Leading Science and Technology: Vision for the Future

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by
Varun Aggarwal, Co-founder, Aspiring Minds
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What India Needs to Do?

Let us move from the abstract to the concrete. What can India do to invigorate our research ecosystem? The government has taken several measures in the last few years. However, most of these have been "Band-Aid" solutions to fix bad policy rather than an attempt at structural change. What structural and policy changes would be actually helpful, at a national and institutional level? Let us discuss these now.

Focus on Universities as Places for Research

In India, four times as many researchers work in government research labs as in university labs. This contrasts poorly with countries that demonstrate the highest research output (refer Chapter 9). The world discovered long ago that productivity increases when faculty and stu-dents, together, take the lead in research work. The university-based research model creates high-quality research training and a continuous flow of new researchers.

The Indian government needs to promotes universities as the place to do research. A larger part of the current research budget should go to universities. A thorough audit of government laboratories will help identify where funding can be reduced and redirected. Labs that perform well can be retained and aided in growth. Those that are underperforming or engaged in obsolete areas can be phased out in due course. The government had good success in reforming the PSU sector. They have been reformed, prodded to become profit-able, and some were divested or even shut down. A similar campaign can help our research sector as well.

We must also encourage university/government partnerships. There is much potential for government labs with strategic goals such as DRDO and ISRO to interact with university personnel and embark on collaborative research projects for mutual benefit. We see models for such collaboration in DARPA and NASA, which offer funding in various problem areas through calls for proposals.

Make Institutions Autonomous, Independent, and Accountable

Government can also be helpful by allowing our research institutions greater freedom to make their own decisions. Government should not dictate how they should spend their money, how much to pay their personnel, how to manage promotions, and how or when to scale up. The research institutions and academics who are directly impacted by these decisions are best able to decide them. Furthermore, political interference on appointments and decision-making, besides being unhealthy and inefficient, goes beyond even the current ruling public charter. Such interference and micromanagement is demoralizing and deters the best people from entering the university system to pursue academic careers. This must stop.

With autonomy comes accountability. Our universities must justify their public funding against clear performance metrics. Public universities should be required to compete with each other for resource allocation. Such an approach to funding will help them improve themselves.

Autonomy begins with the governing board. The boards of public universities should be independent, choose their own chair-person, and decide the leader of the universities. Given that the universities are supported by public funds, government representation is proper. However, this representation should be a limited number of members, including both the central and state governments. The board should be primarily concerned with the institution's progress. They should be free to deliberate independently, balancing the views of all interested parties including the government, to steer the university along the correct path.

Consider a recent example from the University of California, San Diego. In 2012, the board appointed Pradeep Khosla as chancellor with a base salary incrementally larger than the salary paid to the previous chancellor. Gavin Newsom, California's lieutenant gover-nor and the government's representative on the board, was the lone dissenter. However, the

board overrode his dissent, citing Khosla's "proven background in fundraising and bringing in research dollars.… Chancellors make a difference, we have to recognize that." Furthermore, the board explained that the additional salary would be mostly covered by foundation money and not by taxpayer money. India's institutions would benefit from such freedom to make decisions without fear of government objection or reprisal.

Second, the boards have power over academic and administrative issues, but not financial issues. The government and the IIT Council makes all decisions on capital investment, salary guidelines, fee structures, and other such matters. Financial autonomy is key to making our institutions world class. Again, autonomy can be supplemented and buttressed by accountability. The government should set certain performance benchmarks in proportion to the funds provided. Accountability should start at the leadership and flow to every faculty member in the institute. The disbursal of future funds must depend on how well these metrics are satisfied. The government has already instituted a similar arrangement with the PSUs, where funds and autonomy are set in proportion to performance.

Overall, university finances should be run in a more businesslike manner, with line items detailing the profit/loss of various university operations. Instead of the present flat grant system, a more sophisticated accounting system will reveal what the government is really subsidizing: is it undergraduate teaching, scaling research, postgraduate programs? When each component is examined individually, the government can deliberate and decide what they want to subsidize and where they want to invest. In turn, this will force the institutions to examine their operations and programs more critically. They may even price their courses and programs differently for the public, creating a market.

These things cannot happen overnight. Until now, our universi-ties have had little experience managing their own finances, making businesslike decisions, and performing research administration. The drive for autonomy will be pushed back by decades if the universities mismanage themselves to the point where the government has to bail them out. Before we can hand over significant autonomy, we need to establish the right management structures and conduct proper training for administrative personnel. In my opinion, we should seek training collaborations with top universities abroad. Training partner-ships with institutions in the West and in South Asia will give our administrators a holistic experience. When Hong Kong University of Science and Technology (HKUST) was starting up, the governor insisted that the university head should be president of a top Western university. I do not think that we should set such preconditions for our leaders, but rather select the best person for the job whether in India or abroad.

India liberalized its economy in stages, allowing the market to react harmoniously. We should follow a similar path with our universities: limited autonomy leading eventually to full autonomy. Limited autonomy could mean approving budgets for different line items in the financial statement and adhering to particular overall performance benchmarks rather than analyzing every spending decision. Limited autonomy could also mean more flexi-ble salary bands, rather than the narrow ranges dictated by the pay commission.

The government should treat the liberalization of university system with priority similar to that it gave to economic liberalization. We need a great team to do it. As the government pursues limited autonomy, they must resist the temptation to make it a goal rather than an end. The divestiture of power should be the guiding princi-ple, with full autonomy as the ultimate goal. We need to plan for the future.

Our private universities require more autonomy as well. However, accountability is tricky in their case (see "Autonomy and Accountability at Private Universities").

Autonomy and Accountability at Private Universities

The Indian government also exercises control over private universities and institutions. The government places various restrictions on the programs they can run, the salaries they can award, the number of students they can admit, and the fees they can charge. There are also regulations on infrastructure—the amount of land and property required, and the kind of laboratories and classrooms. These regulations are not always optimal. Different institutions have different strengths and weaknesses, and should enjoy the freedom to make different trade-off choices based on their mission.

Besides, these regulations create space for corruption in regulatory bodies. Regulatory entities have often been accused of bad behavior. It is unclear whether government regulations have actually improved quality or if they have simply created an industry of higher education entrepreneurs who know how to lobby government agencies and bend the rules. These conditions dissuade able and well-meaning individuals from establishing new educational institutions because they do not want to deal with a corrupt system.

We might be tempted to think that we can solve this problem with the same remedy we prescribe for public institutions: autonomy and accountability. However, accountability is tricky in the case of private schools. Ultimately, they are only accountable to the students and parents who are their customers. In an ideal market system, poor performance would lead to loss of customer interest, fewer applicants, and declining revenues.

Education is not a perfect market entity, however. Consumers cannot easily distinguish between good and bad. We do not have objective measurable parameters for comparing institutions. Many universities make up numbers and facts on student placements, number of faculty, faculty qualifications, and collaborations. Others use showmanship and optics that have nothing to do with education or research: marble flooring, chandeliers, celebrity endorsements, and even foreign-accented teachers in advertisements! Consumers are often swayed by such gimmicks—especially the first-generation learners. Therefore, accountability is really difficult.

I believe the solution lies in creating a credible rating system for these educational institutions and widely disseminating the results to the public. The market itself cannot create healthy com-petition or control the quality of our universities and colleges. Government should not itself run the ratings system, but should create a market of credible rating agencies. The big four consulting companies, education research, and think tanks are natural candidates. The government has already done a similar exercise in credit ratings, establishing approved agencies among which companies and banks may choose their preference.

Once established, the government should mandate that all institutions—public and private—must go through the rating process. They should take it upon themselves to ensure that the school ratings are widely disseminated among the public, through newspaper publication and Internet websites. As the public becomes more aware of which factors indicate institution quality, we can begin to remove direct government oversight and regulation. The best processes for achieving this, and the measurements of effectiveness, would constitute a research project in itself!

Identify Areas for Excellence

No nation, institution, or person can do well in all research areas. Each entity operates according to their talent and comparative advantage. India can share in this world by identifying research areas in which to excel. Three principles can help identify these areas. First, we need only consider our natural strengths. Because we already have a large IT industry ecosystem, computer science is a natural point of concentration. In fact, computer science should be a research priority if we wish to preserve our edge—the dulling of which has already begun to show. Additionally, our demonstrated success in space research raises the opportunity to specialize in world-class instrumentation and equipment produced at a lower cost.

Second, we need to invest in new and emerging fields that show promise and potential to drive the next generation of innovation. Data science and AI are two such fields that have recently seen disruption. Given our IT industry combined with the aptitude of our citizens for computers and numbers, India could share in these fields. I also find that India has an aptitude for the quick and economical collection of data. Could we create large data sets for important problems, be uniquely positioned to solve them, and have all top researchers in the world work with us, our data set? Other important areas are biotechnology and neuroscience, where we do have a fledgling industry and ecosystem.

Third, we should identify areas for specialization by examining those areas that are of our own national interest. Defense research comes first to mind, as manifest in nuclear, mechanical, robotics, material, cybersecurity, and also data science. Another national inter-est is manufacturing and manufacturing processes, including allied fields. If we wish to successfully convince the world to “Make in India,” we should pursue research in production and manufacturing processes. And most importantly, we need to consider public health and medicine, where India has a long way to go.

But who decides in which areas India should invest? The biggest mistake is to leave it to a single politician, bureaucrat, or even academician. What is hot and not in research changes rapidly. Research progress is nonlinear: suddenly a process, technique, or area previously of little importance sees a breakthrough and becomes an area of great attention. For example, the academic community had largely lost interest in neural networks about 20 years ago. Now they have come to dominate AI after Hinton’s deep learning work. It has suddenly become the largest focus of investment in the field.

No single person knows all our strengths: they are many and decentralized. The government rightly has a voice on what is of national importance. However, there needs to be other voices, and decisions on narrow areas of research need to happen through a decentralized process involving researchers. Grant-making agencies allocate funds in focus areas. Researchers on the other hand have discussions and alert the program managers to promising areas where they could create new programs. As an area of investment becomes successful, we need to accumulate investment and effort in it and grab a leadership position. Similarly, the heads of universities and funding agencies can meet periodically, to discuss priorities and align goals.

The institution’s specialties should also be determined through a deliberative process involving the department heads and high per-forming faculty. This is a bottom-up, top-down process to identify areas of strength and build capacity to take leadership in it.

Accumulate Effort

To build leadership in an area, the most important requirement is a critical mass of researchers working collaboratively. When researchers combine forces, they make faster progress, can adapt to new methods, and can build on each other's successes. Successful and productive research communities guide the direction of research in the field. Impressed by their success, new talented researchers aspire to join them, they build their own forums such as conferences and workshops, and influence spreads to the industry. In this way, MIT, Harvard, and the United States in general have become doyens of new knowledge, amassing research success for a century or more.

One way to accumulate effort in identified areas is through mission-driven programs. Presently, DST runs about a dozen mission-driven programs including those in data science, clean energy, and supercomputing. Their nanotechnology program has been some-what successful in kick-starting quality research in this area. The number of programs is too small to be consequential. By contrast, DARPA has 100 program managers looking after 250 research pro-grams. They govern the competitive bidding process to accumulate effort in in their field. The United States dedicates considerable funding to all new promising fields, seeking to identify and extract their maximum potential. Some areas see success and draw more funding while others drop off to await some future breakthrough.

India could use more such mission-driven programs in narrower areas and problem statements, which could also be those of national interest. Worthwhile endeavors include cleaning the Ganga, decreasing pollution in cities, or effectively treating Indian strains of viruses. We can determine these areas of attention involving multiple area specialists and program managers, keeping them in steady rotation to ensure a steady stream of fresh ideas. The competitive grant process raises the bar, motivating people to do their best in writing a winning proposal. Such a process helps to accumulate efforts in areas of national interest and also attracts new talent. The further accumulation of funds, resources, and talent will be in the winning areas.

Currently, our defense and space organizations, DRDO and ISRO, respectively, have minimal interaction with universities. They should invite university researchers to help solve their research problems through call for proposals. This can help accelerate university research through supply of research questions, funding, and solution deployment opportunities. On the other hand, it will create local capabilities in the research areas relevant to them. We must note that defense-oriented research has led to some of history's greatest scientific successes, including innovations in air travel and the Internet.

Like nations, institutions also specialize and accumulate effort in those areas. No single institution can be good at everything. Within the fields of electrical engineering and computer science, the Princeton University is great at theory while CMU does very well in robotics, UIUC in building systems, and Berkeley in circuit theory. Our Indian institutions should also seek to determine their natural area of leadership through a collaborative process. Their specialty could be a function of their local strength, such as areas in which they have great researchers/funding already, proximity to certain industry, or problem space. They should accumulate faculty and resources in these areas. Institution leaders should utilize their wide networks to find champions in those fields outside the university and bring those people in.

A great way to accumulate talent and effort in new areas is to create new institutions that focus exclusively in the target field. These could be specialized institutions dedicated to neuroscience, biotechnology, and materials, among others. Google recently established a Google Brain Project, accumulating multiple star researchers in the field of machine learning to lead the effort. Allen Institute for Artificial Intelligence funded by Microsoft cofounder, Paul Allen, is another example. Such dedicated institutions have the potential to provide leadership in the entire field.

We must acknowledge a contradiction in the notion of accumulating effort in a particular area or creating specialized institutions: today, more and more research is multidisciplinary. In practical terms, this means that we need to build mechanisms for specialized institutions to work collaboratively on problems. There are many options to achieve this. For example, most important is that related institutions working in related fields should be situated in geographic proximity. In Delhi, we find IIT, AIIMS, and Delhi University institutions all in a similar locale. In planning new institutions, we need to consider geographic proximity.

Also, calls for proposals for interdisciplinary research will naturally incentivize people to work together. We should have interdisciplinary centers in the vicinity of institutions. They could house seed funding for interdisciplinary projects, equipment, support staff, and host talks and discussions. Champions recruited through a competitive process should run them.

Make Public Science Aware

Much of our efforts to achieve research eminence will depend on public awareness and support. Multiple stakeholders must coordi - nate to create greater public awareness about science and research.

For starters, the government should raise the profile of scientific research by including it in its strategic priorities and giving it a place in the national discourse. India's scientific achievements should warrant the same attention as our economic growth numbers, IT power, and start-up culture. Attention should not be limited to ISRO, as it is today. A few words from the prime minister each year could inspire many young people to pursue a scientific career. As the government talks about pollution, constructing toilets, and saving electricity, they should also talk about promoting scientific thinking. How they could attach the abstract idea of scientific thinking to tangibles—like Gandhi's charka—is something I will let them innovate upon!

We can also create awareness through our current educational institutions. Our school curriculum and books should properly cover India's historic contribution to science: objectively, not with jingo-ism. We must go beyond Arabic numerals and Pythagorean theorems to discuss the contributions of our civilization to science. A focus on our heroes and national pride goes a long way in creating role models and instilling the "can do" attitude in youngsters. Such an approach will have the added benefit of spawning new research into the subject, which the government can sponsor through targeted and competitive grants.

Our top institutions should undertake greater outreach efforts to advertise research achievement. They should establish an outreach office staffed by professionals to periodically arrange public talks, campus visits by school students, and even summer camps. Going beyond, they should establish permanent science-related attractions on their campus. For example, MIT has the MIT Museum which chronicles the scientific achievements of MIT affiliates. Why not establish museums at IITs or IISc? Why not go beyond merely copying MIT's ideas and think how an innovative twenty-first century museum can be that would capture the public's attention and bring them to campus? If Akshardham Temple and Kingdom of Dreams can be on the Delhi tourist map for religion and entertainment, can we not think of anything as engaging for our science legacy?

Here is also an opportunity for news and entertainment media. India's English dailies have sections for business, entertainment, and sometimes spirituality, but not for science. Mainstream TV has little any science-related shows—we can only reminisce about the Turning Point from 1991, with the charismatic Professor Yash Pal. We do have Discovery and the National Geographic channel, but these feature little Indi-led content.

In a free market, business must run by demand. However, the airwaves are a public good, and I would argue that the media has responsibility for promoting scientific education and research advancement. I would go further and argue that there exists a latent demand among the public for science programming. We need a champion within these media enterprises, an entrepreneur within, to take a risk and highlight it. The government could help here by sponsoring shows or providing subsidies or tax breaks to media businesses that devote a percentage of their programming to science themes. The government needs to play a key role to seed and build a market.

Make Our Institutions Attractive to Researchers

Above all, we must remember that research is only as good as the researcher. Just as a sports victory depends on the sportsman, research productivity and scientific advancement depend on the researcher. We must attract the best, highest achieving individuals to research careers. Presently we lose them either to careers in industry or to research careers abroad. Indian research careers are not attractive to our best students, who are much better rewarded financially by becoming a software engineer in an MNC, IAS officer, or a doctor.

We should wish that India becomes an ideal research destination not only for our own citizens but for the best researchers from around the world. The top institutions in the United States and Europe are home to a diverse array of talented individuals.

Immediately, we must concentrate on engaging our own best students in research. We are blessed with a critical mass of talented individuals who, when properly motivated, could drive the country's research agenda. Following this, we can market ourselves as a viable research destination to the best from the developing world and countries in geographical proximity. Countries in the Indian subcontinent, Southeast Asia, and Africa are natural choices. Not only would such individuals enhance the quality of our existing PhD cohorts, they would act as bridges to business and education opportunities in their home countries, breathing new life into our research ecosystem. Eventually we can expect to see researchers from the United States and Europe traveling here to work in areas where we have developed a strategic advantage and have accumulated success. Everything is possible, so long as we have both the intention and a defined policy to make it happen.

Awareness

We need to package and sell the research career in India. We can spark general interest by disseminating the research achievements of our top institutions through Indian and global media. Then we need to shine a spotlight on the researchers themselves. Our best researchers should be well-known national celebrities just like our star entrepreneurs, CEOs,

sportsmen, and actors. Institutions should connect their research authorities to media outlets who are searching for answers to topical issues of today. These will serve as role models and inspire our youngsters to build research careers in India.

They have an additional task in becoming good aggressive door-to-door salespeople. Our top institutions must cease their passive ways, waiting for candidates to apply. They need to visit and sell the position of research faculty to PhD students at the top institutions in the world. They need to highlight their strengths by making presentations, meeting individual PhD students, and convincing them to join us by making them feel "wanted." Similarly, they need to aggressively reach out to the top undergraduate institutions pitching their PhD programs, and also engaging them through talks. One should also consider a larger marketing campaign, like the Indian armed forces do today with a dedicated website, TV advertisements, and YouTube videos.

A large-scale structured internship program could help greatly. Our top institutions could recruit bright undergraduates to participate in research projects, working side-by-side with faculty and PhD students. All top universities run undergraduate research program for their students—MIT runs Undergraduate Research Opportunities Program (UROP),8 UCB has Undergraduate Research Apprentice Program (URAP), and UIUC has Illinois Scholars Undergraduate Research (ISUR) among others. Our institutions should aim to recruit hundreds of interns both from the institution and outside, at least at the rate of 1.5–2 per research faculty. The mechanism to allocate these interns should consider the will of faculty (autonomy), merit, and availability of funds. These interns will be our most likely future PhD students.

Such outreach programs would be mammoth in size. They require a dedicated office with professional staff serving equal duty to convince and cajole faculty to participate and also to reach out to external institutions for recruitment. Faculty needs to be sensitized on the importance of their participation in such programs, to build excellence in the institution. Any right-minded faculty would understand the importance of recruitment to multiply the success of their work. The institution should put in the right incentive structure to encourage faculty to actively participate.

Personal Benefits

Good advertising can only sell a good product. As we have seen, salaries for research faculty are lower than salaries offered by Google for a fresher software engineer. PhD student stipends are equivalent to IT service company salaries for jobs that require comparatively few technical skills. We need to more than double the PhD stipend and increase faculty salaries by 50–100 percent.

The long-term solution is through institutional autonomy and accountability. University leadership should have freedom to deter-mine salaries. If they do not provide what is needed to attract the best, they will be left behind and lose on reputation and funding. In the short term, our institutions need to find nongovernmental sources of funding to supplement faculty salaries. To recruit top candidates, institutions must offer attractive salary at the time of hiring. Supplemental funding could come from industry, alumni, and foundations in the form of endowed faculty chair positions.9 Our institutions should strive to add 100–200 chair positions over the next five years. These chairs could be awarded to currently high-performing faculty members and also as a lure to attract promising new talent.10 Similarly, institutions must raise money to double the PhD stipend for the top 25–50 percent of students.

Finding ways to augment salaries and stipends will not be easy. Salary supplements can be viewed with distrust by the government. The government tries to maintain a fine balance of salaries among various public officials. They see any attempt to get add-ons as a way to go around their regulations. Donors on the other hand are happy to invest in buildings, equipment, travel, and even salary for additional faculty and students. But they see the augmentation of salaries for faculty as a "waste."

This way of thinking needs to change. The government should see itself as subsidizing the faculty salary and being one of several donors toward it. In fact, they should encourage private fund-raising and then match over and above what the institute can raise from nongovernmental donors. Similarly, the private donors should con-sider that the government contribution toward salary is a subsidy— not necessarily the entire deserved amount. The fund-raising office of the institute should take it upon themselves to justify to donors why the salary of a chair professor should match global standards (in consideration of parity). They need to explain that in sponsoring a faculty chair position at MIT or Harvard, they would have spent a sum of 2 million dollars in the 1990s. A large portion would go toward salary with no government subsidy! On the question of supplemental salaries to sitting faculty, the office must clarify that they are funding a position, not a person: by virtue of their gifts, better and better candidates will fill the position in the future.

Salary augmentation may be the most formidable task for institutions. In the short term, however, there are many other things institutions can do to make themselves more attractive. These include well-maintained housing systems, medical facilities, child day care, and recreational facilities such as gymnasiums. These typically exist already, but are often over capacity and not well run. Outsourcing such functions might improve their quality and efficiency. Universities could establish an HR division responsible for campus life satisfaction— listening to grievances and addressing problems. At the end of the day (literally), we want our faculty to feel needed, respected, and cared for.

In addition to salary and lifestyle benefits, we cannot underestimate the importance of professional environment. Even by doubling faculty salary, we might not be able to lure a MIT or Stanford faculty here. Here, they would not have autonomy nor great students, great peers, a culture of high performance, or a helpful, nonintrusive bureaucracy. Poor salary and lack of personal amenities might be elimination criteria, but not necessarily a selection criterion.

The professional environment builds over time, by accumulation. It is a chicken-and-egg scenario: good faculty attract good students, good students attract good faculty, etc. Our institutions may not have this environment now, but they need to demonstrate that they are mindful of its importance and must demonstrate to potential hires that they have a vision of how to get there fast. If the university leadership shows commitment to this goal, and has a plan that lists definite steps and can show some progress, it might be enough to entice some risk-taking faculty to take a chance. Anyway, risk-taking researchers often produce the best success.

Another way to go about it might be to get at least a few distinguished faculty members to the institution by any means necessary: persuasion, pleading, enticing, or otherwise! These few are a magnet to their fans: young faculty members who are inspired by their work and who have a strong desire to work with them and learn from them. An MIT alumnus at a private research lab in India told me that he chose to come back because his adviser had come back for family reasons. Several of the adviser's students followed. If we can convince such people to come here and spend some considerable time, then faculty and student recruitment will become much easier.

Finally, we should consider our policies on attracting nonnative Indians. We discussed in the beginning of the section that Asia and Africa can be a fertile ground for recruiting research talent. Unfortunately, most of our government institutions scarcely recruit or fund foreign nationals as PhD students or faculty!11 One of the IIT directors told me that the minister says the Parliament will not allow public money to finance foreign nationals. We should learn from the United States here, the land of immigrants. Even in the current political atmosphere, the United States still actively entices the most meritorious to join their ranks. Investing in great research-ers means investing in India's future. In terms of economic and social benefits, and the enhancement of the Indian ecosystem, the nationality of the researcher is of no consequence. Science is a great uniter and an even better equalizer.

Connect and Spur Collaboration

Researchers are social people who thrive on interactions, relying on their peers and their world at large to discover what is new and worthy of pursuit. Researchers need to communicate face to face, often, for progress to happen. Tacit knowledge is essential to good research, and it can only be communicated and exchanged in spirited discussions and collaborative efforts in geographical proximity—not through tightly written technical papers or cursory e-mail briefs.

How can we facilitate these interactions? For one, researchers and their collaborators must have easier access to international travel. Lack of travel funding remains a top concern among faculty members and PhD students. Our researchers should be free to travel as much as their projects demand. The long-term solution for adequate travel funding is to allow faculty to secure the money through project grants from government agencies. In this way, travel money will correspond directly to the professor's ability to raise money for his or her project, which is also some indication of the worth of the project and there-fore the value of the travel involved. Furthermore, the terms of the grant should not unduly restrict the use of the money for conference travel specifically, but also allow some flexibility for visiting and inviting collaborators and guest speakers.

How much money should the agency allow for a given project? The onus on justifying the travel required falls on the proposal writer. However, it must be considered without prejudices associated with foreign travel grants. Travel is necessary in the work life of a true researcher. By my back-of-envelope calculations, a high-performing researcher and his or her students require more than double the current level.

In addition to supplementing travel funds, we must also lower the bureaucratic regulations and processes surrounding disbursement.

The government and the institution often place additional checks and balance on disbursement, even after approving the travel money. For example, they might necessitate getting an approval from a committee or the institute director for each individual trip. Once the funds are allocated, it is counterproductive to put such additional checks on the process. Researchers should be able to access the money without extra interference. Similarly, restrictions on airlines (such as the directive to fly Air India) must be eliminated. The government should rather create incentives for flying Air India—perhaps in the form of bulk discounts—not mandate it. For visits of foreign researchers, we need to ease the process of getting a visa.

Establishing travel money as a component of project grants may take time. In the meantime, we can find some interim solutions. For example, currently our institutions allocate travel money to each faculty equally. Meritocracy is a better system for allocation, based on factors such as project money raised, number of active PhD students, peer-review ratings, and so on. High-performing researchers deserve a greater portion of available travel funding for the simple reason that they make more productive use of the funds. Similarly, PhD students should also be subject to the merit system. If a student travels one time to an international conference for a great paper, he or she should be assisted with more funding, not eliminated from consideration because he or she used up his or her single allotment.

Governmental and institutional funds need to be made available for inviting international collaborators and guest speakers, together with mechanisms to give it out meritocratically. More importantly, providing reasons why any star researcher would want to travel here is the tough part. What does our present research ecosystem offer to world-class researchers? One possible incentive is money. China and Singapore among others have delivered truckloads of money to institutions such as MIT (and the faculty) for their faculty to come and participate in various programs. I would say we should not buy the vanilla money option, rather combine it with innovative pro-grams. For instance, create a pot that researchers from India and abroad could access jointly for research purposes. The Indo–US Science and Technology Forum operates in this way.

World-class researchers will visit India of their own accord if they think that their investment in time will pay dividends in their research. They can come for our unique research work, problem areas, data sets, forums, and lower costs. A “me-too” approach will not get us far. Consider that the major conferences and workshops were conceived and took place outside India most of the times. Replicating conferences and workshops in similar areas is useless and will garner no interest. But are there gaps to fill? For example, discourse in the area of assessments (my own specialty) mostly takes place in the pages of journals. The field has hardly any conferences. This is an opportunity to take the lead by raising funds and setting up a global program committee to organize and run it. Another example is Learning@Scale conference launched in 2014 buoyed by new research questions and answers MOOCs, such as edX and Coursera, offered. We can find a new or underserved area as well. If we can create recognizable value in our work and forums, the global community will not require extra incentives to come visit us.

Geographically, we need to “look East” in our global collaboration strategy. China, Singapore, Hong Kong, and South Korea have some very highly regarded universities. These countries are in near geographic proximity and have lower cost structures than the European and American universities. They are also more hungry for growth than their Western counterparts are. Enacting programs that could spur people exchange, talks, visits, and collaborations would help us widen our scientific research ecosystem.

Of course, collaboration is not merely an international affair. We should seek to spur collaborations and connections among our own Indian researchers. Simple things as shared cafeterias, inter-departmental luncheons, and various types of social events at our institutions can go a long way. Furthermore, we should not underestimate the importance of informal interaction between faculty and PhD students. Encouraging informal interaction is important in that it encourages and leads to formal collaboration.

Interuniversity centers, conferences, workshops, and summer schools can help spur collaboration among institutions. One novel idea is the National Mathematics Initiative. Established by SERB and led by IISc, it seeks to spur interdisciplinary research through work-shops, summer schools, and compact courses. Indian and international researchers alike participate. It chooses a theme each year and then accumulates effort around it. If we can multiply such initiatives as this, under the direction of faculty directors who are enthusiastic, engaged, and well supported financially, then we will witness another positive step in the right direction.

Bring Speed and Efficiency

Researchers work best when they can work with speed and efficiency. One major roadblock is the difficulty of procuring and accessing instruments and materials. Most often, the reason is the bureaucracy with their associated committees and tenders. It all needs to go!

Excess of regulation stifles performance. Researchers should be entrusted with the independence to spend their allotted equipment funds with speed as needs arise, with the understanding that their purchases are subject to audit. Institutions need to establish procure-ment and financial diligence team in place, such as exist in many global corporations. They should monitor any instances of faking purchases or doctoring receipts and take due action as required.

In the field of research, the wisdom of buying any particular instrument at a particular cost is a tricky arena. The question of value is highly ambiguous in the world of super-specialized instrumentation, given the subjectivity in instrument performance. Furthermore, remember that much research takes place through trial, error, and hacks in instrumentation. Identification of the most suited instrumentation must be left to the researcher himself or herself out of deference for the trust that has been placed in him or her by the grant-making body. Additionally, an institution could establish a peer-review system to determine what is within the norm and provide feedback to researchers.

Such a system with procurement and financial diligence team will work well. Oftentimes, the mere existence of such bodies serves as a sufficient deterrent to fraud. Besides, even absent such systems, the waste or misappropriation of funds will be reflected in the researcher's work, thereby jeopardizing future grant awards. And let us never forget that the most powerful deterrent of all is the loss of respect the researcher would suffer in the eyes of peers.

The system may still experience leakage. As people will never be perfect, we must accept a certain degree of fraud. If leakage remains around 5 percent, it is a small price for the benefit of the 95 percent who are pursuing their work conscientiously and creating value for the economy and society. Anyway, why should we assume the government oversight boards are not themselves fraught with corruption? Are we confident that the multiplicity of bureaucratic committees and overregulation has actually reduced waste, or even slowed it down?

Researchers have difficulty procuring instruments, but they also have difficulty in using the instruments that are already available. This is due to the lack of well-trained staff who operate and maintain the instruments. Well-paid and skilled technicians are indispensable for the efficient use of sophisticated instruments. Without such personnel, institutions cannot even realize the ROI on the purchase of the instrument. They ensure ease of access and ease of use to the entire university community. Without such personnel, use of instruments is often limited to one or two faculty with some pre-existing knowledge of the materials. Additionally, a trained staff prolongs the life of the instrument and learns the nuances of the instrument to use it more effectively and for various purposes. They free the researcher from having to divert his or her time away from his or her research in order to learn how to operate the machinery himself or herself.

Last but not the least, the access to instruments should be widely open. In fact, many university instruments sit idle or are used 10 percent of the time at most. The instrument should be made accessible to all faculty and students in the institution. They should be able to block times to use the instrument. It should be also opened for commercial usage and academics at other institutions at a price. In case of excess demand, any of the regular prioritization methods may be used which takes into account precedence, purpose, and volume. This constitutes a potential untapped revenue source.

Create Research-focused Universities and Leaders

We need to create great research institutions. They must be laser focused on becoming research leaders, endowed with all the resources they need to execute efficiently. All the interventions dis-cussed until now can only be implemented through such institutions. We can reinvigorate the institutions we have already and also build new ones. It is not merely wishful thinking: looking around we can see examples of both. In China, SJTU has existed since 1896. Then in 1998, the school underwent a transformation that now places it among the top 150 institutions in the world, with a ranking of 16 in engineering. HKUST was formally launched in 1991 and is today the 31st university in engineering. In science and social science, it ranks between 101 and 150.

If our institutions are to excel to world standards, they must be led by individuals whose key focus is to advance research. This goal should be their prime motivator. They should not be bogged down by day-to-day administration such as coordinating teaching, regulatory reporting, facilities management, and admissions. This is where a lot of time of our university leaders go today. A strong leader must delegate the administrative tasks required to maintain status quo while he or she devotes his or her time 24/7 to pondering and advancing the vision around great research. In business terms, the relationship between the leader and his or her sub-ordinates should be like that of the CEO and the COO. Building new research programs, recruiting top research faculty, building research centers, raising money for research, and institutional collaborations—these things exclusively should be his or her domain.

And he or she needs to "own" them by accepting both responsibility and accountability.

These leaders must be able to articulate clear goals of where they want the school to be in 5, 10, and 20 years. Such goals can be a mix of outcome and input metrics. Outcomes can be citations, disruptive research results, IP generation, industry collaborations, press coverage, awards, and recognitions. Input metrics can be the number of schools, departments, annual budgets, funding raised, profile of faculty, number of international students, number of international trips, international collaborations, and research facilities. Many of these things are subjective evaluations, and not easily quantified by numbers.13

The university requires periodic research evaluations and bench-marking to determine how well it is achieving its goals. Such evaluations can be done through a combination of self-evaluation and evaluation by the university management, as well as external reviews, both from academia and industry. Evaluations should follow global standards, though informed by our local needs and focus areas. Lately, India prefers to reject global standards, whenever our institutions rank very low according to them. Programme for International Student Assessment (PISA), a test of school student achievement worldwide, recently gave India a low score, as did an international measurement of world universities. India responded that the tests do not align with India's circumstances. I would agree that benchmarking methods must be constantly re-evaluated and adjusted, and must take into account local conditions. However, criticisms and adjustments must be undertaken

scientifically, not politically. I doubt India has such a scientific proposal. The global parameters are 80 percent good enough.

Evaluation and benchmarking should be the domain of an exclusive university office that reports directly to the university leader. The university board as well as other stakeholders should have ready access to these reports, so that they cannot be censured by the leadership. The importance of such an office cannot be overstated. By these measurements, we will hold the university leadership accountable for performance. We have a good example in SJTU. It established the Office of Strategic Planning (originally the Office of Policy Studies in 1999) to take on these responsibilities and support the university to become a world-class institution.

The final ingredient for spurring research progress in India is "research in research." We should embark upon a continuous scientific movement to understand how to best align our institutions to achieve scientific advancements useful both to ourselves and the world. This book is one contribution to such a movement. We need to learn from the examples from all the world-class universities across the globe. Also, we need to take account of our own particular needs, challenges, and strengths—through continuous experimentation, pilots, and analysis of results, we will learn how to move forward with our scientific agenda.

Notable examples include Philip Altbach from Boston College who has done substantial work in international higher education, some concerning India. Jonathan Cole of Columbia University and Henry Rosovsky of Harvard University have written books on the new American University and how to run a university, respectively. The Graduate School of Education at SJTU did substantial work on Chinese science and technology policy in the early 2000s, including how to develop world-class universities. Their work led to the Shanghai World Class University Ranking System, which has become a global standard today. India requires a similar concentrated research effort in deciding our science and research policy. Funding agencies, university leadership, and faculty need to work together to make this happen.

And while we think about the big picture, we must begin putting the bricks in place. A successful, future-oriented university is a well-structured university, with professional offices for industrial outreach, marketing, fund-raising, and alumni affairs. These tasks are critical and cannot be the domain of a few professors or devoted alumni. They require dedicated offices staffed by professionals who are answerable to the university leadership for their results. At the top of these efforts sits the university leader. These engines of growth must be his or her charge.

Nongovernmental Action

The Indian institutions that we have been discussing are public institutions. Harvard University, MIT, and Stanford University are all private. One professor remarked to me that if one private university in India could show the way, it would transform the Indian research ecosystem forever. I could not agree with him more.

There have been some serious efforts at private higher education in India recently. However, most have focused on teaching, while others seek to fill subject matter gaps such as in social science. None of them was designed for pioneering global research. An Indian private research university is an idea whose time has come. Three to four experiments must start, and then some of these will succeed. I feel confident that there is sufficient interest from wealthy private individuals within India as well as Indians abroad who would support such a school. We are merely waiting for such higher education entrepreneurs to emerge and take the reins. In this book, he or she will find the justification and the blueprint for making it happen.

Similarly, there is opportunity to create world-class private research laboratories. IBM Research Labs, Microsoft Research Labs, and the erstwhile Bell Labs, have produced great and impactful innovations. They run on huge budgets: Microsoft Research Labs is estimated at $500 million each year and IBM Research Labs at a billion dollars. Some Indian companies have attempted to establish private labs, and some labs have attempted to extend their operations here from abroad, but these efforts have not seen enough success. These need to be reinvigorated to become world class. We need to learn from the recent nonuniversity private research efforts like SpaceX, which have succeeded in doing the impossible.

Further, private players have intervened and impacted in areas such as policing, food security, and primary education, which are traditionally in domain of the state. They are capable of similar impact in progressing research. They can help with evaluations particularly. They can be watchdogs and advocates. India could use an Annual Research Status Report similar to Pratham's ASER and Aspiring Minds' employability report. Such evaluations would have to be based on data, and fortunately, substantial relevant data is already available in the public domain. Based on its findings, the organization can exercise its advocacy role by exerting pressure on the state and institutions for reform. The organization can also act as a rating agency providing feedback to individual institutions, driving competition, and helping optimal allocation of resources by merit.

Private organizations can provide similar services in consulting for research benchmarking and policy interventions. Such services would be useful for government universities to continuously improve, and private universities that are unsure

about how to go about establish-ing research programs, even if they want to. When I was at Queensland University of Technology (QUT) in Australia, I viewed a presentation from an education-consulting firm that was engaged in this type of work. In fact, QUT had hired the organization to rate it on various indices of excellence in higher education.

The scope of potential activity for private players is limited only by the creativity of individuals. Here are some more examples. Private actors can help research philanthropy. They can help donors find the best programs for their money and interest. Many such organizations operate today in the CSR space, helping funding organizations find the right NGOs. Private actors could create dedicated media companies around Indian science, whether newspapers, magazines, apps, or websites. Other companies could help identify and place PhD students and faculty. The possibilities are endless.

Furthermore, philanthropists can do more than just provide research funding. They can help create incentives and shape the market. Although these functions are also considered the domain of the state, philanthropy can use the power of wealth to influence change. They could create awards and provide monetary incentives for great research. They could help create social respect for researchers by promoting star achievers and recipients of funding through public talks and interviews. They can enable the ecosystem. They can do so much more than just write checks.

Promote Science Entrepreneurship

Indian companies should be second to none. We do not need to merely copy Western models. We can have original ideas that reach the global market. We can create innovative new companies based on true scientific and technological advancements. I urge my entrepreneurial brethren and entrepreneurs-to-be to take up science entrepreneurship. With sound business sense, they will discover a large market, greater value, greater global appeal, and higher returns, than if they continue to pursue the same old, same old.

We need to connect PhD students to entrepreneurship. Currently we steer primarily undergraduates to entrepreneurial careers. A better focus would be on those who actually do research. We could have business and entrepreneurship courses within the PhD curriculum. Departments could host talks with investors and entrepreneurs at which PhD students could showcase their work. We should also encourage PhD students to undertake internships as part of their PhD study.

These efforts will build a bottom-up supply of interested individuals. But the ecosystem needs to respond. This is by providing funding for science entrepreneurship by investors who value innovation, respect the research process, and are patient in undertaking long-term, risky propositions. High net worth individuals should establish funds, incubators, and accelerators for innovative companies. If we can achieve one great success story, it will inspire the market to follow. Unfortunately, today the world seems to believe that we do not create next-generation start-ups. If we have the courage to invest and try, we can change this perception.

Creating competitions and awards for innovative companies can help. India does have forums for “innovative,” but these mostly cater to innovation in the business sense. We need competitions that recognize scientific and technological innovation. Competitions excite people to tread unknown territory—and if the competition holds out awards of funding, there will be great response. They also bestow important social recognition and succor to entrepreneurs who are dedicated for the long haul.

Science start-ups are an essential part of the research ecosystem. They are integral to realize the economic and social benefit of research. They show the public and the government the value of research, which helps build the case for continued support.

Find New Creative Ways

So far in our discussion of how to improve the research ecosystem, we have focused on proven measures of success for which there exists strong evidence. Other countries have faced problems similar to us and have overcome them to create great research programs. While all these solutions hold promise, we are not limited by them. Numerous other possibilities exist for innovation in the pursuit of strong research programs. We can give the world new ways of doing research more successfully and develop unique methods and strategic initiatives based on our unique strengths.

In this section, I will let my pen loose and toss off several such ideas and suggestions. Some of these ideas might sound half-baked, but they might just ignite a spark.

The New PhD

In the last two decades, access and communication have become infinitely faster thanks to new communication technologies. We no longer have to wait weeks or months for the latest research literature, spend extensive time manually marking corrections in documents, or for correspondence from colleagues. Regardless, the duration of the PhD degree has not decreased, nor has the quality of the PhD thesis improved. In fact, in the field of computer science, I find that theses

written in the 1980s are deeper than many of those written today. It seems we are set in a system that is resistant to change. For some reason, we begin with the assumption that the PhD will take 4–6 years, and then the system works to fill up the time.

But is it all necessary? More and more people think not. Can Indian institutions demonstrate that PhD can take less time—say three years—without compromising quality of work? If one institution were bold enough to take on this challenge, they might just prove it to the world. For ourselves, it will be greatly helpful since the long duration of the PhD degree is a top deterrent for Indian undergraduates. This experiment is an opportunity in waiting.

Here is another. Today, substantial research happens in industry. In my company, I employed at least two people whose research output and results would have earned them a PhD from a world-class institution if they had performed the work there rather than here. But of course, no university will award them academic credit for these efforts. They cannot do research and teach in a university without a PhD.

Why not have a "fast-track" PhD program for people who have performed substantial research—enough to fulfil the typical requirements—outside of the university environment? In a year or two, they could satisfy their coursework and write their thesis. It is a win-win. The individual can move ahead in his or her career, industry can attract smart researchers, and universities can get a stronger supply of PhD students. These are just two ideas to create a smarter and more outcome-oriented PhD program.

The New Citations

We traditionally measure research impact by citations. However today citations come in many forms: dissemination aka Twitter, LinkedIn, one's homepage, and networks specific to research such as ResearchGate. These have become favorites of industry. We can aspire to develop new ways of measuring impact that take into account number of tweets, number of downloads, number of likes, etc. This type of communication may have a large impact on people's lives. Here is an opportunity to take lead in creating such impact and measuring it.

Let us also consider the research paper itself. Are there new kinds of papers, just as there are new forms of citations? Already we see how the presentation of content has changed in newspapers, TV, and radio. Should research papers change too? In academia, many conferences in data science and computational biology request data sets and algorithms for verification. A leading data science conference, KDD, requires a short video on paper. Authors compete based on the number of views on their video on YouTube. These are incremental steps but suggest that the time has come for a change. What other new ways can we come up with to present research results for better and wider consumption? Could we use ideas from design thinking?

Network of Private Research Colleges

India has 3000+ private engineering colleges. Today, these focus primarily on teaching. Can they undertake research as well and become viable options for our high-quality PhDs, within their current budgets? They can if each chooses one research area in which to specialize and attracts 5–10 high-quality research faculty. They can choose their areas according to their strengths: geography, tradition, current faculty specialty, or connections to industry. This is a small measure easily achievable within their budgets (costing perhaps a couple of crores annually—roughly $300,000) and could create real output by realizing a critical mass in a single field. Together, they could accommodate 30,000 PhDs in research. Such a program would have a positive effect on teaching quality and reputation, and would inspire more undergraduates to pursue PhD study. Furthermore, these colleges would comprise a network, collaborating with each other on multidisciplinary research. The many colleges I talk to are looking for new things to do. Some would embrace this idea enthusiastically. But they need competent guidance.

The New Research Places

I have often wondered why we need large sprawling campuses to house our new research places. Private labs exist in compact buildings in industrial areas. MIT exists like a set of buildings within the city. PhD students are typically blind to the campus and only see the path from their dorm to their lab! We should consider housing new research institutions in more compact spaces, which offer both functionality and savings. This can help us scale fast and invest in only what we need to get the maximum bang for the buck. Can government change their regulations regarding the physical campus? Can we experiment with private setups that do not require govern-ment approval? We can more easily change government regulation if we can first offer an example of efficiency and success. And here is another thought: what is the structure of the new research place in our age of mobile communication and virtual reality? I suspect that the school of the future would be unrecognizable to us today.

Crowdsourcing Innovation

We find it pays great dividends to ask the crowd—the people at large—how to solve a problem. People engaged in other fields can sometimes solve a problem that confounds practitioners in the particular domain. This should not be surprising, given that they bring a fresh perspective and experience from their own field to the problem. The wider community is great in generating different ideas and approaches to problems that the experts can then develop into full solutions. This is not the traditional way of doing things in the typical research institution. Instead, a single researcher along with his or her student thinks about a problem and attempts to solve it. They do not involve outsiders. At Aspiring Minds, we have begun involving the "crowd." For every new problem we pick to solve, we do a hackathon/competition of kinds. Participants from multiple teams generate good ideas and then the research engineer involved takes one or more to fruition. Can our institutions find mechanisms to involve crowd intelligence in the work of our researchers, perhaps by providing digital platforms and services? Can they determine issues of attribution and IP in such cases? By reaching beyond traditional knowledge, we could probably do better and faster research, with more chances of breakthrough.

Equipment Manufacturing and 3-D Printing

India has connected strengths and weaknesses. If we can learn to address our weaknesses by applying our strengths, we will find our-selves on a fortuitous path. For example, we can build things at low cost, but our researchers suffer from lack of components and materials. Today, 3-D printing is revolutionizing how we think about lab equipment. You no longer buy the equipment, you print it! Today, you can print car and airplane parts, surgical instruments, and organs! Can India take a strategic bet in 3-D printing technology? If successful, we could democratize equipment availability for the world. If we developed a core competency in this technology, we could help researchers everywhere. This could provide a great fillip to applied research by making availability of customized components fast and with quality.

I am confident that India can become a leader in science and technology. This is the most opportune time to reinvigorate our research agenda—it is now or never. We need to take ownership, set our goals, and intervene according to the stated design principles. This is our responsibility to India and to humanity.

Principles for Digital Development

The following nine "living" guidelines designed to help digital development practitioners integrate established best practices into technology-enabled programs.

1. Design With the User: User-centered design starts with getting to know the people you are designing for through conversation, observation and co-creation.
2. Understand the Existing Ecosystem: Well-designed initiatives and digital tools consider the particular structures and needs that exist in each country, region and community.
3. Design for Scale: Achieving scale requires adoption beyond an initiatives pilot population and often necessitates securing funding or partners that take the initiative to new communities or regions.
4. Build for Sustainability: Building sustainable programs, platforms and digital tools is essential to maintain user and stakeholder support, as well as to maximize long-term impact.
5. Be Data Driven: When an initiative is data driven, quality information is available to the right people when they need it, and they are using those data to take action.
6. Use Open Standards, Open Data, Open Source, and Open Innovation: An open approach to digital development can help to increase collaboration in the digital development community and avoid duplicating work that has already been done.
7. Reuse and Improve: Reusing and improving is about taking the work of the global development community further than any organization or program can do alone.
8. Address Privacy & Security: Addressing privacy and security in digital development involves careful consideration of which data are collected and how data are acquired, used, stored and shared.
9. Be Collaborative: Being collaborative means sharing information, insights, strategies and resources across projects, organizations and sectors, leading to increased efficiency and impact.