Spotlight

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Chemistry in India—Unlocking the Potential**

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In inviting us to write an Essay on Chemistry in India, *Angewandte* has presented us with an unusual challenge that has prompted discussion and much introspection. Chemistry is small in its unitary philosophy, but it is also a large central discipline that is ever expanding into biology and materials science. It plays a significant role in academia, industry, and public life. While its advances can be as exquisite as in any other science, the subject is of utmost importance to the economic well-being of a nation. For example, the production of ethylene or sulfuric acid is a good index of the economic development of a country. India is an old, large, and complex country with many hidden talents and untapped potential. It yields its secrets to outsiders only with difficulty. But it is also a very young and scientifically "small" country that is trying to bootstrap itself into the future within the "constraints" and advantages of a lively, chaotic, and still-evolving democracy. Its mindset is changing rapidly from an inward-looking and feudal attitude—a consequence of over 400 years of external domination and colonialism—to its former ethos that is holistic, inclusive, and outward-looking. The present status of chemistry in India and any prognosis for its future growth and development depend on historical, social, cultural, economic, and scientific factors. This is an area where two rather complex systems, India and chemistry, are interacting with each other. The scope of this Essay is therefore open-ended.

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Between independence in 1947 and the late 1970s, India faced economic deprivation and resource scarcity; Indian chemists learned to make do with what was available and research problems were defined accordingly: small in scope and limited to the art of the possible. Consequently, we missed the revolutions in chemistry that occurred elsewhere in the 1970s and 1980s, made possible by the ready availability of NMR spectrometers and single-crystal X-ray diffractometers. All we could do in this period was to set up a dozen or so "sophisticated" instrumentation centers in different parts of the country as service facilities. Not unexpectedly, the overall impact of these centers on the quality and quantity of scientific output was not significant. Scientific growth in chemistry was not commensurate with India's potential in terms of its human resources.

Scientific research, anywhere, is critically dependent on the quantity of public funding and on the quality of science education. The former is needed to create infrastructure, whereas the latter provides the pipeline of students who wish to pursue research as a career. Any discussion of contemporary chemistry research in India begins, therefore, in the early 1990s, when the Indian economy underwent a major transformation from being a protected one that shunned imports and emphasized domestic production, to one that attempted to progressively integrate itself with the global mainstream, in terms of trade, finance, and business. Two decades later, India has become one of the fastest-growing economies of the world. Yet, the country still struggles to balance, in a single generation, the aspirations of a burgeoning middle class of over 300 million with inclusive development that takes into account the rest of our population, which is predominantly poor. The progress of chemistry in India, in many ways, mirrors the growth of the Indian economy. There have been significant advances in some areas and glaring deficiencies in others. There are many lessons to be learned as India copes with social and cultural turbulence, the inevitable consequence of rapid economic change.

The Government of India continues to be the major provider of funds for science and technology. By 2005–2006, 70% of the funding was from the Government, and the remainder from industry. This is lower than the 86%

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Government investment in 1990–1991, and shows a progressive increase of investment from industry in the period following economic reforms. The major Government funding agency for chemistry research is the Department of Science and Technology (DST), which was created in 1971. The Science and Engineering Research Council (SERC) of the DST was set up in 1974, and until very recently, was the major channel for research funding, when it morphed into the Science and Engineering Research Board (SERB) that has enhanced financial and administrative autonomy. The SERB (like the SERC in its time) operates through a system of Programme Advisory Committees (PACs) that are responsible for evaluating proposals through a peer-review process and recommending appropriate levels of funding. This apart, many other agencies of the Government also fund chemistry research. The largest among them is the Council of Scientific and Industrial research (CSIR), which apart from funding its own laboratories, also supports some university research through its extramural programs. The CSIR also administers the National Entrance Test for admissions to the PhD programme and provides fellowships to qualifying students to pursue their research in any institution of their choice. This unique way of funding students has worked well and is worthy of emulation by other countries. The Board of Research in Nuclear Sciences and the University Grants Commission also fund chemistry research.

The decade since 2000 has seen exponential growth in investments in research and education. Research expenditure nearly doubled from $12.9 billion in 2002 to $24.8 billion in 2007, and further to $41.3 billion in 2012 (on the basis of purchasing power parity). Around 50 new universities and institutions have been started. These include 5 Indian Institutes of Science Education and Research, 9 Indian Institutes of Technology, 16 Central Universities, and several National Institutes of Technology, and National Institutes of Pharmaceutical Education and Research. There has been a concomitantly large induction of young chemists in teaching and research in these institutions. Funding is in the form of grants to individual project investigators (PIs) and to large interdisciplinary teams involved in Mission Mode projects. Above all, there has been an increase in the enrolment of students into PhD programs, even drawn significantly from regions of India where education itself did not have a serious foothold in former times.

As far as research output is concerned, the results of enhanced investment are tangible. India's share, which showed a downward trend in 1981–1995, started to rise and the country now accounts for 3.5% of world research output, occupying ninth position. In chemistry, India attained fifth position, overtaking countries like the UK and France (Figure 1). The recent years have also seen increased international collaboration in chemistry (18% of total output during 2006–2010). The USA is the most frequent collaborating partner (4.2% of total output) followed by Germany (2.9%).The proportion of papers with authors in India in prominent international chemistry journals ranges between 1% and 7%. During 2007–2011, the percentages are as follows: *Angew. Chem.* (1.1%); *Phys. Chem. Chem. Phys.* (2.2%); *Org. Lett.* (2.5%); *Langmuir* (2.9%); *J. Phys. Chem.*

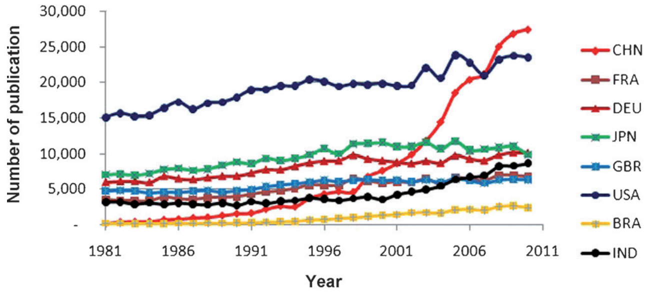

Figure 1. Chemistry research output of selected countries (number of papers per year).

C (3.8%); *J. Phys. Chem. A* (4.0%); *Inorg. Chem.* (5.0%); *J. Org. Chem.* (5.2%); *Dalton Trans.* (5.4%); *J. Phys. Chem. B* (6.5%); *Cryst. Growth Des.* (7.0%). While these figures may look promising, we feel that they are less than what they ought to be, especially when public funding for research has been generous. We are confident that more funding in more institutions will be possible in the future in single-investigator, international-collaborator, and multi-institutional consortium-type projects that include industry. Resources are not a constraint for the growth of chemistry in India, as they were in the 1970s and 1980s. So what is holding back the promise of chemistry in India? What is its true potential and how do we unlock it? Some of the causes that inhibit Indian chemistry reaching its full potential are cultural. Others are systemic. We shall try to address both.

A sound system of undergraduate education is a sine qua non of research excellence. Most Indian universities have had to contend with increasingly large numbers of aspiring students. Consequently, they ceded undergraduate education to smaller affiliated colleges and restricted themselves to postgraduate instruction and research. These affiliated institutions lacked funds, quality teaching staff, and research focus. They were also particularly vulnerable to political interference. It is no surprise that the quality of undergraduate training deteriorated rapidly. One of the casualties of the declining financials of affiliated colleges was the virtual elimination of laboratory instruction at the bachelor's and master's levels. This has had a telling effect on the preparedness of the students for research. There has been an attempt to bring back some undergraduate teaching into the ambit of a research university campus in some of the newly created institutions; however the numbers are still too small to make any noticeable impact. Most Indian universities have also had to battle with the competing demands of quantity and quality, in other words, the trade-off between equity and elitism in education. This battle is not likely to see any resolution soon, given the enormous diversity of the Indian population in terms of religion, ethnicity, language, class, and caste and income levels.

Another limitation of Indian chemistry is that it is too isolated and insulated. Geography and economics have limited the ability of Indian chemists to be widely visible in international forums and scientific collaborations. Chemistry research is organized according to the classical verticals, namely, physical, organic, inorganic, and analytical chemistry.

Chemistry is also distinctly separated from biology and physics. There is very little horizontal interaction, either in teaching or research, in most institutions. Most significant advances in modern chemistry are occurring at interface areas; yet the training that we offer our students ignores cross-disciplinary learning. "Purity" of the discipline is valued more than the impact one can make on chemistry as a whole. Young scientists are afraid of crossing vertical boundaries, because they fear that they will "fall between stools" at the time of appointment, promotion, or recognition. We still seem to be uncomfortable with the notion that today's interdisciplinary areas will become tomorrow's mainstream areas.

Largely because of such reasons, many students trained in this environment may not be suitable for professional careers in academia or industry. Their breadth of knowledge is too narrow to pursue an independent academic career; their training lacks the ability to seek solutions to problems across disciplines that is so important to industry. To alleviate this situation, we have turned to appointing only those who have postdoctoral experience abroad, seemingly assuming that this foreign "endorsement" is sufficient to overcome the deficiencies of training in the Indian PhD program. In seeking such foreign postdoc experience in aspiring academics and industry scientists, we unwittingly devalue our own system, driving its quality further downward. This has created an unfortunate class system that discriminates between those who have pursued PhD or postdoc training outside India and those who have not. This has led to another peculiar situation: because of the premium given to a foreign postdoc experience, Indian PhDs are not anxious to do a postdoc in an Indian group, however good it might be. This, in turn, has had a seriously negative effect on the quality of Indian research—all scientifically advanced countries depend heavily on the quality of their postdoc program.

The other issue confronting chemistry in India is that there are only a few islands of excellence in a vast ocean of "average" science. This "average" has to improve substantially if excellence is to appear consistently. There has been sporadic talk as to why no Indian chemist has ever won a Nobel Prize. Few bother to admit that Nobel Prizes are far more common in scientifically advanced countries where the number of practitioners is large and the average quality high. It is individuals who excel but the ability to excel is far more likely in an atmosphere where the average level tends towards competence rather than towards mediocrity. Indian chemistry is definitely top-heavy at the present time. Although the quality and quantity of publications in chemistry has been increasing over the years, around one half of this output comes from some 20 top-performing institutions with some 500 odd universities contributing to the other half. A rough estimate suggests that there are only 10000 researchers in chemistry in India producing around 3000 PhDs annually. These figures are abysmal for a country of 1.2 billion people, and will need to be multiplied many times before India can be counted as a global player. However, the recent initiatives of the Government to make education more broad-based will surely lift the average to more credible levels. When PhD students from the top 20 or so institutions start occupying faculty positions in the 500 secondary- and tertiary-level universities, there is bound to be a positive effect on the overall productivity and visibility. This phenomenon has already begun in China and there is no reason to believe that it will not happen in India.

The interface between academia and industry is weak barring a few niche areas like the generic pharmaceutical industry. This is despite the $100 billion (2010) Indian chemical industry, which is growing at a healthy rate of 13%, contributing 3% to India's GDP and 14% to its exports. That the chemical industry's investment in universities is small is because the industry itself is fragmented in terms of size; there are too few big players and the domestic market is demand-driven. New products based on frontier science neither offer major competitive advantage for firms, nor is their survival and growth dependent upon science-driven innovations. Typically, even a basic interaction such as between chemistry and chemical engineering is practically nonexistent in India.

Systemically, there is much that is missing in the way chemistry is organized in Indian institutions. There is urgent need for more autonomy, less bureaucracy, less interference from the Government, greater internal democracy, and participative decision making. Start-up grants for faculty are yet to become a norm in most institutions. Institutions need to aim high and build international linkages for rapid growth. The peer-review system needs to become more rigorous, transparent, and objective, both in appointments as well as in according tenure and promotion. Overdependence on numerical indicators must be replaced by more thoughtful responses on the quality of the science and its impact. The peer reviewers themselves are not all equally accomplished; hence the system is not robust. In many emerging areas of chemistry, it is difficult to find a critical mass of accomplished peers within the country. Peer review of projects is rather staid and conservative, and tends to filter out truly unusual ideas, largely because they are untested, have no precedent, or are unfamiliar. The PAC members of DST, who decide the level of funding, were trained at a time when caution was the watchword. In a modern context, they tend to be needlessly conservative in their approaches to funding. This mindset actually pervades much of the mentor group of today's PIs, who tend to look for problems based on what is available, in other words like in the situation that was prevalent 30 years ago. The students are not too different from their teachers! Culturally, we Indians are comfortable with this so-called "gurukulam" (family of the teacher) system, which was common in classical Indian music and dance. To paraphrase, young chemists are becoming unnecessarily conservative in trying to adjust themselves to an environment in which the funding decisions are conservative. Progress cannot be impressive in such a scenario even though the economy is growing rapidly. The country is ready to invest in big research but Indian chemists are either not able or not willing to ask the big questions. They seem to be unable to appreciate that if they are to make their mark in the world of chemistry, they should first learn how to pose an interesting question and then exert themselves and find the means to address the question.

Such concerns lead us naturally to cultural issues. Undoubtedly, there is the general tendency of Indians to play safe and be risk-averse. This is common in Asia and indeed is a characteristic of all overpopulated countries that have once been wealthy and have then encountered poverty. Risk of failure inhibits breakout thinking, since failure is often penalized. A second problem is the culture of conformity. Indian society tends to make heroes out of quite ordinary men and women and is constantly in search of role models. While role models in themselves are not undesirable, blind allegiance to authority that is deemed superior is detrimental to free thinking. Being always reasonable or politically correct saps the environment of true voices of constructive dissent. Age is often equated incorrectly with wisdom. The culture of collaboration, say with biologists, physicists, and engineers, is weak. In a colonial hangover, Indians tend to look to the West for approval and approbation of their scientific endeavors. This has led to Indians becoming followers of a discipline rather than to creating their own disciplines (gurukulam). We are the first to be second. Following fashions or fads has become more important than relevance or originality of thought. Because of our conformist culture, there is a tendency for Indian chemists (including those responsible for funding decisions) to unfairly shift the entire burden of responsibility to policy-making departments like the DST. While policy imperatives are critical, it is the responsibility of Indian chemists as individuals and as members of the chemical community to enhance quality. There is a need both for individual responsibility, and for raising the bar in standards of collective decision making responsibility. While individual aspirations do not synthesize easily into national goals by merely adding the outputs of individuals, a measurable national impact cannot be had without individual excellence. In other words, before one can say that the whole is greater than the sum of the parts, one should remember that without the parts, there can be no question of a whole. The chemistry community of India needs to introspect, and deeply at that.

Indian chemistry is at an inflection point and there are several enabling initiatives that can accelerate growth. We will benefit substantially if we are able to hire non-Indian faculty members (not merely foreign passport holders of Indian origin), and select foreign PhD students and postdocs. Substantial innovations in the system of science administration and funding, as well as coordination between various Government departments are necessary if this is to become a reality. This could be a major goal of the newly created SERB, a body that has created high expectations from the Indian scientific community because of its potential to transform the research scenario at a fundamental level. Scientific institutions and university departments must stand up to periodic scrutiny and review by global peers. The diversity of Indian population offers a strong ecosystem for creativity and innovation. There is an increasing tendency amongst Indian women to pursue higher studies in science. However, many of them do not continue with research because of prevailing social systems. Chemistry worldwide also seems to have been rather unsuccessful in including women into its research ranks when compared to other disciplines, notably biology. There is a real need to induct more women into research careers in Indian chemistry, especially after interruptions in their professional life.

In addition to increasing funds to individuals and institutions, funding agencies need to find even more ways to make teaching and research in chemistry more attractive. Although India does not yet have a tenure-track system in place (and there are questions as to whether this system will ever suit us), new schemes have been introduced such as the INSPIRE Faculty Fellow Scheme of the DST that helps institutions hire new faculty for a five-year period. During this period, salary and nominal research support are provided by the DST, while host institutions give infrastructural facilities. The idea is that the INSPIRE inductee is offered a sufficient amount of academic and financial independence by the host organization. Eventually, though, these young scientists will need to secure independent teaching and research positions in a university.

To conclude, we articulate the need to increase the density of chemists, increase their outreach into biology and physics, make larger investments in basic research and undergraduate teaching especially in the laboratory, convert gains into profits, and introduce new paradigms of governance for science including the reduction of our crushing bureaucracy. These are some lead suggestions to our policy makers. We have already paid the price for not deciding correctly or for not deciding quickly enough. In many ways, the last decade has been something of a missed opportunity in that we have allowed our cultural biases to overcome reasoned and pragmatic thinking. The real change agent is the chemistry community itself led by a more enlightened leadership that is unencumbered by notions of patronage and patriarchy. An over-cautious attitude has not served us well in the past and it will certainly not serve us well in the future. Indian chemistry today faces a crisis of leadership. Adherence to quality by scientists and the ability to take risks by fund givers, especially in the Program Advisory Committee mechanism of the DST, are critical, even mandatory. These committees are enablers of progress and not custodians of wealth. They have the greatest opportunity now to help Indian chemistry grow by taking calculated risks. They need to do this with both accuracy and daring. If we are able to take this leap of faith into the future, all else seems to be in place for chemistry in India to grow exponentially. We note that both the global and Indian economy are slowing down. It would have been easier to take risks a decade ago when the economy was in an upswing. But there seems to be little choice now. However, the situation is hopeful today in terms of attitude and demographical changes all over India. On an even more hopeful note, attitude and demography shifts are in themselves such powerful agents of change that a positive outcome seems to be inevitable with or without these committees.

Essays

Spotlight

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Chemistry in India—Unlocking the Potential

Hidden talents: Chemistry in India is currently ranked as fifth in terms of worldwide research output. G. R. Desiraju et al. discuss the current state of chemistry in India and the historic, social, cultural, and economic factors that influence its growth. They also address the issue of how to unlock the true potential of chemistry in India.