how the Director of IISc also motivated their team to move forward even when they had just a couple of oxygen concentrator units ready. "He told us to at least get those out into the field, because if we could use them to save even one life at a time, that would be fantastic."

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One Disc to Rule Them All

- Debraj Manna

The story of SlipDIISc, IISc's Ultimate Frisbee club

Photo: Sanjeev Kilarapu

SlipDIISc member Sharan jumping up and grabbing the disc in a match

It was a sunny Saturday afternoon in Bangalore. The Gymkhana cricket ground was crowded with heavily sweating fitness enthusiasts, some of whom jogged all around the field in circles while others walked. Some exercised under the shade of the trees, and some played in groups. The sidewalls bordering the ground offer a place for people to sit and chat in the evenings as they take in the spectacular sunsets beyond the World Trade Centre building in the distance.

Among the people on the ground were a crowd of students running after a flying disc. Looking closer, one could find two groups tossing and catching the disc across the field. The players, all in high spirits, were participating in a session of Ultimate Frisbee – more commonly known as Ultimate – and were members of one of IISc's most popular clubs, SlipDIISc. This was not an official match, but a practice session, giving a crash course on the sport to newcomers.

The players included Ravi Jambhekar and Devathi Parashuram, both former students of IISc, who keep coming back to campus to play with the group and help motivate the new inductees. Soon after the practice session ended, the groups playing opposite each other shook hands and sat down in a circle to have a friendly discussion about how each of them played and what they could have done differently. They call this the 'spirit circle', which is essentially a feedback system woven into the very fabric of the game.

In action, Ultimate is a mix of several sports like football, rugby, and basketball. What makes Ultimate unique is that the game is typically played without any referee. Players are expected to own up to their fouls and games can end with engaging discussions between rival teams. There is, however, a 'spirit captain' in each team, who is like a coach and makes sure that the players are playing by the rules.

It is also one of the few mixed-gender sports. "You'll see top female athletes competing against male athletes at the same game, at the same time," says Vibhanshu Golia, who is the co-convenor of the IISc team and a UG student. "If you talk about women empowerment and gender equality, I think there's no other sport that comes as close to Ultimate in that regard."

Every team consists of seven players with either four women and three men or vice-versa. Ultimate is played on the field or turf, on a beach, or even indoors. The court is divided into the main playing field in the middle and one end zone at each extreme. Catching the disc in the rival team's end zone scores a goal for each group. Every team has a mix of two types of players: cutters and handlers. The cutters run behind the disc and help move it across the field by catching and tossing it to other players, and scoring goals by catching the disc in the opponents' end zone. The handlers are masters of throws and determine the course of the game through their skillful tosses of the disc.

Like Ultimate, several other sports can be played with a flying disc, such as disc golf, flying disc freestyle, disc guts, and so on. The official Indian governing organisation for all flying disc sports, the Ultimate Players Association of India (UPAI), organises tournaments and charts the playing seasons for Ultimate in India. The contests are first at the sectional level, then regional and finally at the national level. SlipDIISc played in the Nationals in 2019, which was the last playing season due to the COVID-19 pandemic. The players are hopeful that the new season will begin later this year.

A trip down memory lane

Cleverly named SlipDIISc, IISc's official Ultimate team has had an interesting journey. It started in 2015, when Navendu Page, a former PhD student in IISc, and Devathi bought a disc at a beach in Gokarna for Rs 50 and started throwing it around just for fun. They continued playing when they came back to IISc in the short turf between the New Boys Hostel and the New Girls Hostel until the security guard chased them out, and then hit the Gymkhana grounds for their first "official" game. Soon, they found themselves playing together with Ravi, Manvi Sharma and a couple of other students from the Centre for Ecological Sciences. "Slowly, we kept ... arm-twisting people into coming and joining us, and at one point, we had 20 people doing throws with that first disc. It was just a fun thing to do in the evenings after we all got out of the labs," recalls Devathi.

Photo: Sanjeev Kilarapu

SlipDIISc member Ritu Ghanghas with the bronze medal and third place trophy from the Asia Oceania Ultimate and Guts Championships 2019 held in Shanghai, China, where she was a part of the Indian team

But there was also plenty of pain. Having never played any sport before, most of them were not aware that they had to warm up and cool down before and after playing, and would literally hit the ground running. This led to multiple injuries. Ironically, Devathi ended up suffering from an actual 'slipped disc' after eight months of starting to play.

Although the team was reluctant at first to get bound down by rules, they soon decided to seek the help of professional Ultimate players in Bangalore like 'Airbenders' from Malleswaram and 'Learning to Fly' from Bannerghatta. Later, they started recruitment drives on campus to encourage new members of the IISc community to join their club and play with them.

Ritu Ghanghas, a PhD student in IISc, remembers the one afternoon in her first year that would leave a lasting impact on her life. After finishing her lunch, she came out of the mess to find a small gathering of cheerful faces throwing and catching a flying disc. Intrigued, she moved towards the crowd, and they invited her to try her hand at it. She then started attending the club's practice sessions to learn more about the sport, and was soon tossing and running after the disc with the other members regularly. She went on to play for the team that represented India at the World Championships in July 2019; the team won a bronze medal. Ritu says that she is grateful to the team members who patiently taught her the game from scratch.

Like Ritu, most of the club members have never played Ultimate before joining the team. Rishi, the current convener of the club and a UG student, says, "Before joining IISc, I knew that kids just throw Frisbee on the beach or parks for fun! I did not know that it was a legit sport that was being played."

One specific challenge for university teams is the considerable turnover they face year after year. Students remain associated with the Institute for the duration of their degree or project. During this time, they join the clubs on campus and, with practice, become more skilled at the sport. These skilled players are invaluable to the team's success. However, after their degrees and projects are completed, they move on to other places. This leads to an imbalance of skilled and new players in the team. In SlipDIISc, this results in fewer handlers. Therefore, the senior club members try to teach the newcomers as much as possible before leaving. Despite this turnover, SlipDIISc has strived to stay among the top 15 Ultimate teams in the country for some years now.

Tours, tournaments and time management

Back in 2015, the club's founding members did not anticipate that SlipDIISc would become a full-fledged club that would play several tournaments. It was a three-day game hosted in Bangalore called 'Bangalore Ultimate Open' that helped them become official. Among the 31 teams participating in the contest, SlipDIISc was the youngest and placed at the last position in the ranking. At that time, they had been playing for only two to three months and had just moved from the stage of casually tossing the disc around to actually trying to play by the rules of the sport. While taking on an experienced Chennai team that was playing for the top five positions in India, they found themselves at the 'Universe Point', which serves

Photo: Sanjeev Kilarapu

SlipDIISc team after winning the South Central Sectionals in 2019

as a tie-breaker. This novice group of IISc students managed to win the game with their last move and make their first match a huge success. They picked themselves up from the 31st position to the 24th position when the tournament ended after three days.

After that, there was no turning back. SlipDIISc has been participating in many tournaments every year. But this requires serious practice every week. Ritu explains, "Usually we have practice sessions twice a week – Tuesdays and Fridays from 5.30 pm until we have the lights on. We try to have a minimum of two sessions every week, and then we try to schedule one game for the weekend. Either we play amongst ourselves, or we used to invite some outside local teams from Bangalore and have a friendly match." It can be challenging for some people to fit these practice sessions in their tight academic schedules. However, as Ravi recalls, other than the time he had to go for fieldwork in Goa, he managed to balance work and play quite well. "When I was in IISc, I wouldn't miss practice at all. From 9 am to 5 pm, I would work, and after 5 pm, I would go to play. My [PhD] guide was very supportive and encouraging … she wouldn't plan meetings at all after 5 pm, because she knew that I go to play."

> ***SlipDIISc has strived to stay among the top 15 Ultimate teams in the country for some years now***

Like their first win, Ravi also remembers another contest they played called 'Chennai Heat'. This time, SlipDIISc was represented by a lot of newcomers and only a few experienced players. Instead of on turf, like most other matches they had played in, this match was on the beach. Due to the windy weather, the disc kept flying in all directions. The team also struggled to run on the sand and lost the match badly. The students were initially sad, but when they went back to their rooms, they ended up cheering and motivating each other. The event turned out to be a nice bonding experience for the newcomers.

SlipDIISc has also managed to demonstrate its prowess in the World Championship, where Ritu played for India. The club members encouraged her to go for tryouts along with seven other IISc students. There were two rounds of selection. Five of them qualified for the second round, and ultimately only she was selected for the final team to play for India. For the next eight to nine months, she had to practise hard and travel to camps across the country. Finally the team went to Shanghai, China, in July 2019 to play in the tournaments, where they bagged the bronze medal. Ritu says that she came back with a renewed love for the game.

Photo: Sanjeev Kilarapu

A spirit circle after a game with the opponent team in 'Sakkath 2019'

More than just a sport

Members of SlipDIISc also credit the club for helping them stay healthy and fit, and learning valuable life skills. Devathi mentions, "I think most of the leadership skills that I have learned come from [Ultimate] Frisbee. It is useful even in my work."

Most team members also appreciate the networking and the sense of community that the sport creates. Ravi, who is especially interested in science illustration, says that has benefitted from interacting with designers, filmmakers, teachers, and artists whom he met through this sport.

Devathi adds, "When I went on to do a second Master's in Cambridge, after I arrived there, I left my suitcases in my student room, and immediately went to play [Ultimate] Frisbee. It's a great way to make new friends!"

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The Moral Scientist

- Sunreeta Bhattacharya

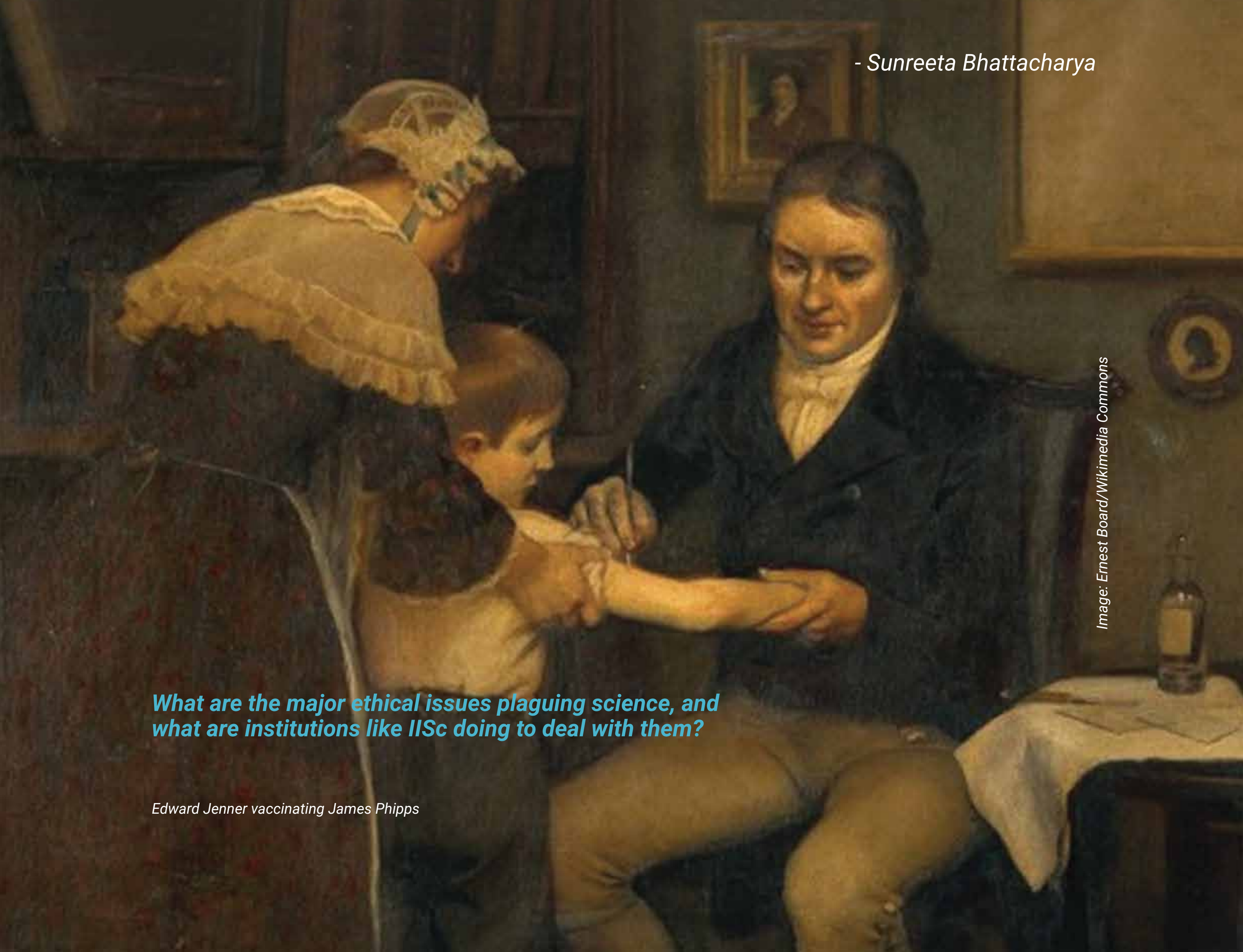

Image: Ernest Board/Wikimedia Commons

What are the major ethical issues plaguing science, and what are institutions like IISc doing to deal with them?

Edward Jenner vaccinating James Phipps

On 14 May 1796, an ambitious country doctor from Gloucestershire in England injected cowpox pus taken from pustules on a milkmaid, Sarah Nelmes, into the arm of James Phipps. Almost immediately, Phipps, who was the eight-year-old son of the doctor's gardener, became unwell with fever, chills, loss of appetite, and soreness in his armpits. However, he soon recovered. In July that year, the doctor again injected the boy with pus, but this time with pus drawn from the more deadly smallpox lesions. As the doctor had predicted – and much to the surprise of the scientific community – Phipps did not develop smallpox, leading the doctor to conclude that the boy was now immune to the disease, thanks to his bold experiment.

When the doctor tried to publish the study, it was rejected by the Royal Society for lack of substantial evidence. So, he repeated his experiment on several other children. The physician's name was Edward Jenner, who is remembered today as the pioneer of vaccination. Nevertheless, the ethics of his scientific conduct has been the subject of much disdain.

Broadly, ethics can be thought of as the set of moral principles that guides human behaviour. While ethics matters in every sphere of human activity, scientists are among those who come under greater scrutiny because of the nature of their work and the influence of science on society.

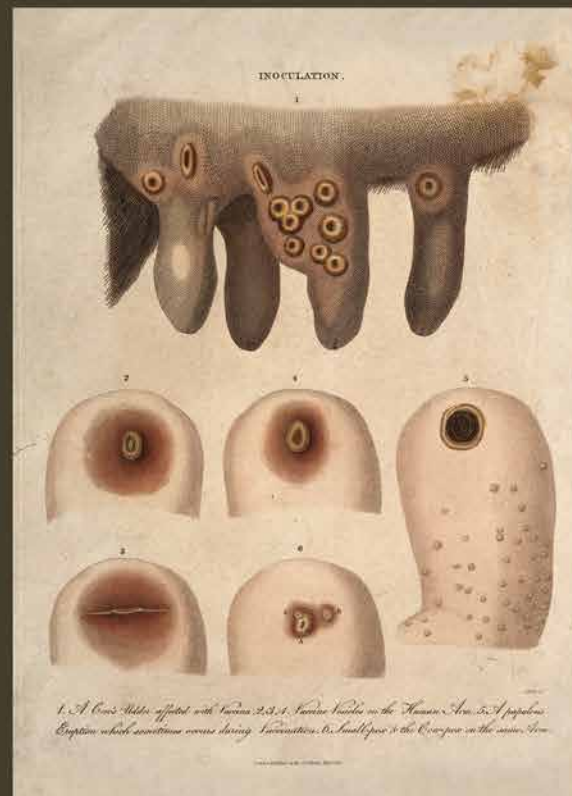

Image credit: Wellcome Images/Wikimedia Commons

Jenner's discovery of the link between cowpox and smallpox allowed him to develop the smallpox vaccine

Informed consent

Images: Kadir Nelson and Gerry Shaw/ Wikimedia commons

Left: Portrait of Henrietta Lacks (1920 – 1951), an African-American woman, whose cervical cancer cells were used to create the HeLa cell line, still used in medical research, Right: Fluorescent image of immortal HeLa cells

Take, for instance, studies that involve human subjects. Such studies require prior consent of the participants because the experiments could have an impact on their physical as well as psychological health. At IISc, the Institutional Human Ethics Committee (IHEC) ensures that research involving human subjects abides by strict guidelines to ensure the subject's overall well-being and privacy.

Sridharan Devarajan, Assistant Professor at the Centre for Neuroscience in IISc, studies aspects of human cognition through a variety of experimental methods and these studies require human subjects. "Informed consent is a very important part of the ethics of human research. The subject is made aware of exactly the kind of effects the experimental setup can have on them," he says.

But there is an even more nuanced area related to consent that is becoming increasingly relevant. As many scientists are shifting to an open-science framework, they make their data available to anyone interested in it. "In such cases, one has to take the subject's permission before any data collected from them goes into the public domain. Even if it is anonymised, this must be done. Even the sound of someone breathing cannot be recorded or shared without the person's consent. These things can potentially be exploited as bio-fingerprints," Sridharan cautions.

Scientists make ethical decisions in nearly every step of the scientific process – from framing a question to communicating the results of their study. Therefore, policymakers have established broad guidelines for ethical conduct of scientific research. In India, researchers must abide by the guidelines laid down by bodies like the Indian Council of Medical Research (ICMR) and Council of Scientific and Industrial Research (CSIR). But often, even these guidelines are insufficient to deal with the plethora of ethical considerations in the practice of science.

Ethics Committee at IISc

Research institutions are therefore establishing their own mechanisms to prevent and investigate issues of misconduct in science. For instance, in 2017, IISc set up the Committee for Academic Integrity in Research (CAIR), which was chaired from August 2018 to August 2021 by Sriram Ramaswamy, Professor at the Department of Physics. “We are an internal body of the Institute, not mandated by an Act of Parliament. The procedure we carry out, although very detailed, is technically termed the preliminary inquiry, under the Central Civil Services (Classification, Control and Appeal) Rules. We present our findings and recommendations to the Director for further action under those Rules,” he explains. “Since its inception, we have looked into a few cases, usually related to plagiarism or somebody using somebody else’s data inappropriately.”

CAIR has also drafted an academic integrity policy for IISc’s researchers. It identifies five main classes of potential misconduct in research activities: plagiarism, fabrication, falsification, deliberate interference and misrepresentation.

The Big Five

The word *plagiarism* is derived from the Latin word *plagiaius* that means kidnapping, and refers to the theft of ideas and efforts, especially while giving the impression of originality. One can plagiarise, intentionally or unintentionally, and in a variety of ways – from verbatim cutting-and-pasting to failing to cite your own prior work (self-plagiarism). With the advent of plagiarism checkers like Turnitin, plagiarism is relatively easy to spot nowadays. But the misdeeds continue. For example, recently, two papers with identical abstracts were published in two reputed journals (one of them was eventually retracted). Plagiarism is not restricted to science – literature and journalism are also prone to this misdemeanour. Consider the irony in cases like the Jonah Lehrer debacle where his rampant self-plagiarism went unchecked even as he wrote popular books and columns on creativity under the *New Yorker* banner.

However, while it is tempting to think of plagiarism as a black-and-white issue (and it often is), there are many grey areas, and scientists agree that it is often a matter of personal judgement in matters of paraphrasing and rewording existing literature.

While plagiarism is concerned with not giving credit where it is due, data fabrication (“inventing”) and falsification (“cooking” or misrepresenting to get a desired result) have to do with distorting scientific knowledge. Surveys show that two out of every 100 scientists admit to data fraud of some kind, and this number goes up to 15 percent when they admit to fraud by colleagues. What is more troubling is that defaulters often exhibit a pattern of repeated misconduct.

Even when it comes to data, there are grey areas. Improper data handling and communication is a pertinent issue that often calls for a sound understanding of analytical and statistical tools, says Sridharan. “Sometimes it can be an honest and unintentional mistake. If a mistake takes place from ignorance of some technique, the researcher can be educated as required. However, if any person acts unethically with mala fide intentions, no amount of education can correct that.”

Another related ethical issue is that of data dredging. Scientific journals incentivise reports with "statistically significant" results. Now, there are ways to wrongfully twist and turn experimental data to achieve apparently positive results approved by a statistical measure such as the 'p-value'. Unethical data manipulation to only attain levels of significance makes up a worrying part of scientific fraud today. Also termed p-hacking, these practices contribute to the publication of studies that may not be replicable. This worrying trend has led to a movement that encourages “pre-registration” of research studies.

Scientific progress is driven both by collaboration as well as competition. And herein lies the potential for another ethical transgression: deliberate interference in others’ scholarly work. Be it with your research collaborator or a university colleague, misrepresenting someone else’s contributions counts as wrongdoing. The golden rule of “Do unto others as you would have them do unto you” applies as much to research practices as it does to social interactions.

Image: Tyler Vigen/Wikimedia Commons

The spurious correlation here is an example of data dredging. There appears to be a relationship between two things (number of letters in a word and deaths from venomous spiders) statistically, but it is so much more likely to be a coincidence

50 shades of grey

"When we start our PhD, we receive training in animal ethics and biosafety. Things like data fudging and plagiarism are relatively easy to avoid because there are set rules and ways to know if you are violating any norms. You can avoid such problems by acting honestly," says a PhD student in the Division of Biological Sciences.

But ethical conundrums often arise in the grey zone between right and wrong. "On the other hand, it's a difficult thing to deal with credit sharing in collaborative projects, and issues like conflict in your lab which affects your research. We students often don't know how to deal with such situations."

There are also ethical issues that students face because of the power asymmetry in the academic structure. "In fact, I was not given credit for my original work and there was deliberate interference from my advisor, which affected my research progress. Such incidents are very unfortunate," the student adds.

Since every step of the scientific process is potentially ridden with ethical implications, lab PIs play a crucial role in educating their students in this regard. "The domain of ethics is very broad – advisor-advisee relations, how to report data and analysis methods and others – they all have grey areas. As for disagreements between a mentor and a student, it is best to settle it through dialogue," Sridharan says.

New ethics for new technologies

Even if scientists were to diligently follow ethical practices in conducting their research, new challenges continue to surface as new technologies arise. The power to manipulate genomes, and to create intelligent machines capable of literally superhuman tasks, for example, imposes a responsibility that all researchers might not be prepared for. Frank Rudzicz, an AI researcher in the field of speech recognition at the University of Toronto, believes that there are three main concerns with AI research: what it is used for, who has access to it, and how AI solutions might conflict with human values.

A recent controversy reflects one of the many challenges as the use of AI becomes more widespread. It arose when researchers developed an algorithm to "put a face to a voice" – predicting faces from just voice recordings. Sociologists claimed such a voice-to-face prediction linked biology to identity, which undermines the representation of transgender people, for instance. Google's translation algorithms have also come under fire for suffering from sexist biases.

Kartheek Nareddy, a machine learning researcher at IISc, says he has become more aware of the ethical implications of his work now that journals and conferences require researchers to consider the ramifications of any innovation. An encouraging observation is that AI technology may not always be at odds with our principles of equity and inclusion. "My colleague, Siddarth Asokan, observed how GANs [Generative Adversarial Networks] that generate new human faces create more natural-looking male or female faces when they are trained on images of faces across genders rather than faces of any one gender."

Intellectual property

Another area of science that does not always receive enough attention in discussions on ethical issues is intellectual property (IP). IP-related matters in collaborative projects such as ownership and conflicts of interest need to be clarified at the start. Sridharan admits that as a graduate student even he was not aware of all the IP ownership rules. However, he stresses that students ought to be more conscious of the extent of their IP rights. "As graduate students, most are not aware of who actually owns the intellectual property of the work that they produce. In most cases it is the lab which owns the IP of research carried out there, unless a student brings in some documented IP that they already own."

In research institutions like IISc, IP may be generated in the form of lectures, presentations, publications and patented devices, and deciding ownership of the same can be an involved issue. Guidelines regarding these issues are laid out in the country's IP laws as well as by international bodies like the World Intellectual Property Organization, a special agency of the United Nations.

Kiruba Daniel, a postdoctoral fellow at the Department of Electronic Systems Engineering at IISc, has filed six patents in the last two years with IISc's Intellectual Property and Technology Licensing (IPTeL), which serves to protect the intellectual property of IISc's researchers and students. "When we file for a patent, the researcher is the inventor and IPTeL plays the role of the applicant. So, in the future if some start-up wants to use this innovation, they must license it from IPTeL."

Researchers who file for patents must make sure they are not infringing prior art in the field. Many online databases and search engines such as Google Patents are available today for individuals to thoroughly check prior art and avoid infringement of IP.

The practice of science has come a long way since the time of Jenner's vaccine trials on children. But the struggle to ensure that it is done ethically continues. Fortunately, institutional mechanisms have been put in place in order to prevent malpractice and to help scientists navigate through the minefield of moral choices they have to make.

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Why Are Indian Archives Coming Together?

- Donna Eva and Connect Staff

Photo: KG Haridasan

The collective hopes to facilitate interaction between archives of all sizes and enable public access to them

"Milli", a group of people interested in archives, organised a series of events for International Archives Week for a second year running. What does it aim to achieve?

"I belong to River Teesta, and I belong to Mount Khangchendzonga," said Minket Lepcha, a filmmaker and former teacher in Darjeeling, before narrating river folklore told in her community about how the River Teesta came to be, and how it got its name. "The very fact that stories have traditional knowledge and wisdom is where my story began," she had said earlier, when describing her own journey as a filmmaker, teacher and storyteller. "We need to tell the stories of our ancestors." Minket shared the tale about the Teesta at a session on community archiving that coincided with International Archives Week 2021 in June, organised by Milli, a consortium of individuals that aims to nurture archives. Minket's storytelling raised many of the questions that Milli has been trying to engage with: What is an archive? What material – and whose stories – get to be told in an archive, and who gets to claim ownership of them? How can archival material be made accessible to the public, beyond just academic scholars, so that diverse stories can emerge from them? Over the course of seven packed days, these and other questions were discussed during the sessions organised by Milli, which saw historians, artists, journalists, archivists, conservators, librarians, performers and others in conversation about archives.

Milli began in 2020, with a similar series of talks that coincided with International Archives Week that year. The people that form Milli include individuals from a range of backgrounds, such as academia, computer science, and people who work in archives – institutional ones such as those in the National Centre for Biological Sciences (NCBS) and IISc as well as small community archives such as the one run by the Keystone Foundation in the Nilgiri hills – to name just a few. Oddly, it was the COVID-19 pandemic and lockdown in 2020 that brought the many people who volunteer at Milli together, and kickstarted the events that the consortium would come to organise.

Why have a collective?

Maya Dodd, an Associate Professor at FLAME University, Pune, works in the areas of culture studies and digital humanities. She is one of Milli's founding members, and points out that conversations about archives in India and the need to improve them had been going on in different circles – among educationists, archivists, historians, and others – for a while. But with people being located in different places, figuring out a physical meeting point had been hard until the pandemic drove everything online. Suddenly, organising became easier – meetings and conversations on Zoom led to a plan to organise talks and panel discussions pegged onto International Archives Week; participants in remote rural areas or even in other countries such as Pakistan and the USA could be invited without the usual hassles of organising travel and managing visas, and barring small costs such as the purchase of a Zoom account, it could all be pulled off without having to seek funding.

> ***"The hope is that through this process we'll make a space for different kinds of archives, big and small, to be able to speak to each other"***

As Aparna Vaidik, Associate Professor in history at Ashoka University, Delhi, and fellow founding member of Milli, puts it, there are very few fora for archivists to come together with scholars, community workers and others to talk about their work. She says the pandemic "freed us up" in terms of time, distance and resources and made organising a range of events possible. "The hope is that through this process we'll get to know other people working on similar ideas and similar questions, and make a space for different kinds of archives, big and small, to be able to speak to each other," says Venkat Srinivasan, archivist at NCBS in Bangalore. "The archive means many things to many people, and we wanted to see what that umbrella would look like," he adds.

Image courtesy:Milli YouTube channel

Archivists from government and institutional archives to business, family and community ones offering glimpses of their workplaces during a Milli session

Access to the archive

One of Milli's major goals is to improve public awareness about and access to archives. "If we open up the definition [of the archive] and the engagement with an archive, then the kinds of resources available to the public and storytellers changes by having such a network and shared spaces to know that this exists," says Venkat. A way of making archives more accessible is by encouraging structure for archives in terms of helping provide a framework for conservation of materials, standards for describing archival material, and developing legal standards for accessing archives in India, among other things.

Digitising archival material and providing a catalogue of the content online can also help. Maya talks about her work in the digital humanities classroom with students to create catalogues of different archive collections. She believes that there ought to be two-way traffic between universities and archives, and conversations across these spaces. "But if we can't even arrange this material in a digital catalogue, how are we going to have these conversations?" she asks.

Language can also pose hurdles where access is concerned. TB Dinesh, another founding member of Milli and founder of the tech non-profit Janastu, cautions that people who are not literate are often simply not seen, but that new kinds of [audio and visual] content can help make archives accessible to them. Then there's the question of dominant languages. "How do you break down the hegemony of one language that marginalises others?" asks Aparna, who asserts that it is necessary to push for multilingual archives.

The language of description, called metadata, and the way in which archival material is described can also affect whether it is accessible. Metadata in archives typically involves keywords that tag information, potentially making this information easier to find during a search. "You discover material using keywords," says Venkat. "We have an opportunity to explore this in India and I don't think we do this often enough. We don't engage with this question of how the way something is described impacts whether or not it is going to be found and who is going to find it. The archivist's description may not take into account different ways of seeing an object. If the public is able to point out other ways of viewing an object, archives are richer for it." With the goal of facilitating public involvement in how archival material is described, Milli is working on an open-source platform to allow people to add their own annotations and tags to catalogued material as additional layers of description. The platform is also intended as a means to discover and find archives and archival material by building "a catalogue of catalogues", to use Venkat's term.

Community archives

Dinesh sees the platform for annotations that Milli is building as a bridge between different kinds of archives, connecting traditional institutional archives to community archives, which are an area of focus at Milli. "We need new directions and ways of including more people in what we traditionally think of as archive spaces," he emphasises. "One of our goals when we came together was to highlight, amplify and support community archives and community archiving efforts," says Aparna. Community archiving also forces a reckoning with the ethical questions that come into play when archiving people's lives – about representation, about whose perspective defines the way a community is seen, about the value assigned to community lives and community knowledge, about ownership of and access to the material that is archived, and who the user of the archives is. "Community archiving," says Aparna, "is about embedding the community's concerns, their vision, and their gaze into the archive. And when a community creates its own archive, it has ownership of that knowledge, which can impact the way that knowledge is presented and taught."

> ***"One of our goals when we came together was to highlight, amplify and support community archives and community archiving efforts"***

Community archiving can also point to new directions for the field. Maya points out that Adivasi Lives Matter, one of the participants in the Milli sessions this year, uses the internet and social media to enable indigenous people to document and share stories about their communities. Khabar Lahariya, a grassroots feminist media publication, began as a print newspaper with hyperlocal stories almost 20 years ago, and today also has online editions and YouTube shows, still with a hyperlocal focus. Kavita Bundelkhandi, its editor-in-chief, emphasised during a Milli session the importance of engaging with people in their own language.

Dinesh, who is also involved in a community radio initiative near Tumkur in Karnataka, says that it is important to envision a space where storytelling is driven by the archive and is available to all. An example of this at the community level, he says, is the community of Helavarus in Karnataka, "tellers", who travel from home to home singing of each family's history, which is based on written genealogical records that are constantly updated. Opening up access to archives, he says, allows people to bring their voices and connections to all these archives. "It could be the truck-loader's son who has become a scientist," he offers as an example. If archival information about this scientist was accessible to the truck-loader's community, they could use this to tell stories about themselves, drawing a relationship with and building on records in institutional archives.

Milli is keen to facilitate the use of archives in storytelling as a way of breaking down how we think about scholarship, says Venkat. "Historians are perhaps the most frequent visitors of the archives. [One of Milli's goals] is to ask what kinds of knowledge are produced in their fields, and ask what are the gaps in this knowledge." "If historians continue to draw on big institutional archives, it is [only] those stories that will get represented," says Aparna.

Milli's future

At the moment there are two components to Milli, the organising of talks and discussions, and the building of the tech platform. The collective itself is an informal and open-ended one, with a loose structure and no official membership. So far, it has served as a place for discussion and collaboration, and has led to programmes such as the Ownership of Public History in India, funded by the British Academy, and projects such as the Indian Community Cookbook Project. "We're facilitating conversations that would be difficult to have individually," says Farah Yameen, an independent researcher and contributor to Milli. "Right now it is essentially run on enthusiasm, which a lot of us have in a fairly healthy amount," Farah adds.

Whether to develop a formal structure is one aspect that the collective has been debating. "We are not an official body – that is not our goal," says Maya. Though she sees the loose formation of the collective as being one of its strengths, she also sees it as a limitation. A more formal and long-term structure would enable its members to go beyond hosting discussions to doing consulting and applied work. Aparna also feels that the collective needs to be clearer in its vision. But that would mean more involved internal discussions on what the group's different members agree on, including ownership of data, whom to accept funding from. And "boring" questions such as "Should we have a mailing list?" Venkat jokes. These are aspects that the collective still needs to work out.

For now, it continues with its goal, as Venkat puts it, of raising public awareness about what archives are, to interrogate, and to celebrate them.

Donna Eva is a freelance writer and illustrator

44 years at IISc and counting

- Kavitha Harish

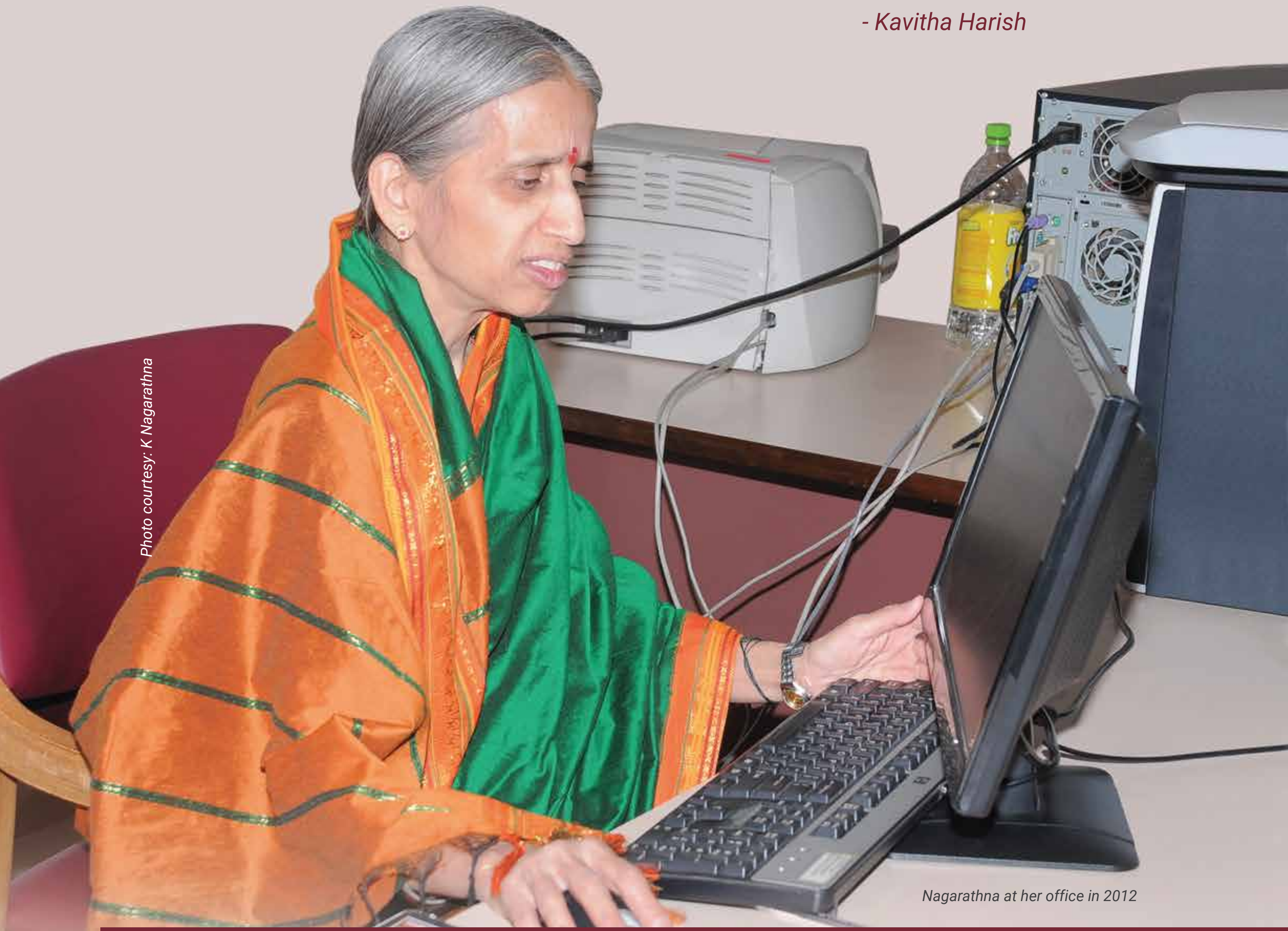

Photo courtesy: K Nagarathna

Nagarathna at her office in 2012

K Nagarathna joined IISc in June 1977 at the age of 23. She was the only daughter of her parents, with five brothers who studied science and engineering. Nagarathna dreamed of joining the Institute ever since one of her brothers pointed out to her IISc's 'tower' on the horizon from a temple in Basavanagudi. After completing her BSc, she acquired secretarial skills and applied to IISc for a stenographer's post. She had to plead with her mother, who was against her taking up a job, to let her try it out for a year. That was the beginning of a long career which spanned the Department of Aerospace Engineering (AE), the Centre for Atmospheric Sciences (now the Centre for Atmospheric and Oceanic Sciences, or CAOS) and the National Institute of Advanced Studies (NIAS). With forty-plus years at IISc, KN, as she is known, continues to work after retirement at the Supercomputer Education and Research Centre (SERC).

Tell us about the time you started working at IISc.

I joined as a Stenographer Grade II. Mr Nagesh from the Establishment Unit sent me to the Aerospace Engineering Department saying, "As you are coming from a far-off place, I will put you in a department closest to the bus stop!"

At that time, Prof Roddam Narasimha was looking for a secretary. Since he was abroad when I started, his colleagues showed me around and briefed me about the work. On the morning of 4 July 1977, Prof Narasimha walked into the office – a small room in the Fluid Mechanics lab – saying, "So, you are the new girl here? What is your name?" From that day on, I became "KN".

How was CAS established and what was your role in its running during those early years?

[In the 1980s], Prof Narasimha realised the need for a department at IISc to study meteorological sciences. With the support of Prof Satish Dhawan, the then Director, he submitted a detailed proposal to the government. The sanction order to establish CAS came on 23 September 1983. A new building, shared with the Centre for Ecological Sciences, came up some months after, and I was asked to move to that Centre. I was promoted to a senior grade.

Photo courtesy: K Nagarathna

Nagarathna at her office in 1979

This was also the time when Prof Narasimha relinquished the Chairmanship of AE and became the Director of the National Aerospace Laboratories (NAL). He originally wanted me to go with him to NAL, but later decided that I should be his contact with the students and the Department at IISc. We used to meet in the evenings or on weekends to continue with his work here.

I took charge of the office at CAS, building it along with an increasing number of students and staff, acquiring everything from doors, carpets, locks and keys, to measurement towers and equipment for meteorological observations.

Under what circumstances did you move to NIAS?

Photo courtesy: K Nagarathna

The two bosses: Roddam Narasimha (left) and N Balakrishnan (right)

In 1993, Prof Narasimha retired from NAL and returned to IISc and to his old office in CAOS for barely a year before leaving again to become the Director of NIAS. This time, he was serious about me going with him. He requested the IISc Registrar to depute me to NIAS. So, I became Personal Secretary to the Director at NIAS for the next seven years.

In 2003, Prof Narasimha joined the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR). He had already built a dynamic fluid mechanics group in the Engineering Mechanics Unit there. I was reluctant to leave IISc, because I would not only lose my service but also my living quarters. This was a concern, since my aged parents lived with me. So, I asked the Registrar for advice.

Once, as I was telling Prof Narasimha that the Registrar had not yet made a decision, and that I was to be at NIAS for some more days, Prof N Balakrishnan walked in. He asked me whether I would like to be in the administration or in a department, and I answered that a department would be better for me. He immediately processed the paperwork and took me into SERC.

Your brothers have had successful careers in science and engineering. Did any of them work at IISc?

Two of my brothers did their PhDs from IISc, one from AE (incidentally, he joined the Department when I was already in IISc) and the other from Mathematics (he was about to complete his degree when I joined, and left soon after to become a faculty member at the Indian Statistical Institute). The third brother did his PhD from Bangalore University, but collaborated with the chemistry researchers at IISc, and with the Department of Chemical Engineering after he retired. One of my younger brothers has been a Visiting Scientist at the Department of Electrical Engineering and another worked with Prof N Viswanadham in the Department of Computer Science and Automation for a few months after his Master's degree from IIT Bombay and before going to Georgia Institute of Technology for his PhD.

So, my family has had a very strong connection with IISc, but I am the only one who is not a scientist and still works in a science institute.

What are your fondest memories of your early years at IISc?

I have been walking on the roads of this beautiful and soothing campus for 44 years now. When I joined the Institute, I was a young girl. I had little exposure to the outside world and was scared to talk to anybody. I assumed that whoever joined IISc must be really intelligent and so, I needed to improve myself to survive here, and give utmost respect to everyone. Slowly, I became friends with other girls, especially those from Prof Balakrishnan's lab. I distinctly remember admiring his serious expression as he sat in front of the computer! I never imagined that I would be working for him years later.

Photo courtesy: K Nagarathna

At Hogenakkal Falls with the SERC team

Working with Prof Narasimha was challenging. He was an expert at recognising the potential of people and extracting the best from anyone. To learn more and to work to his satisfaction became my primary goal and it kept me busy all the time. This earned me good grades in my first evaluation.

How has the Institute changed since you joined?

The campus was greener and more silent then. With the infrastructure necessary for the growth of the departments and research activities, it is inevitable that some green leaves turn to grey cement. In the last couple of years, there have also been phenomenal changes in the administrative system, with modernisation and digitisation of work in all sections. This has streamlined the system and made it transparent, but we miss the person-to-person contact.

What was it like to work with Roddam Narasimha?

Photo courtesy: K Nagarathna

At the yearly ritual of Nagarathna visiting Roddam Narasimha on his birthday. Seen here with former PhD student Sarita Azad

I lived with my father for 45 years, but hardly had any close interactions with him. He was scholarly but reserved. But with Prof Narasimha, I had the fortune of seeing him every day for 44 years, and understanding his way of thinking, his meticulous handling of projects and people, his hardworking nature, his intelligence and far-sightedness, his uncompromising commitment to perfection and, last but not the least, his kindness.

The lessons I learnt from him have guided me throughout my life.

For some reason, he had huge confidence in me. On one occasion, he was in the Indo-US strategic studies meeting, and had forgotten some important piece of paper at home. He could not step out of the meeting and there was no one at home that day. He called me and said, "Take the key, go to my house, go to my bedroom and search for that paper and bring it as soon as you can." Another time, my father was in the hospital before his death. I had rushed there and it was impossible for me to leave him unattended. Prof Narasimha was supposed to go to Delhi early the following morning and I had his flight ticket. I had to give him detailed instructions about collecting the key to my house from the office, going to my house and taking the ticket from inside the almirah!

He was kind enough to take me to the Rashtrapati Bhavan in Delhi when he received the Padma Vibhushan from the President. It was rare that a person of my stature could participate in such a ceremony.

Knowing my wish to get a grip on the English language, he encouraged me to complete a Diploma in English and always talked to me in English (although Kannada was the mother tongue for both of us). The first gift he brought for me from his trip to the US was a small handbook on the duties and responsibilities of a secretary!

Prof Narasimha was very particular about using appropriate words in his sentences. He demanded absolute scientific accuracy and impeccable language and style from his students, research assistants, colleagues and collaborators. Students would say, "The draft has been given to the Prof, but the bleeding has to happen and then the healing will start!" ('bleeding' referred to the red ink that marked the corrections).

Photo courtesy: K Nagarathna

At the first Asian Congress on Fluid Mechanics in December 1980. From left to right: Krishnaveni (Civil Engineering), Maya (Civil Engineering), Vimala (a volunteer from NAL), Rajalakshmi (a volunteer from NAL), Vinitha (Aerospace Engineering), Nagarathna

What do you remember most from your time at SERC?

Soon after I joined AE, I was asked to prepare a notice for a meeting that was to take place at 11.30 am. Unexpectedly, Prof Narasimha told me to change it to 4 'o'clock. I changed 11.30 to 4 but am did not become pm. People laughed heartily when they saw the notice for a meeting at 4 am! Later, when I came to SERC, 4 am was not at all considered an unearthly hour. Prof Balakrishnan is well known in IISc for going to the Department like a ghost in the middle of the night. By the time others come in the morning, his work is 100% cleared.

Did you meet many dignitaries during your time at the Institute?

My position at NIAS and later in SERC provided ample opportunities to meet many dignitaries and top-class scientists from across the globe. We had the good fortune at SERC to meet the late President Dr Abdul Kalam. We made friends with the secretaries at the Prime Minister's and President's offices, so we were free to call there directly.

Do you believe that the skill of a stenographer is still useful today?

Stenography has lost importance in the modern age. When I started, a typist's help was absolutely essential even for a line to be written. Today, the faculty and students prepare documents on their own. There are searchable formats for every kind of document. So, the biodatas of most applicants to departments look alike, with sentences like "a quest to work and learn in a professional ambience that enables me to cope with the emerging as well as latest technology and with scope for widening the spectrum of my knowledge." All this, and the candidate has not even read or understood the meaning of it!

Photo courtesy: K Nagarathna

With Dr Abdul Kalam, March 2012

How are you spending your retired life? What are your hobbies?

As mentioned earlier, I am still working at IISc. In parallel, I am trying to reawaken my interest in classical music, learning Sanskrit and vedic chanting. I need more time!

What would you consider your greatest moment of pride in such a long and eventful career?

Prof Narasimha rarely praised anybody directly. I feel very humbled by an email I received just a few days before he left us. It said, "Dear Nagarathna, you are far too kind to an often-forgetful scientist, but I am really very touched. But I must honestly also say that the help and kind assistance I have had from you for some four decades or more has had an irreplaceable effect on my own scientific career, and in fact even on my family life. So please accept my gratitude to you for your ever-cheerful attitude to work and life – very rare in this world indeed. With all best wishes and thanks again, RN." I consider this my 'lifetime achievement' certificate.

Kavitha Harish is Personal Assistant to the Assistant Registrar (HR, Council) at IISc

Dancing with cells, surfing the laminar flow

- Jyotsna Dhawan

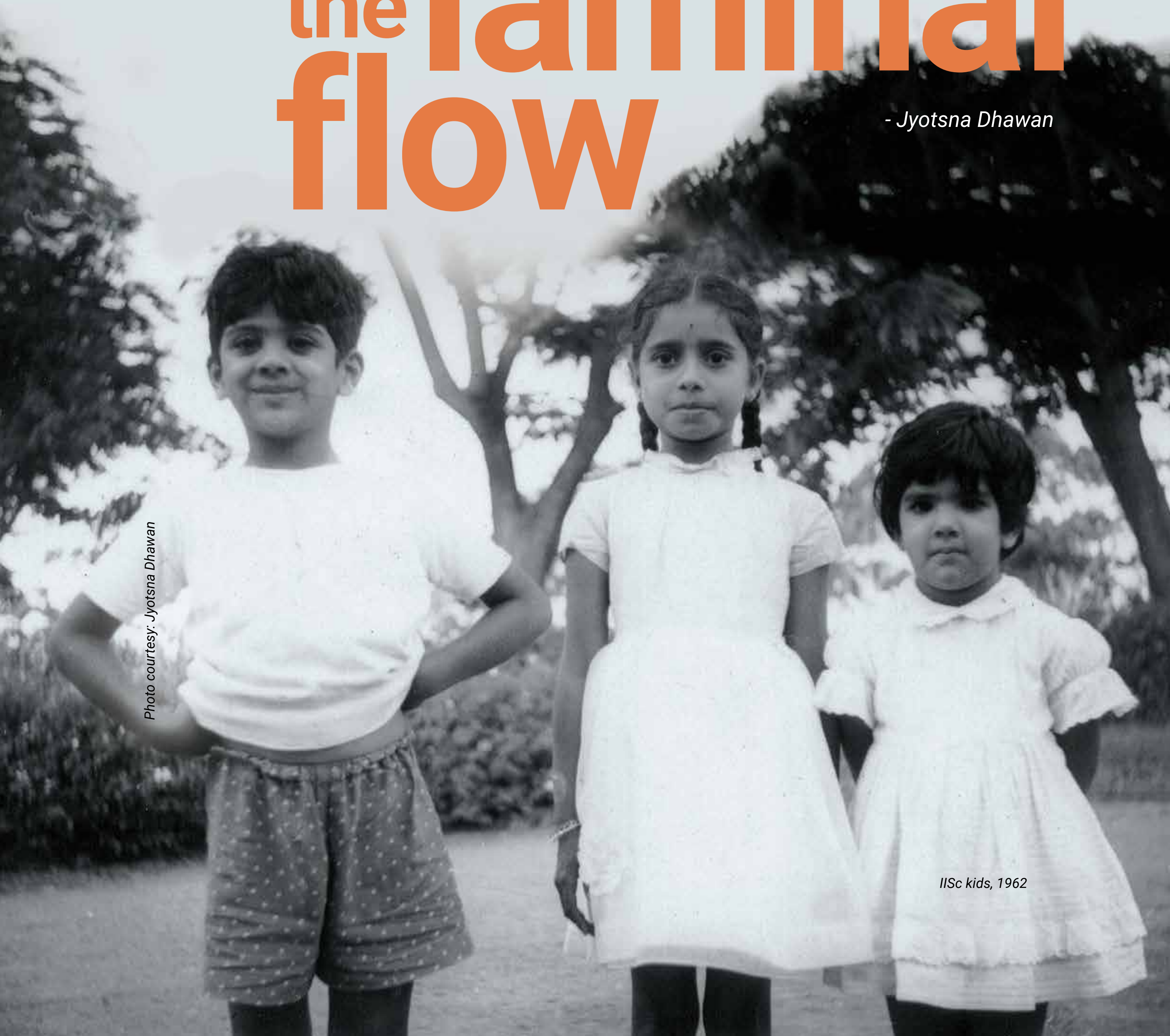

Photo courtesy: Jyotsna Dhawan

IISc kids, 1962

Ahead of Satish Dhawan's birth anniversary on 25 September, his daughter Jyotsna writes about her childhood on the IISc campus, life beyond, and her father's indelible presence

In the 1960s, while our parents (mostly fathers) worked away in labs and offices, libraries and classrooms, the children of IISc staff (mostly barefoot and unsupervised) explored that magical campus, wild and mysterious as it was in those days, and revelled in the natural world. That world is still in us, we return to it in dreams, it is the source of our imagination. As Borges wrote, "Time is a river which sweeps me along, but I am the river."

In this essay, inspired by the 100th year of my father's birth, I recall an incident from my work as a cell biologist that simultaneously triggered a return to my childhood in that paradise, and propelled me towards a new beginning in my research.

Dependent relationships

"A triskelion is a Buddhist meditational symbol," writes Victor Mansfield in 'Time and Impermanence in Middle Way Buddhism and Modern Physics'. "It resembles three commas chasing one another round a circle, and represents the three aspects of Dependent Relationship which give existence to all functioning things. The Buddhist teaching on Dependent Relationship states that phenomena exist in three fundamental ways. Firstly, phenomena exist by dependence upon causes and conditions. Secondly, phenomena depend upon the relationship of the whole to its parts and attributes. Thirdly, and most profoundly, phenomena depend upon designation by the mind. The appearance of motion of the three swirling blades symbolises that the impermanence of all compound phenomena arises from these three ever-changing relationships."

The art and craft of cell culture

For about a hundred years, scientists have been able to dissociate cells from a chunk of tissue and keep them alive in a dish, watch them multiply and specialise, and in so doing, understand about the molecules that control all these behaviours including how cells organise into tissues, communicate with other cells near and far, how they die and how they escape normal controls to become cancerous...

Photo courtesy: Jyotsna Dhawan

Jyotsna in front of a laminar flow hood holding a tube full of purified muscle cells, 2014

The experimental protocol for culturing cells engages the practitioner in a sort of restricted dance form. You are mostly seated in front of a glass-fronted biosafety cabinet that protects the sterile cultures from your microbe-laden breath. The key to preventing air outside the hood from mixing with the sterile atmosphere around the cells is a vertically flowing air-curtain, a laminar flow. Inside the cabinet, there is space for petri plates and tubes, bottles of media and sterile pipettes for dispensing nutrient broths that bathe the cells which grow clinging to the surface of a plastic petri plate. At the back of the cabinet, another vertically flowing air sheet reinforces the sterile atmosphere. You must reach through the airflow behind the glass front to perform your tasks, and if you are not in rhythm, or have too many things in your hands, you can spill or contaminate your cultures. Primarily, the tip of the pipette that dispenses liquid must never touch any surface outside the sterile media bottle. So, an elaborate set of coordinated hand movements is required to open and close dishes, uncap bottles and pick up small test tubes, all the while staying aware of the need to keep things separated and clean. Moving liquid around, transferring cells from a dish where they have grown too crowded for comfort, and keeping your hands from entangling themselves in your pipettes – those essential extensions of hand and mind – requires that your consciousness be focused simultaneously inside the plate with the cells, while double-checking all your actions by examining their consequences under the microscope. And above it all, in your thoughts floats the experiment that you are doing to probe the cell interior, asking how does the cell perform this or the other task, marvelling at the beauty of the precisely organised subcellular milieu...

The gleaming steel and glass of the cabinet, the pink and orange culture media, the rapier-like pipettes, the living moving metabolising cells tantalisingly close under the microscope, are all a product of the art and science of tissue culture.

North Carolina, August 2003

I am in a crowded basement lab, late one summer evening, seated at the laminar flow hood, isolating progenitor cells from the skeletal muscle of mice, performing my familiar solitary culture dance, moving to a practiced music. There are time-bound experiments to be done, a grant proposal to be written, pressure and questions swirl around me, including the most pedestrian – why have I pushed myself to do all this while working so far from home, as a visitor in this American lab? My host lab has engineered transgenic mice that I need to test a hypothesis raised by my earlier work. I am unable to import the mice to my lab in Hyderabad due to long regulatory paper-tangles, so I have exported myself. I could just as easily be at home in my peaceful messy house, chatting science or lab gossip with my husband; I could be in my own lab, arguing with my students to do something my way instead of their way, but here I am, rooming in a long-stay motel on a rural highway in North Carolina, working to a crazy schedule to complete this work in the month given to me by my travel fellowship. My time is nearly up, I have not completed the experiments, nor have I completed writing the proposal for funding my group's research for the next several years…

I am an experimental cell biologist. What makes my heart beat faster and my brain sing is figuring out how muscle stem cells stay in a dormant state. What, you say, why is that important?

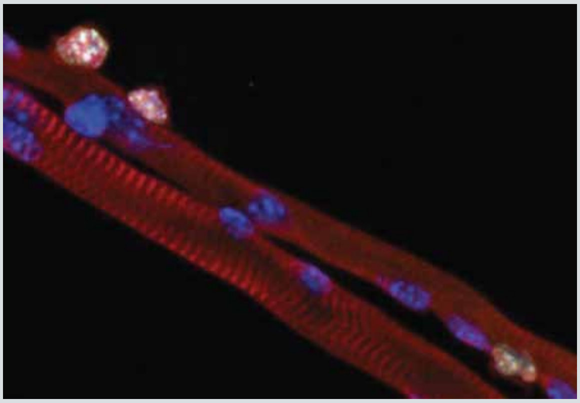

Photo courtesy: Ajoy Aloysius, student in Jyotsna's lab in 2016

Muscle stem cells (white) from a mouse limb perched on the surface of skeletal muscle fibers (red). The blue dots represent the multiple nuclei of the muscle fibers.

Skeletal muscle is a wonderful tissue, contractile and strong – and it forms more than a third of our body mass, allows us to move, breathe, and express emotions through the 42 muscles in our face. Think of the immense range of emotions conjured by a Kathakali dancer's dramatically mobile visage! Muscle is also a major contributor to our overall metabolism, because it burns nutrients to create energy for movement. Working continually whether we are at rest or actively exercising, with time, muscle tissue wears out and needs replacement. Luckily for us, we have a batch of reserve cells that evolution has set aside exactly for this purpose. These are called muscle stem cells, and they regenerate damaged tissue. Defects in muscle repair can cause devastating diseases, spurring labs across the world to understand the molecules and cells that normally control how muscle regenerates. Muscle repair also declines as we age, but remarkably, this decline can be mitigated by regular exercise, which keeps muscle tissue supple, and the rare stem cells tuned for action.

To isolate living cells, I have dissected out the muscle from a mouse, and must manually chop the tissue into very small pieces with two scalpel blades before adding enzymes to release the stem cells. The mouse is no longer alive. Its cells, however, are still fizzing with metabolic activity, capable of growth and division, immortalising their mousely past, a testament to their host's instant in time. Each muscle requires 15 minutes of finicky precision chopping – picture a 3 millimetre-long onion being diced very fine (Thanks to Tom Rando for that evocative image of the tiny onion, articulated during a daylong session of muscle chopping when we were postdocs in the 90s). I have been doing these experiments repetitively since 7 in the morning, and am nearing exhaustion, close to giving up. I berate myself for imagining that working half-way around the world would be a practical way of addressing this question. My mind flits between negativity and self-doubt as I mince the tiny piece of muscle tissue mechanically, my own muscles tiring from the stiff position I have had to maintain for hours. A little scraping sound disturbs my reverie, but I ignore it, forcing my own screaming arm muscles to keep dicing. The sound stops, then starts again, persists, and out of the corner of my eye I see a little silver object spinning around on the surface of the perforated laminar flow barrier. I stop mincing and stare, unsure of what I am seeing...

The little silver foil packet sputters, then swirls around on its axis in the flow of the sterile air curtain, lifts gently and precisely off the perforated steel flow cover to a height of about two inches, then settles back down momentarily, swirls again, lifts perfectly off in a little repetitive dance...

Just by chance I have opened the aluminium foil package of the scalpel blade such that it creates a perfect triskelion with arms of equal length, and just by chance I have placed it at a serendipitously correct angle in the laminar flow, leading to this propeller action in the stream of air. Placed at any other angle, it would not have behaved in this fashion. As it is placed, it catches the vertical airstream in the curtain exactly right, it flickers and starts to rotate, then goes into a perfect loop of stable smooth rotation, lift, then loss of lift, obeying gravity, settling back down, again perfectly, to catch the flow, and repeats.

This goes on for a full minute until I move my arm and the angle of the flow changes. Word associations flood my mind: aerofoil, lift, drag, aerodynamics, Reynolds number, Bernoulli, fluid flow: I know none of the scientific bases for any of these, but these words swirled around my childhood, and settled in my imagination, accompanied by my father's excited voice and sparkling eyes, you could always hear the smile in his words; Satish fills my spirit and I float back to Bangalore.

Bangalore dream days, 1962-78

The idyllic wild campus of IISc in the 1960s offered a fund of aerodynamically active natural objects to anyone who cared to look. On our rambly walks through that paradise, Satish would pick up winged seeds from the bursting mahogany pods, spiral purple flowers from the petrea creeper and the little parachutes of dandelion seeds, playing by flicking them into the wind at distinct angles, watching their flight with glee and satisfaction, encouraging us to do the same, and describing their descent.

Photo courtesy: Jyotsna Dhawan

Garden of Bungalow No 5 in 1972

He is observant about the tiniest phenomenon linked to air movement, relishing the chance to revisit and revel in it. We are walking in another campus near IISc, passing a creeper-covered wall. Only one out of the thousands of near-identical leaves catches the slight breeze such that it goes into a repetitive flapping, fluttering motion; aeroelastic instability, he says, pleased; then he tells me about advanced aircraft wings and how they must deal with this eventuality. I nod with little comprehension, but it settles into the soup.

I am little; we wash the car on Sundays, Satish making it into a fun thing for us kids. With his rolled up trousers, and wielding a gushing garden hose, he makes little rings with the water flow, the stream broken into bursts as we clamber over the sides of the ancient Morris Minor, water streaming into droplets that catch the morning sun, delighted to be getting our clothes wet with permission; a glorious Bangalore day; someone steps on the hose, he smiles and points out the momentary sputter in the flow.

Photo courtesy: Jyotsna Dhawan

Dipanker and DK Banerjee with Bhute and Shakhi at Bungalow No 10, IISc in1965

On summer evenings, when we are too rambunctious to be in the house before dinner, we are bundled into the venerable Morris, the cracked canvas roof rolled down, we are instructed to bend our heads back over the seat and scan the sky for Sputniks, as Satish drives slowly around campus in the deepening dusk, velvety flying foxes winging out of the drumstick trees. I see it, I see it, we all claim at every glint in the sky, letting our imaginations reel away into space, pretending that we are Gagarin in the little white and red plastic rocket given to us by a visiting Russian.

I am much younger, maybe 5, we are wandering along the unpaved campus paths, he squats down to my height and shows me a tiny conical funnel, a minute depression in the chalky soil, small orange sand grains skeetering down the steep side – an antlion sitting in the base is trapping its bait. Years later we are on a similar walk, another antlion, he explains the geometry of the perfect little trap, I half listen, lost in the trilling manic call of the barbet and my own thoughts.

Rain
Cathartic, sensuous, fecund, sacred
Chasing barefoot, a twig in brown gushing gutter
Childhood drenches me

My sister and I walk with him after a sharp April downpour, a delicious deluge of flood water stained orange-red with the iron-rich Bangalore soil, swiftly coursing through the deep open gutters, lined with ancient Deccan granite; we stop at intervals to flick in leaves, flowers dropped by the merciless rain drops, sword-like seed pods from the gulmohurs overhead; we run downstream to catch our flotilla; Satish finds us more objects that give better swirl patterns.

I am not ready to sleep so I wheedle to accompany Satish to the Aero Department when he goes back to work after dinner; I first contemplate the big propellor on the side of the entrance thinking about the plane from which it came, and then press my nose against the perforated end of the wind tunnel, crossing my eyes

Jyotsna, Vivek and Amrita at Bungalow No 5 at IISc in 1963 to play with the Moiré patterns caused by the imperfect superposition of the double layers of wire mesh.

We are swimming in the newly refurbished gymkhana pool; for a whole summer we cling to the poolside beating our legs and trying to get afloat, dog-paddle ineffectually. Then we accompany Satish on his sabbatical to California, his alma mater Caltech; we have heard about Caltech with a reverence and joy in his voice ever since we can remember; those magical names – El Camino Real, Pasadena, those legendary people – Von Karman, Hans Liepmann, Anatol Roshko. We take swimming lessons, the open Californian attitude spurring our learning, and in a week we are more proficient than in the whole last summer. We are given lifesaving lessons, have to pass a test in which we must stay afloat for 10 minutes with our hands and legs tied, the technique for bobbing up and down without struggle by just letting our breath and lungs be our flotation devices gives us huge confidence; Satish is pleased.

Photo courtesy: Jyotsna Dhawan

Photo courtesy: Jyotsna Dhawan

Satish and Jyotsna outside Bungalow No 11 at IISc in 1962

Back in Bangalore, lying on our backs in the summer sun on the high platforms flanking the founder's statue, we lazily watch the stately unhurried climb of the kites into the thermals over the IISc quadrangle. Walking home, a sudden gust shakes free the papery thin winged seeds of the *Tabebuia argentea* trees lining the avenue, a shower of parchment white.

Running laughing through an evening field of ruby grass ruffled by the surface riffles of a Bangalore monsoon, stomping hard to make sure the snakes feel the vibrations and leave us alone...

North Carolina, August 2003

I gently set down my pipette and close the dish with the muscle sample, and laugh uncontrollably at the improbability of this levitating, rotating triskelion. Some peaceful energy returns to my bones, I complete my experiment. An hour later, I head back to the rural highway motel, and get down to writing. I finish the grant at 3 am.

Hyderabad and Bangalore, 2004-2009

Of the two tasks I struggle with in North Carolina, I never do publish the results of the experiments with the muscle cells from the transgenic mouse, but find out much later that I was on the right track. A colleague from Colorado follows the same hunch, does the right experiments, adds a line to the understanding of muscle progenitor cell behaviour and the molecules that regulate repair.

But I do get the grant – a larger source of funding than I can imagine at that stage of my career – it allows me confidence, flexibility and sweep in my work, enables me to buy sophisticated equipment, fund my students to travel to meetings. We find evidence for genetic programs that we had hypothesised, molecules that help dormant muscle stem cells stay potent for future activation. It sets me on a path quite different from the one I might have trod without the liberating influence of flexible funding. Beyond the financial support, I am drawn into a group of scientists who are asked to participate in larger programs – we encounter each other all the time, work together and progress as a cohort … a new horizon, still filled with wonder at the natural world, crystallised in a fleeting self-levitating triskelion moment when Satish's presence sustained my flagging spirit.

Photo courtesy: Jyotsna Dhawan

Satish in 1995, demonstrating his favourite paper plane design for school children

Dedicated to that roving band of IISc kids of the 60s and 70s: Pitku and Amrita; Sudha and Chakrapani; Subbu; Jayanti and Arun; Radha, Sudha, Anu and Ramudu; Nannu and Pommy, Gowri and Indrani; Ravi and Yashoda; Chandrasumitha, Patanjali and Divyavardhana; Dippy and his fierce friends Bhute and Shakhi; Raghu and Malathi; Ramakrishna, Vasanta and Baba; Ganesh; Subbarao; Nina and Ashok; Maithreyi and Aditi; Ranjan, Alak, Palak and Anjan; Sridhar and Jayaram, and Goofy. May the force be with you.

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Author: Jyotsna Dhawan is a cell biologist who as a child was fortunate to roam free in the untamed campus of the IISc as it was in the sixties, when Satish Dhawan was on the faculty of the Aerospace Department. She works at the CSIR-Centre for Cellular and Molecular Biology at Hyderabad (https://www.ccmb.res.in/People/Research-Group/Jyotsna-Dhawan), and is part of a new effort to generate philanthropic funding to support life science research in India (https://ignitelsf.in/).

ABSTRACTS

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