prompted further revision of existing notion about the Indo-Australian plate as two plates separated along the 90ER with a southwestern continuation at its southern end to intersect SEIR near 80°E (refs 2, 3). Further, reports of repeated anomalous off-ridge earthquakes[4] along this southwestern trend hinted at the need for re-definition of two-plate configuration.

Using magnetic sea-floor anomalies and seismic data, and based on deformational history of adjoining Somalian and Antarctic Plates, Royer and Gordon have proposed a revised plate geometry and a set of angular velocities that are consistent with current seismicity of the area. In the opinion of the authors, the fundamental departures to the rigid plate characteristics can be resolved if the Indo-Australian plate is considered as made up of three plates having diffuse boundaries. Based on record of deformational history they propose:

1. A new Capricorn plate with diffuse boundary on the northeastern side (Capricorn–Australia plate boundary).
2. The pole of relative rotation of the two plates lies between the NW-SE zones of stretching and shortening (Figure 1) and it indicates rotation of $0.78 \pm 30°$ about 29.1°S, 90.3°E.
3. Since 11 Ma, a point now at 17°S, 105°E in Australian plate has moved 27 km approximately along N45°W relative to Capricorn plate.
4. Convergence of 23 ± 26 km since 11 Ma between Capricorn and Australian plate.
5. The convergence rate of 2.1 ± 2.4 mm/year is much slower than global average rate of convergence in trenches (~ 70 mm/year) and happens to be slowest rate of convergence (~ 20 mm/year).
6. The convergence rate, though slow, may yet have triggered large earthquakes and folding of lithosphere, the latter confirmed by gravity undulations.
7. Divergence between Capricorn and Australian plates since 11 Ma at a rate 1.2 ± 2.2 mm/year, is much slower than global average rate of spreading along the mid-ocean ridge (MORs) ~ 40 mm/year and is also less than slowest rate of sea-floor spreading (~ 10 mm/year). The divergence is mainly taken up by normal faulting and consequent thinning of crust during 13 ± 24 km of divergence in this period.
8. Southwestern zone of NW-SE stretching, northeastern zone of NW-SE shortening are all caused by relative rotations of Indian, Capricorn and Australian plates.
9. Indian–Capricorn, Capricorn–Australian zones of shortening merge and are terminated by an overriding plate of subduction zone.

Thus according to Royer and Gordon, the assumption that Somalian, Antarctic and Australian plates are rigid is not valid, and also the traditionally defined Indo-Australian plate consists of three component plates and multiple diffuse boundaries. These plate reconstructions explain all the deformational aspects like stretching and shortening and are also in conformity with one of the main concepts of plate tectonics, namely a rigid plate-interior, as exemplified by little deformation within the new components.

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A. V. Sankaran lives at No. 10, P&T Colony, I Cross, II Block, R.T. Nagar, Bangalore 560 032, India.

OPINION

Science in India: 1947–1997

Avinash Khare

The year 1997 is a landmark year in our history as we have completed 50 years of our independence. It is a good time to look back and see how we have done as a nation in various spheres of activities in the last half century. Unfortunately, I am disappointed that not many people have come forward and presented a serious analysis. Apart from some semi-popular articles in our magazines and newspapers, I have not come across a single article examining in depth our achievements and failures in S&T or for that matter in any sphere of activity. I was hoping that a serious science journal like *Current Science* would carry articles on our achievements and failures in S&T. In fact it is ironical that apart from the British journal *Nature*, which brings out an in depth study on 'Science in India' once in every ten years, no Indian journal has ventured to do anything similar. I am aware that my knowledge of Indian science (apart from physics) and technology is rather limited but I feel that some one has to take the plunge and initiate a serious debate on our achievements and failures in S&T in the last 50 years. Hence this article.

I am quite aware of the serious dangers involved in undertaking this exercise. This is because, by and large, we Indians have a tendency to take either an extremely negative view or an extremely positive view, both of which are harmful. For example, over the years, I have seen that many of our scientists have developed quite a cynical attitude. These people refuse to see positive things in our science and criticize almost everything in it. I think this attitude is highly dangerous. Apart from painting a distorted and wrong picture, it makes one lose his confidence which is the most important thing in achieving success. Of course, many of these people are using the criticism of the system as an excuse for not working hard and doing their own work with full vigour and enthusiasm. I think only those people who are working extremely hard and doing their own job satisfactorily

have a right to criticize. The other extreme are people (specially in power) who are unwilling to initiate a debate on this topic and are unwilling to critically examine our failures and the possible underlying reasons. In order to progress satisfactorily in the coming 50 years, it is necessary to rationally identify our strengths and weaknesses and take appropriate corrective measures. Thus, it is very important to guard against both of the extreme tendencies.

Before I come to details, let me say that my own assessment is that, over all we have done quite well in the last 50 years in S&T and we can be proud of our achievements. In spite of our poverty, lack of technological base, etc. at the time of our independence, our achievements are not insignificant. It is one of the tragedies of this country that while we take great delight in finding faults and highlighting our failures, the success stories are not given any publicity. As a result, most of us are not even aware of the several success stories of Indian S&T. However, there is also no doubt that we were capable of much more. So much could have been done and it is also a case of missed opportunities. In order to properly assess how we have done in the last 50 years, one must first examine the status of S&T in India at the time of our independence and then see how things have changed in the last 50 years.

Status of S&T in 1947

At the time of our independence, there were very few universities and of course hardly any institutes in the country. Even in many of the premier universities, people hardly knew modern subjects (like quantum mechanics in physics). For example, I have been told that even in BHU, hardly any one knew quantum mechanics in those days. In 1947, we simply did not have scientific manpower even to teach, leave alone doing any research in most of these modern areas. Since basic research is the mother of applied research as well as technology, no wonder we were simply nowhere in applied research and in technology development.

It is worth remembering that at the time of our independence, famines were quite common, life expectancy was low, malnutrition was rampant and infectious diseases were there all around. Majority of the houses in the cities (not to talk of villages) had no electricity and other modern gadgets. All in all, the picture was extremely gloomy when we became independent in 1947.

How have we done in the last 50 years?

If we compare the conditions prevalent in 1947 and the situation today, there is no doubt that, over all, we have done well in the last 50 years. Thanks to the green revolution, famines have been banished. Life expectancy has risen substantially, infectious diseases have been by and large brought under control, malnutrition is absent in a substantial share of our population, electricity and other gadgets are now all around, not only in our cities, but even in small towns, and also in quite a few villages.

There have been many success stories in Indian science in the last 50 years. On the whole, we have done very well in targeted research. In areas like agriculture, medicines, space, nuclear energy, defence research, etc. where there were specific goals to be achieved, our scientists have done remarkably well even with our meagre resources. Let me now mention some of these success stories briefly.

Huge talented scientific manpower

I think the major achievement in the last 50 years is that we now have a huge talented scientific manpower. It may be any area of science, but now one can find an expert in the country who would know all the intricacies of that field and who is working in the forefront of that field. Our universities and institutes are now producing excellent scientists who have got their entire training up to the doctoral degree, in the country. Before 1980 or so, in most areas of science, foreign scientists were coming to India mostly to lecture and to offer expert advice. However, in the last 10–15 years, the situation has changed, in at least a few areas of science. For example, in theoretical subjects, it is now quite common for foreign scientists to visit us, not just for lecturing, but for carrying out collaborative research work. In mathematics and statistics, a few of our institutions have the reputation of being some of the best in the world and in these institutes, such collaborative research work has been taking place for a much longer time. The same is perhaps not true in experimental areas of science and there is a reason for it, namely that our technological base is still quite poor compared to the developed world. Of course there could be one or two exceptions here.

One remarkable aspect of the scientific manpower produced in India has been that most of them have come from poor and lower middle class background. We all should be proud of the fact that in this country even poor people have been given opportunities to reach the top. Our society has by and large respected and encouraged talent. The stories of many of our scientists, the way they have overcome all odds, worked hard with very meagre research facilities and reached the top, is most remarkable and inspiring. I am afraid that the way the *liberalization* is taking place in our country, the way our major scientific institutions, including the IITs, are threatening to increase the tuition fee, soon S&T may close the door to the poor and the lower middle class people and that will be a disaster of the Himalayan magnitude. This is really a matter of very grave concern.

Another remarkable thing that has happened in the last 50 years is the tremendous enthusiasm of young people for S&T. If only we can harness this talent properly, I have no doubt, we will become one of the leaders in the world of S&T.

Green revolution

The food grain production which was about 50 million tons around 1950 is now close to 190 millions. As is well known, till the 1960s, India was a perpetual seeker of food aid, but thanks to the green revolution, we are not only self-sufficient in food but are even exporting a little bit. Our agricultural scientists have played a major part in this revolution. The green revolution required progress on several fronts in S&T like irrigation, production of new varieties of seeds and storage and processing techniques. What is perhaps not so well known is the fact that the same approach has been extended to oilseed and pulses. India is the first country to develop and use hybrids in pearl millet. Further, India is the only country in the world to have produced and commercialized hybrids in cotton.

White revolution

The milk production which was about 17

million tons around 1950 is now around 70 million tons and India is poised to become the largest milk producer in the world. S&T has played a key role here – in the improvement of non-descript cattle through cross-breeding, improving animal health facilities, developing varieties of quality fodder, developing appropriate technology for preservation and transportation of milk, etc. What is most remarkable is that this revolution has happened through a cooperative movement where a majority of the participants are marginal and landless farmers.

Space odyssey

Indian space programme has ushered in the country a revolution in the areas of telecommunication, TV broadcasting, meteorology and surveying and management of natural resources. It must be noted that the space programme required us to develop, indigenously, very advanced and sophisticated technology including the design and construction of satellites and vehicle launch technology. Very few nations have acquired this sophisticated technology so far.

Nuclear energy

This is another area where we have done remarkably well. After the 1974 Pokharan implosion, the foreign help stopped totally in the key areas of technology and it is to the credit of our nuclear scientists, that they have been able to develop such an advanced technology on their own. In fact, this is one of our remarkable traits that, whenever we are pushed to a corner, we have been able to bounce back!

Drug and pharmaceuticals

The Indian pharmaceuticals which was almost a non existent industry at the time of our independence, has today emerged as one of the largest and cheapest producer of medicines. This has greatly helped in improving the standard of health care and has helped in producing modern medicines to the people at an affordable cost. This has been possible due to the domestic R&D in devising novel cost-effective processes for generic drugs and in developing formulations.

There are several other success stories in the last 50 years like leather industry, chemical technology, aviation technology, etc. Besides, there are several success stories at an individual or group level. Again it is impossible to mention all of them. Some of them are, precocious flowering of bamboo, tissue culture technique, development of rice husk particle board, clinical gynaecological methods, cholera enterotoxin mechanism, short term chemotherapy, discovery of J-receptors in lungs, the famous Jaipur foot, blood bags and artificial valves at affordable prices, etc. I must apologize to all those scientists and institutions whose pioneering work has not been mentioned here.

Our failures

In spite of all these success stories, there is no doubt that ours is also a case of missed opportunities. Much more could have been done in the last 50 years. For example, while it is true that we have a large talented manpower, it is also true that we have not produced many outstanding scientists of the calibre of J. C. Bose, C. V. Raman, S. N. Bose and M. N. Saha. Similarly, in spite of several CSIR laboratories, we are still importing most of the technological knowhow. The number of useful patents coming from our laboratories is still not too large. There is not much interaction between the industries and the research establishments. Finally, our S&T has not made a noticeable impact on the every day life, especially in the villages. Of course it is a very complex issue and there are several reasons why we have not done very well. It is necessary to consider these issues seriously, identify our mistakes and try to rectify at least a few of those mistakes. Some of the reasons for our failure are as follows.

Missed industrial revolution

To my mind, the single most important reason for our lack of progress in S&T is the fact that we missed the industrial revolution by several decades. Till 1947 we had almost no technology in the country. It must be remembered that technology is not a static thing but is being developed every day. Besides, in many cases there are no short cuts. Thus it is not very easy to catch up with the developed world who has got a lead of several decades over us. This has also affected the quality of basic and applied research. I think that even today, the lack of front-ranking technology is one of the main reasons why we are unable to do well in the basic as well as applied research work. It must be emphasized here that physics, chemistry and biology are all experimental sciences and progress in theoretical ideas and in experimental ideas usually go hand in hand. That is why we are not doing that well in theoretical areas too. I am convinced that unless the quality of our experimental research goes up, the quality of theoretical research work in these areas will also not improve substantially.

As a support to my argument, let us look at mathematics and statistics which are purely theoretical subjects, and one does see that in these areas, the standard of some of our institutions is comparable to the best in the world. The same cannot be said of any institution in the areas of physics, chemistry or biology. Unfortunately, in mathematics and statistics, the top quality is confined to only a few institutions while the standard in most other institutions is extremely low, much worse than, for example, the standard of physics in these institutions.

I believe that unless we can find some innovative solution to catch up with the developed world in terms of our technology base, there is no hope for our S&T to progress by leaps and bounds.

Feudalistic society

For thousands of years, our society has been an agricultural society and even now it is primarily so. This has its ramification in our attitudes, which are by and large still those of a feudal society. We have given more importance to loyalty than to calibre. This has affected our society, including our science, considerably. In many cases, appointments, promotions and even scientific decisions have been made on loyalty considerations and not on the basis of pure merit. Only in the last 10–15 years or so, one can see a ray of hope. This is intimately related to the pace of our industrialization. Of course, an industrial society has its own evils – no doubt we will catch them soon!

Colonial attitude

We have been subjected to foreign rule for more than 1000 years and specially the British rule in the last 200 years has been utterly devastating. 'The white man superiority syndrome' is still in our blood and we still have not acquired enough confidence and maturity as an independent nation. We still look for patronage from the West. We are unable to judge good work of our fellow Indian scientists. Only

when he/she gets recognition in the West, we join the bandwagon. As a result, early in the scientific life, we learn how to write papers by extending the ideas of some western scientists. This has of course its incentives in foreign visits, fame, money, etc.!

Mind over matter

One of the traits of our civilization (unlike the Chinese) has been that we have always given more importance to the mind over the matter. This is continuing even today and is affecting our society, including our science in a big way. There is utter neglect of instrumentation in our country. No due recognition is given to technical innovations but we would give more weight to some theory paper which may have merely extended an idea of some western scientist.

Neglect of universities

All the reasons mentioned so far are the creations of very complex factors over the years, and our planners cannot be blamed for them. Let us now turn to the failures which are due to the mistakes of our scientific and political leadership. I think the single, most vital, mistake made by the leadership is to open research institutes for carrying out research in basic sciences. This has directly led to the utter neglect of our universities! This was a blunder of Himalayan proportions, since it is the universities which provide us with the scientific manpower, and by neglecting them we have only helped in destroying this scientific base. The growth of the research institutes has affected the universities in several ways. Firstly, since the institutes were compact, well funded bodies with good research facilities and no teaching responsibilities, they attracted the cream of our scientists. As a result, the intellectual level of the universities deteriorated. Also, with the mushrooming of the universities, the research facilities in the universities dwindled and the quality of research, by and large became even worse and slowly the gap between the universities and the institutes widened. This encouraged our bright young people to opt for research institutes instead of universities for their career. With the lack of facilities, including very poor laboratories, the universities are not able to convey the enthusiasm and the excitement of science to the students. As a result, we are no more able to attract the brightest minds to science which in turn is hitting the Indian science including the research institutes! One of the ironies of our university system is that even though teaching is the most important function of the universities, good teaching is given no credit while considering promotions and awards. In fact, even after 50 years of independence we have not devised any method for distinguishing a good teacher from a bad teacher.

I must add here though, that in spite of this situation, there are some teachers in the universities who are doing excellent work and are motivating young people to science and are also producing good students in spite of the lack of facilities. It is thanks to these few people that at least some bright students are still coming to science.

I might add here that this isolation from the broad based university atmosphere has also affected the research institutes. Many of these institutes specialize in a very narrow area of science. The scientists in these institutes do not have contact with scientists in other areas of science. As a result, what has happened is that many of these people lack the proper perspective and they tend to become extremely narrow minded and many of them lack vision. It is quite common in science that some of the best work has happened through cross fertilization of ideas in different fields. But this is not possible in these specialized institutes.

I strongly believe that unless one can take back the basic research to the universities, our science cannot really progress by leaps and bounds. This is of course a very difficult task since the universities are almost dead and have become highly bureaucratic and political. I hope, some way can be found to overcome this problem and one can make sure that every scientist working in basic sciences will also teach the university students.

Bureaucratic interference

Another blunder of our leadership (in this case the political one) is to adopt the old British bureaucratic system. This is one of the major obstacles to progress in science (and in fact to all the progress in this country). The bureaucracy has caused havoc in the universities and slowly the disease is spreading to the institutes too.

Lack of vision

In many cases, our scientific leadership lacks vision. Most of them cannot think big. For example, one might ask, what world standard projects have been planned and are being planned in VIII and IX five-year plans? Apart from GMRT, I am unaware of any other world class project in physics. What is required is that our leadership should identify our strengths and then should have big plans in those areas. I shall elaborate on this point below while comparing with China.

Lack of hard work

Most of us do not work hard. Unlike other routine jobs, a scientist is expected to be fully devoted to his/her work. But in India, most scientists do not work very hard. Many of the senior scientists, who are expected to set an example before the youngsters, spend quite a bit of time in committee meetings but devote hardly any time to actual research work. One finds that most of the scientists are aspiring to become science managers. It is not that we Indian scientists are incapable of working hard. In fact, when we go abroad, most of us work extremely hard with full vigour and enthusiasm.

India vs China

Perhaps a good way to judge as to how have we done in S&T is to compare our progress with that of China. We are countries of similar sizes, we both got independence around the same time and we both missed industrial revolution (one important difference though is that China has not experienced colonial rule, except for a small period by the Japanese).

In the first 20–30 years, India had a head start over China since the Chinese leadership concentrated more on providing basic amenities to the masses. Only about 20–25 years ago they decided to invest substantially in S&T and there is no doubt that there are several areas (specially in experimental and applied sciences as well as in technology) where China has gone ahead of India. From my experience and after talking to several other scientists, I got the impression that the key reason for their success has been judicious use of the available resources. They have identified their strengths and have decided to concentrate in those areas

Let me give an example. Both India and China have advantage of having very tall mountains. These are ideal for cosmic-ray studies. In India, Bhabha realized it early and started this research at TIFR. But the funding has remained sub-critical and the leadership is unable to think big. In China, there is a cosmic-ray laboratory in Lhasa at an altitude of 3500 m. Recently, in collaboration with the Japanese, they have strengthened it considerably and they can now carry out first rate gamma-ray studies for energies greater then 10 TeV. Contrast this with India, where at one time we were world leaders in cosmic-ray research at the Kolar Gold Mines but what have we done? We have closed it down! This is one of the glaring examples of the failure of our scientific leadership. Similarly, take the example of experimental high energy physics. Here again, we have not built any facility in India while the Chinese in collaboration with the Americans have built an electron–positron collider as well as proton synchrotron. (It may be noted that they are also participating in all the top high energy experiments throughout the world.) Similarly, the Chinese are world leaders in growing crystals. I think, two reasons why they are doing better than us are that unlike us, in their society matter is given equal (if not more) importance over mind and secondly, unlike us, they use their resources judiciously. Our first priority is always grandiose buildings and comfortable offices while in China, experimental facilities are given priority almost to the extent of neglecting other things. It is worth pointing out that the day to day working condition of our scientists is much better than that in China. One thing which impresses an outsider in China is the tremendous amount of pride and enthusiasm among every one for building their country and every one seems to be working hard and not spending hours criticizing the system.

I must add, though, that China has one major advantage over India. Once decision is made to do a certain thing, there are no bureaucratic hindrances, no labour problems, etc.

Conclusions

Analysis of the problems confronting S&T in India is a very complex subject and clearly there are no simple solutions. However, to my mind, the single most important thing that needs to be done is to strengthen our universities (and also our colleges) and take back basic research to the universities where it should ideally belong. We must stop building more research institutes in basic sciences except inside the university environment. Secondly, we must identify our strengths and try to plan big in those areas.

With the current wave of liberalization, some people seem to think that only technology is relevant for progress, and one need not spend money on basic or even applied research. But this will be suicidal. It must be remembered that basic research is the mother of all applied research and technology. Unless we can produce a talented scientific manpower with a strong scientific base, it will simply not be possible to make progress in applied research or to develop new technology. I strongly believe that basic science, applied S&T and development are all equally important. However, one must also not go to other extreme and all three must be encouraged to grow side by side.

Obviously many more things need to be done and hopefully these points will come to the fore through the debate. There is no doubt that several major problems remain to be solved but I would say that, overall, there is room for optimism and hope that we can make great progress in the coming fifty years. What is required is to think positively, do not give up, and work hard.

Avinash Khare is in the Institute of Physics, Sachivalaya Marg, Bhubaneswar 751 005, India.

SCIENTIFIC CORRESPONDENCE

In vitro flowering and seed setting formation of coriander (*Coriandrum sativum* L.)

Coriandrum sativum L. is an important spice, cultivated for its medicinal and aromatic properties. Seeds of coriander developed from the allogamous flowers (family Umbelliferae) are of genetically variable nature. So improvement of coriander through conventional breeding strategies were not found to be suitable in spite of their enhanced production. Tissue culture techniques were found to be suitable and utilized for the improvement programme.

Shoot tips of coriander var. Co-1 excised from aseptically raised 7-day-old seedlings and multiple shoots were cultured on SH[1] medium supplemented with different combinations of naphthaleneacetic acid (NAA) and gibberellic acid (GA_3) (Table 1). The pH of the medium was adjusted to 5.8. Cultures were incubated under 16 h photoperiod at 28 ± 2°C. For each treatment a minimum of 25 replicates were used and each experiment

Table 1. *In vitro* plantlet regeneration in coriander

Treatment (mg l^{-1})	Rooting plantlet formation after 25 days	
	No. of roots/ plantlets	No. of developed leaves
I NAA 0.05 ± GA_3 0.5	2 ± 0.3	Thin leaves
II NAA 0.1 ± GA_3 0.5	4 ± 0.2	4 ± 0.4
III NAA 0.15 ± GA_3 0.5	5 ± 0.8	7 ± 0.8
IV NAA 0.2 ± GA_3 0.5	8 ± 0.9	9 ± 0.6