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India's innovation engines must raise their game

The number of prestigious Indian Institutes of Technology trebled in the space of a decade. The new arrivals have a lot of improving to do.

There probably isn't a country in the world that isn't looking to build or expand billion-dollar tech corporations. The United States and China dominate the landscape of 'unicorns', privately owned technology start-ups valued at US$1 billion or more. But now some of the most rapid development is happening in India.

According to government data, India recorded 44 new billion-dollar technology companies last year, compared with 10 in 2020 and 9 in 2019 (the country has a total of 83 unicorns). Some analysts are predicting that 2022 will see another surge, with new companies in financial, agricultural and educational technology joining new life-sciences companies, games companies and online marketplaces.

A proportion of the founders and staff of these companies are graduates of the swiftly growing and prestigious Indian Institutes of Technology (IITs). There were 7 of these institutions before 2008; by 2016, the number had more than trebled, to 23. This rapid expansion is the subject of a report by the country's Auditor General, published at the end of last year. It should make for uncomfortable reading for the eight IITs assessed, which were established in 2008–09.

These IITs are criticized for not meeting targets for research and faculty- and student-recruitment. All have been hit by infrastructure delays, and in some cases students leave after enrolling. This is deeply concerning, not only for the institutions themselves, but for the richly deserved global reputation of the IIT system as a whole. Together, the national and state governments and the IITs must turn things around — and quickly.

India's emergence as an engine in global technology innovation is entirely expected. For decades, students and staff from the first generation of IITs have excelled at US universities and in Silicon Valley companies, something that has been repeatedly acknowledged as "brand IIT" by business, political and scientific leaders, including former US president Bill Clinton, as well as Amazon and Microsoft founders Jeff Bezos and Bill Gates.

The founding vision of the first IITs in the early 1950s was to provide education and research in engineering and technology, with an additional emphasis on knowledge and skills in management and humanities subjects. The first IIT, at Kharagpur near Kolkata, opened in 1951, with 210 undergraduate students and 14 postgraduates. In 2021, more than 700,000 applicants competed for 40,000 places across all IITs.

> **"The newer IITs are beset by problems that threaten to limit their potential."**

Some graduates will no doubt want to follow in the footsteps of alumni such as Twitter chief executive Parag Agrawal, Google chief executive Sundar Pichai and IBM chief executive Arvind Krishna. But the overwhelming majority are building and working in companies at home. Although there are no publicly accessible pan-IIT data, Anurag Mehra, a chemical engineer at IIT Bombay in Mumbai, told *Nature* that "in the early years after the inception of the IITs and almost till the later 1990s, a very large fraction — sometimes as high as 60–70% — used to go abroad. Now the numbers are down to a few per cent."

Some in India want more of the IITs and their graduates to consider careers outside technology, and to do more to address India's socio-economic and environmental challenges. But the Auditor General's report shows that the newer IITs are beset by problems that threaten to limit the quality of their future expansion — and therefore their potential. In 2008, a policy was set to vigorously expand the numbers of IITs; by 2016, a further 16 had been established. The funding for all IITs subsequently rose, from 49.8 billion rupees (US$670 million) in the 2016–17 national budget to 83 billion rupees in the 2017–18 budget.

Last year's report looked at how eight IITs performed between 2014 and 2019. Some of their areas of research include 5G, mobile sensor network technologies, metal additive manufacturing, artificial intelligence, bio-inspired engineering, catalysts, energy and health care. But at four out of the eight, research was taking place without the strategic oversight of the Research and Technology Development Councils that each IIT was supposed to establish. Five of the eight did not set PhD enrolment targets, and the three that did fell short. Five received no patents on any of their inventions or innovations during the audit period, and none attracted significant external funds (such as from businesses). The report also found that in half of the institutions, around one-third of faculty positions were unfilled during the audit period.

In addition, the report says that all of the IITs assessed are experiencing delays to infrastructure, with construction of new buildings delayed in seven of the eight. Perhaps not surprisingly, students have not been coming. Only around one-third of an expected 19,000 students were admitted over the first 6 years of their operation.

Some of the other IITs (not assessed in the report) have taken steps to fund more multidisciplinary research, encourage start-ups and address a long-standing gender gap in recruitment of faculty members. IIT Madras in Chennai, for example, is attempting to raise $2 million for a new endowment fund to increase the proportion of women in assistant-professor roles from 15% to 20%. And last June, IIT Bombay received funding to establish the institute's first faculty-chair position to be held by a woman. Such practices need to be shared more widely across IITs.

It is true that high-quality universities do not become high-quality institutions overnight. For example, when the Nature Index compiled a list of some of the world's leading universities under the age of 50, around 70% were at least 20

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years old. But youth is not a reason for infrastructure delays, nor for failures in research governance. India's national and state governments must work with IITs to address the audit report's concerns quickly. All need to grasp the nettle so that the IITs can continue to provide science and technology leaders for India — and the world.

Webb telescope has beaten the odds to look like a success

Science will gain from the James Webb Space Telescope, but there are also lessons to learn from the project's epic management failures.

It was a big-science project plagued with so many problems that it seemed destined to fail. For years, the James Webb Space Telescope — an ambitious observatory planned and funded by NASA, the European Space Agency and the Canadian Space Agency — was the target of astronomy's most scathing jokes. Delayed for more than a decade owing to technical and management problems, Webb's development and operations budget ultimately ran to almost US$10 billion, far above the initial $1 billion estimated when the project was conceived.

Yet on 25 December 2021, an Ariane 5 rocket lifted into the skies above French Guiana and carried Webb into space. Within half an hour of launch, the telescope separated from the rocket. It subsequently embarked on an intricate dance of deployments to unfold major pieces, including a tennis-court-sized sunshield and a 6.5-metre-wide primary mirror. On 24 January, Webb reached its ultimate destination, an orbit around the L2, or the second Lagrange point (see page 495), some 1.5 million kilometres from Earth. Holding its sunshield behind itself like a giant umbrella to keep its mirrors and four scientific instruments in the shade, the telescope will now prepare to begin observing the Universe.

Webb was designed as a next-generation infrared telescope to succeed the Hubble Space Telescope. Between now and June — the earliest that science results are expected — the telescope will cool down to its operating temperature and start up and calibrate its instruments.

Remarkably, Webb has pulled off an essentially flawless deployment so far. Scientists and engineers are breathing huge sighs of relief. It's an apt moment to assess how other big-science projects can avoid the pitfalls that plagued Webb — and to look ahead to the astronomy that scientists hope the telescope will reveal. There are also management lessons to be learnt. For many astronomers working on an upcoming space mission, the number-one aim is probably to avoid the problems that bedevilled Webb. These boil down to two interconnected faults: the massive underestimate of the project costs and the failure to stop scientists adding a host of new technologies along the way.

> **"Scientists kept asking for more capabilities, and engineers kept adding more complexity."**

NASA gave Webb the green light in 2002, expecting it to launch within a decade. But throughout the 2000s, the agency and its main contractor, Northrop Grumman in Falls Church, Virginia, struggled to turn ambitious designs into functional hardware that could fly in space. No one had ever built anything like the enormous sunshield — made of five gossamer-thin layers that had to be folded for launch and then unfolded in space — or the similarly folded primary mirror. All had to be designed, built, tested and retested from scratch. Scientists kept asking for more capabilities, and engineers kept adding more complexity to satisfy them.

In 2010, an independent review, now a classic in the literature of project management, flagged fundamental errors, including the failure to produce multiple bottom-up estimates of the true cost of the telescope as time went on. (Even early on, few believed the initial $1-billion estimate.) The main problem was that NASA management had accepted an unrealistically low figure and had not adjusted its thinking adequately as time went on. By 2011, Congress was fed up with cost overruns and lawmakers threatened to cancel it. Ultimately, Webb cost NASA $8.8 billion to develop — nearly double the amount expected even in 2009. It is the most expensive telescope in history.

NASA has worked hard to try to avoid the pitfalls that afflicted Webb from affecting future missions, such as the Nancy Grace Roman Space Telescope. This is the big space telescope the agency is building to follow Webb, and should be launched in 2027. Managers on the Roman project have been relentless in their efforts to keep the mission to its cost cap, with the main extra expense so far the result of COVID-19-induced delays, which pushed costs up by almost $400 million to $4.3 billion. Project managers in other areas of science would do well to follow this model, and regularly acquire independent cost estimates, as well as periodic reviews as the Roman project managers have done, to be sure they remain on track.

Clearly, no one should ever build a telescope in the way NASA built Webb. But now that the observatory is in space and so close to being functional, it is time to sing its praises. Humanity has never built such an awesome machine.

With its gigantic mirror and sensitive instruments, Webb will peer at the Universe in infrared wavelengths. It will almost certainly — and immediately — smash the record for the most-distant galaxy ever observed, and study such galaxies for clues to the evolution of the Universe. It will sniff out molecules such as carbon dioxide and water vapour in the atmospheres of exoplanets, helping scientists to understand the chances of life on these other worlds. It will reveal the secrets of star formation by peering through the dust that enshrouds stellar nurseries and prevents them from being seen with other wavelengths of light.

In line with our support for open data, *Nature* reaffirms that the journal will have no embargo on any early-release science (data from the first five months of observations); nor on the first year of science, known as Cycle 1 of the General Observers programme. We can hardly wait for the insights that the telescope will bring.