

# INDIA'S SCIENCE TEST

*The south Asian superpower has made great strides in research and development, but it has a long way to go.*

**W**ith her jeans, T-shirt and spirited attitude, Tapasya Srivastava could pass for a student as she works in her brightly lit cancer-biology lab on the University of Delhi South Campus. Srivastava, who oversees a team of eight researchers, is thrilled that she earned “a small research space of my own” in 2010, while still in her thirties. “With a decent list of publications under my belt, I am one of the few who have studied and undergone training entirely in India,” she says.

Eight kilometres away, in the chemical-engineering department of the Indian Institute of Technology Delhi, Shalini Gupta's team is developing sensors to detect early-stage sepsis and typhoid. Gupta did her doctorate in the United States but returned to India to focus on its needs: “I am more connected to society and its challenges,” she says.

Srivastava and Gupta are part of a wave of young Indian scientists convinced that they can do high-quality research at home rather than having to move abroad. Such optimism reaches all the way to the top: in January, Indian Prime Minister Narendra Modi told an assembly of scientists to “dream, imagine and explore. You will have no better supporter than me.”

India has much to be proud of. Last year, it became the first to reach Mars on its initial attempt. It boasts a thriving pharmaceutical industry that produces low-cost medications that are desperately needed by the developing

BY T. V. PADMA

world. And in his first year in office, Modi launched an ambitious plan to make India a leader in solar power.

Such successes cannot hide the huge challenges facing this country of 1.3 billion people, which leads the world in tuberculosis incidence and maternal deaths, and lacks electricity for one-quarter of its citizens. India is expected to become the world's most populous nation within a generation, and it will require a robust science and technology sector to supply the needed energy, food, health care, jobs and growth. Yet researchers in India and abroad say that the country has a relatively weak foundation in science and engineering.

Indian research is hampered by stifling bureaucracy, poor-quality education at most universities and insufficient funding. Successive governments have pledged to increase support for research and development to 2% of India's gross domestic product (GDP), but it has remained static at less than 0.9% of GDP since 2005. Despite its huge size, India has a relatively tiny number of researchers, and many of its budding scientists leave for other

countries, never to return. Only by tackling its systemic problems can India compete with other emerging powerhouses such as Brazil and China.

“The density of scientists and engineers in India is one of the lowest in the world,” says Sunil Mani, an economist at the Centre for Development Studies in Trivandrum, who is assessing Indian science and engineering for an upcoming report by the United Nations Educational, Scientific and Cultural Organization. “There are very many important areas where we are not able to do research.”

## SPACE TO GROW

In one of the cleanest rooms in India, Mylswamy Annadurai is busy conducting fitness tests on a 750-kilogram patient — a gleaming satellite called ASTROSAT. The probe is strapped to a table, where it is being shaken at six times the strength of gravity to simulate the intense forces of lift-off. ASTROSAT must also pass tests in extreme high and low temperatures and vacuum conditions, followed by checks on its solar arrays and antennas. If all goes well, the satellite will blast into orbit by September, armed with two telescopes and four other instruments to study both nearby and distant stars.

Annadurai, who is head of the satellite centre of the Indian Space Research Organisation (ISRO) in Bangalore, says that ASTROSAT will



**SCIENCE IN INDIA**  
A Nature special issue  
[nature.com/indiascience](http://nature.com/indiascience)



India is one of the leading nations in wind power and it has ambitious goals for increasing solar power over the next decade.

PRISMA BILDAGENTUR AG/ALAMY

be India's "first full-fledged science mission" in space. It will carry instruments ten times heavier than those on India's first mission to the Moon, 2008's Chandrayaan-1, and its 2014 Mars Orbiter Mission, nicknamed Mangalyaan.

With its run of recent accomplishments, India has earned international acclaim for its ambitious space programme, which includes launch vehicles, communication satellites and one of the world's largest constellation of remote sensing satellites, as well as its science missions. Since ISRO was founded in 1969, the government has invested heavily in it, and even established a dedicated university in 2007 to train personnel. "The ISRO technical test, assembly and launch facilities are first class," says Paul Spudis, senior staff scientist at the Lunar and Planetary Institute in Houston, Texas, who was the principal investigator for one of Chandrayaan-1's experiments.

Chandrayaan-1 carried an orbiter and a 35-kilogram probe that took images as it smashed into the Moon at high speed. ISRO plans to follow it in 2017 with Chandrayaan-2, which will gently set down a lander and a six-wheeled rover; together with an orbiter, they will study the composition of the Moon's surface. Up next after that is the Aditya mission to study the Sun's corona, in 2018.

Spudis is critical of last year's Mars mission, calling it "largely irrelevant" and saying that it would have been better to return quickly to the

moon. ISRO, he says, "seems to lack a strategic vision of what it wants to accomplish in space". But the agency counters that it is pursuing several missions in parallel; the Mars mission just proceeded faster than Chandrayaan-2.

And the success in reaching Mars has convinced others at ISRO that they can carry out world-class space-science missions, says Annadurai. "The Mars mission experience has once again strengthened our belief that we can."

### BIOTECH BONANZA

In Genome Valley, a biotechnology park in Hyderabad, entrepreneur Krishna Ella is confounding expectations. Ella returned home from the United States in 1996 with a 12-metre shipping container filled with vaccine-making equipment to support his grand plan of producing a US\$1 vaccine for hepatitis B. That goal, which would make his vaccine at least an order of magnitude cheaper than the available one, struck investors as crazy, he says. But within three years, Ella's company Bharat Biotech International Limited (BBIL) succeeded in producing the Revac-B+ hepatitis vaccine at \$3 a dose, which has since dropped to 30 cents per dose. It went on to develop vaccines against Japanese encephalitis, rabies, haemophilus influenza virus B and, most recently, rotavirus. Each costs barely a dollar per dose.

Affordable medicines are the cornerstone of India's health-care sector, where

publicly funded hospitals struggle to provide treatment. The country has long battled infectious diseases such as tuberculosis, malaria and dengue, but is now facing rising numbers of non-communicable illnesses, including diabetes and coronary heart disease. A 2014 report from the World Economic Forum and Harvard School of Public Health estimates that non-communicable diseases and mental illness could cost India \$4.58 trillion by 2030.

Low-price vaccines and generic drugs have helped India to carve out a niche in the international pharmaceutical industry. The global medical charity Médecins Sans Frontières (also known as Doctors Without Borders), which relies on Indian generics for 80% of its anti-HIV drugs, hails the country as the "pharmacy of the developing world". Other international organizations, including the UN children's charity UNICEF and the Global Fund to Fight AIDs, Tuberculosis and Malaria, routinely use Indian vaccines and generic drugs to treat infectious diseases (see *Nature* 468, 143; 2010).

But India is battling criticism over the quality of some of its pharmaceuticals. In 2012, for example, the World Health Organization took BBIL's hepatitis B vaccine and oral polio vaccine off the list of drugs preapproved for use by the UN. Ella says that the issues related to documentation submission and that they have since been sorted out. The vaccines are now back on the list.

In 2014, the US Food and Drug Administration (FDA) sent warning letters to seven Indian firms over various concerns relating to pharmaceutical production there. An FDA spokesperson told *Nature*: “While some Indian companies meet US product quality standards, others have been found to lack sufficient controls and systems to assure drug quality, both of finished product and active ingredients.” The FDA has an India office to work closely with Indian drug regulators to solve those problems.

And some in the biotech sector warn that India has a long way to go to create a thriving enterprise in developing new drugs. The country’s success in the generics industry relies on a different set of skills: reverse-engineering pharmaceuticals created elsewhere by breaking them into their components and remaking them through cheaper routes.

“The challenge for the sector will be to graduate from reverse engineering to new-drug discovery,” says Pallu Reddanna, a biotechnologist at the University of Hyderabad. “There is need for incentives and promotion of academy–industry interactions.”

The government and private sector are trying to jump-start such efforts by setting up incubators that help transfer university and lab know-how to industry, and provide infrastructure and financial support to start-ups. Such incubators are the “greatest changer in the drug-discovery sector in India”, says P. Yogeeswari, a chemist at the Hyderabad campus of Birla Institute of Technology and Science.

Krishnaswamy VijayRaghavan, secretary of the government’s Department of Biotechnology, commends “incredible growth” in India’s biotech entrepreneurship — despite the lack of big drug companies and the relatively low domestic investment in drug discovery. International and industry collaborations with academia are helping to advance the sector, he says (see page 148).

In 2013, the department started two major projects seeking drugs for drug-resistant tuberculosis and chronic disorders such as heart disease. In early leads, scientists have zeroed in on some human proteins that are crucial for the survival of multidrug-resistant tuberculosis strains. Proof-of-concept studies in mice have demonstrated that targeting such host proteins could help to kill the drug-resistant strains, says VijayRaghavan (S. Jayaswal *et al.* *PLoS Pathog.* **6**, e1000839; 2010). “We are at an exciting early applied stage,” he says.

## POWER HUNGRY

Nearly 2,000 kilometres north of Genome Valley, 9.7 hectares of solar panels cover a building in Punjab state, generating 7.5 megawatts of electricity. This project is India’s largest roof-top solar installation that is connected to an electrical power grid, and it signals India’s outside ambitions in renewable energy.

Coal supplies two-thirds of the electricity

in India and will remain king for some time. But the government has set aggressive goals for installing solar-energy capacity. In 2014, Modi’s government announced that it would develop 100 gigawatts of solar-energy capacity by 2022. This is a huge leap from the existing 3.7 gigawatts of solar capacity — just 1.4% of India’s total electricity generation today.

## “WE ARE CAUGHT IN A VICIOUS CIRCLE OF MEDIOCRITY.”

“India is one of the most attractive markets in the world,” says Pashupathy Gopalan, Asia Pacific head of SunEdison, a global solar-energy company based in Maryland Heights, Missouri, which is joining Adani Enterprises of Ahmedabad to build India’s largest solar-panel-manufacturing facility. “We are entering a new era where solar electricity is competitive and has achieved ‘socket parity’ with other sources of energy in India.”

There are other big international collaborations. The Solar Energy Research Institute for India and the United States was established in 2012 to target emerging research areas. In one project, researchers are trying to generate solar thermal power by using sunlight to heat up a highly compressed fluid form of carbon dioxide so that it turns electricity-generating turbines. This could be used in much smaller plants than conventional steam-driven turbines.

But some analysts say that India suffers from “gigawatt obsession”. The focus on giant solar plants comes at the expense of smaller facilities that do not require large parcels of land, but could provide electricity to isolated towns, even without being connected to the grid.

“The gigawatt rush must pay attention to the pace with which the capacity is to be built in India,” says Satish Agnihotri, former secretary of India’s Ministry of New and Renewable Energy. Plans to build large plants could run into opposition in densely populated or heavily farmed areas, and in remote areas it can be difficult to hook gigawatt projects up to the electrical system.

News and debates about the government’s current focus on solar power have overshadowed past successes in wind energy. India has more than 23 gigawatts of installed wind-power capacity, which puts it roughly even with Spain as the world’s fourth biggest producer. And Mumbai-based Suzlon is the world’s seventh-largest turbine manufacturer.

India has been able to develop its wind power in part because of long-term

government policies and financial incentives, as well as a growing interest from independent power producers and financiers, says Shantanu Jaiswal, lead analyst at Bloomberg New Energy Finance in New Delhi. But some of the concerns about solar power also hamper wind projects, which face difficulty acquiring land, encounter lengthy permitting processes and often have trouble connecting to the electrical power grid.

## EDUCATION OUTLOOK

Back on her leafy campus in Delhi, Srivastava and her fellow young faculty members are less concerned about big national projects than about producing their own high-quality research. They are lucky, they acknowledge, to work in one of India’s top federally funded universities, which has superior faculty members and equipment.

Others are not so fortunate. India has some 700 universities of varying quality, from the elite institutions funded by the central government to more than 300 state universities and about 200 private ones. “The landscape of science education is uneven,” says Sri Krishna Joshi, former director-general of India’s Council of Scientific and Industrial Research (CSIR) and former chair of the advisory committee of the University Grants Commission, which funds and oversees university education in India.

In the top institutions, he says, “science students are doing world-class research, publishing in leading journals and boosting the global reputation of our country”. National scientific research institutes and leading universities have all contributed to India’s growing strengths in research: the country’s output of scientific publications quadrupled between 2000 and 2013.

Even so, India is not keeping pace with some other emerging nations, which have increased their scientific output more quickly (see page 142). And the advances in India’s global science metrics mask some signs of declining quality in university science education, especially at the cash-starved universities funded by state governments that account for the majority of India’s science undergraduates, says Joshi. Publicly supported universities depend on the Ministry of Human Resource Development for funds, and the higher-education budget was hit by a 3% cut in the 2014–15 budget cycle.

“Lack of even bare, minimal and sustainable funds for teaching, let alone research, has seriously plagued the quality and standards of science education,” says Krishna Ganesh, a chemist and director of the Indian Institute of Science Education and Research in Pune, one of five top universities set up in India since 2006.

Many students at state universities are receiving a substandard education, says Joshi. “Here, there are no good science teachers, no good Indian textbooks, and most of the science laboratories are poorly equipped,” he says.



Graduates celebrate at the University of Delhi, a top institution. The majority of science students in India graduate from lower-quality universities that lack funding.

RAJ K. RAJ/HINDUSTAN TIMES VIA GETTY

“We are caught in a vicious circle of mediocrity,” says geneticist Deepak Pental, former vice-chancellor of the University of Delhi.

Most analysts are concerned over the plight of science departments in state universities. At the University of Calcutta, for example, even procuring a laptop involves endless red tape, says physicist Amitava Raychaudhuri. At some other institutions, support from funding agencies helps to purchase equipment, but there is a shortage of qualified faculty members to train the students.

Beyond questions of quality, the quantity of available university spots is a persistent problem. India has gone through a university building boom, but there still is a huge shortage of slots for students (see *Nature* 472, 24–26; 2011).

“There is a rise in the number of students going for higher education in India, which reflects the rising aspirations of its society. But this rise should be matched by better infrastructure and financial support,” says Joshi.

## RESEARCH INVESTMENTS

Investments in science have also dragged. India’s research intensity — the share of its gross domestic product devoted to research and development (GERD) — remains lower than those of many other nations, including Brazil and Russia. Twenty years ago, India’s GERD exceeded China’s. Now, it is less than half.

But those numbers do not tell the whole story, says Ashutosh Sharma, secretary of

the government’s Department of Science and Technology — one of India’s largest research-funding agencies. “The total funding is, perhaps, not as poor as it seems in terms of absolute numbers, because the number of full-time scientists doing research is also low.”

India averages about 4 full-time researchers per 10,000 people in the labour force, whereas China boasts 18 and nations with advanced science and technology sectors have around 80. “India spends about \$150,000 per scientist per year, which is probably not too far from the optimal levels,” says Sharma.

India’s notorious bureaucracy deserves part of the blame for the problems afflicting science education and research. The administrators of several state universities are political appointees rather than leading academics. “Often the appointed person has never been exposed to a good university in India or abroad,” says Kizhakeyil Sebastian, chair of the science-education panel of the Indian Academy of Sciences in Bangalore.

“There is over-bureaucratization within the universities and their controlling bodies,” says Pental. It often takes two years to recruit an academic after announcing an open post, which means that the best applicants can slip away, says Raychaudhuri.

The governmental quagmire has begun to affect some elite national research institutes, too. Of the 38 national laboratories that are part of the CSIR, only 25 have full-time directors. The rest are making do with acting directors, or temporary arrangements.

Even the CSIR headquarters in New Delhi has been without a full-time leader since January 2014. Interim director-general Madhukar Garg says that “the current situation is indeed challenging. CSIR is the backbone of scientific and technological research in the country. In case the prevailing scenario continues, it will affect the national innovation system as a whole.”

Sharma acknowledges that red tape is “all-pervasive”, but he says that the challenges are not bogging down Indian science. “In terms of output indicators such as the number of papers per dollar spent, Indian science is among the very top performers in the world,” he says.

And there are some signs that India might be slowing its debilitating brain drain. Although the vast majority of Indians who obtain science doctorates in the United States remain there for at least 5 years after graduation, the proportion has declined: from 89% in 2001 to 82% in 2011, the most recent year for which data are available.

Kaustuv Datta, a geneticist at Delhi University South Campus, is one of those who returned. Datta may “hate the red-tapism” at universities in India, but he still prefers doing research back home. “My parents are here, in India. And academics have a strong, positive influence on the next generation of students,” says Datta. “I wanted to make that contribution in India.” ■

T. V. Padma is a science journalist in New Delhi.