COMMENTARY

Measures of progress in science and technology*

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Research publications are clearly one of the quantitative measures for the basic research activity in a country. The root cause for stagnancy in the number of research publications from India seems related to talented and bright young students not opting for careers in science in recent years. Apart from basic research, there are other kinds of research and technology development also, e.g. mission-oriented, industry-oriented, country-specific, etc. The Principal Scientific Adviser's office has taken up projects on measures of progress of science and technology in some areas: on Indian patenting activity, on agricultural and rural development and on publication output. It is also necessary to measure achievements in high-technology and in country-specific research.

The Science and Technology Policy 2003 of the Government of India[1] re-emphasizes – following the scientific policy resolution of 1958 and the Technology Policy Statement of 1983 – the importance of science and technology (S&T) as crucial elements of national development and recognizes the need to view them together. While stating that 'the nation continues to be firm in its resolve to support science and technology in all its facets', the Policy recognizes the central role of our science and technology system 'in raising the quality of life of the people of the country, particularly of the disadvantaged sections of society, in creating wealth for all, in making India globally competitive, in utilizing natural resources in a sustainable manner, in protecting the environment and ensuring national security.' It is in this context that it would be useful to study and analyse the measures of progress in S&T in all its dimensions.

There has been a great deal of discussion recently on India's scientific research output. According to Arunachalam[2], based on a bibliometric study of *SCI* journals,

- The scientific research output of India – as measured by the number of research publications – has been stagnant during the last two decades.
- On the other hand, the number of publications from China and South Korea has grown substantially during the same period.

This is a factual statement; a similar trend, but with some growth in the case of India, is seen if the bibliometric count of research publications is made based on data[3] from the Web of Science (Figure 1). Research publications are clearly one of the quantitative measures for the basic research activity in a country. It must be added, however, that what excites the common man, as well as the scientific community, are the peaks of scientific and technological achievement, not just the statistics on publications. There are also other kinds of research and technology development – mission-oriented, industry-oriented, country-specific, etc., progress in these cannot be obviously measured by counting only the number of publications.

Interestingly, there seems to be no direct short-term correlation between research publication rate and GDP growth rate. There was a time when the United Kingdom was getting the Nobel Prizes and Japan was getting wealthy! At that time Japan was not laying great emphasis on basic research. If we look at South Korea or China, their GDP growth rate was strong even when their research publication rates were low. So basic research has to be seen as a long-term investment for sustainable development. India's relative immunity against sanctions, I feel, is because of our investments in basic research since independence and this is a strong argument in favour of increased investments in basic research. It is also seen by Gupta[4] that in some areas, e.g. some sub-fields of physics, India is doing better than China in citation rate[3], even though the number of publications is lower (Table 1).

Data (S. K. Sikka and R. P. Gupta, unpublished) on number of scientists and research expenditure, both per capita of population and per scientist is given in Table 2. This spending decides the magnitude of scientific infrastructure, including the number of scientists, scientific equipment, computing facilities, library facilities, communication facilities, etc. available to S&T persons. It also determines their mobility, e.g. attending international conferences, etc. so essential these days. In 2003, the expenditure on S&T in India was about US$ 5 per capita compared to US$ 240 for South Korea and US$ 705 for USA. Again, in developed countries, the R&D spending by industry is quite substantial. This is very small in India. This situation also has to be rectified.

It is also interesting to look at the ranking of countries, in terms of citations: Table 3 is derived from a recent article of King[5]. If the publication rate is plotted against GNI (Gross National Income) per capita (Figure 2), using data from King[5] and WDI[6], the most productive countries seem to fall into two groups: India, China and Russia, with relatively lower GNIs but with strong scientific communities and traditions and a group of already developed countries, where the publication rate seems to follow the population strength.

Sikka and Gupta (unpublished) and King[5] have tried to correlate citation rate with per capita GDP/GNI (GNI = GPD + receipts from abroad); clearly, the richer a country, the wider is the reach of its scientific work. The former have plotted citations per paper against GNI per capita and the latter has plotted citation intensity (total citations/national GDP) against wealth intensity (GDP per person, after correcting for purchasing power parity). Correcting for PPP in the latter may be alright for salaries, but certainly not for purchasing imported equipment, for instance.

When we discuss technology, we should take a national perspective and be clear about the reasons for developing technology in a country. These may be one or another of the following, or a combination of them: creating national wealth; improving

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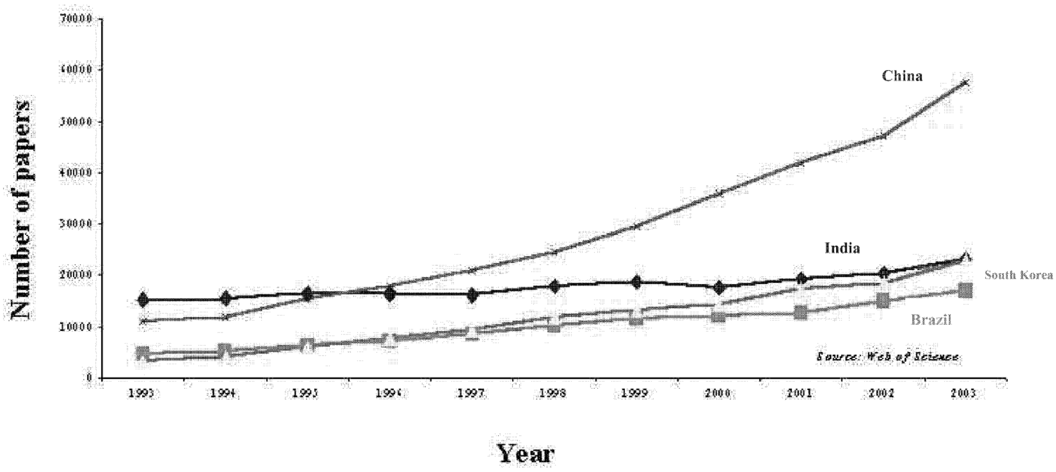

Figure 1. Year-wise number of publications for China (including Hong Kong), India, South Korea and Brazil (1993–2003). (Source: Web of Science[3]).

Table 1. Number of papers and their impact for China and India in selected sub-fields of physics from 1991 to 2000

	Number of papers		Citations per paper	
Branch	India	China	India	China
Nanotechnology	636	3168	3.15	2.42
Neutrinos	486	239	18.26	6.74
Photonics	23	183	9.17	3.94
Quantum dots	117	677	4.79	2.92
Opto electronics	1279	2621	2.36	1.57
Fuel cells	77	93	2.84	1.27

Source: Web of Science[3]

Table 2. Number of Scientists and Research Expenditure Data from Human Development Indicators (World Bank) 2003 (Sikka and Gupta, unpublished)

Country	Scientists per million population	Expenditure on R&D per capita (US$)	Expenditure per scientist (US$ 1000)
India	157	5.5	35
China	545	11.7	16
Japan	5095	978	192
South Korea	2319	241	104
Australia	3353	285	85
UK	2666	460	172
USA	4099	705	230

Table 3. Top ranking in terms of citations (1% of highly cited publications, 1997–2001, data from King[5])

Country	Total number of publications (1997–2001)	Per cent of world	Total among top 1% cited	Per cent comparator group
1. United States	1,265,808	34.86	23,723	62.76
2. E.U. 15*	1,347,985	37.12	14,099	37.3
3. UK	342,535	9.43	4,831	12.78
5. Japan	336,858	9.28	2,609	6.9
20. China	115,339	3.18	375	0.99
21. South Korea	55,739	1.53	294	0.78
23. India	77,201	2.13	205	0.54
24. Brazil	43,971	1.21	188	0.5

*E.U. 15 is a group of 15 countries, including the UK, and has been included here for comparison with the States.

the quality of life of the people, particularly those living in rural areas; and enhancing national security. National security must be interpreted broadly to include not only military security, but also food and nutritional security, health security, energy security, etc.

Patterns and priorities in Indian R&D

Some years ago, Chidambaram[7] analysed the various important kinds of R&D going on in India. Briefly, these are:

Basic research

It is a cultural necessity in any civilized country. The highest intellects in a country must be allowed to work on fundamental problems of their choice. Basic research is also a long-term investment for national development and national security, as today's basic research may lead to a useful product or process in the future. Also the equipment used in basic research experiments uses cutting-edge technologies, which can diffuse into the rest of the system. Even when doing technology development (say design of nuclear weapons), unexpected gaps in knowledge often appear, which only existing experts in basic research can fill. In fact, basic research in some strategic areas is regarded as a part of 'technological deterrence' capability of the country. Basic research is best carried out in academic institutions and universities and the output is mostly research publications in peer-reviewed journals.

Applied research and technology development by mission-oriented agencies

Such focused research has been very successful in India. Besides providing immunity against technology-control regimes, it has had spin-offs. For example, work in the Department of Atomic Energy has not only had well-known spin-offs in medicine, agriculture and industry, but also in unlikely (at first sight) areas like non-destructive testing and welding. Similar examples can be given from the work of the Department of Space and DRDO.

Industry-oriented research

As Indian industry becomes stronger, industry-oriented research in the laboratories of CSIR and in the universities and IITs will increase. Already we see signs of increased academia–industry interaction as Indian industry gets ready to face global challenges in a liberalized trade environment in which technology transfer from abroad to Indian companies will become increasingly difficult though technology may diffuse into the country by multinationals bringing high-technology product production into the country. There are other mechanisms like Mission REACH and Home-Grown Technologies of TIFAC (Department of Science and Technology), which are also contributing to increased academia–industry interactions. This type of research requires protection of Intellectual Property Rights through patenting.

Country-specific applied research

There are problems which are India or region-specific like endemic, infectious and parasitic diseases, prediction of the Indian monsoon, dryland crops, etc. which have to be addressed largely by the Indian scientific community though inputs may come from abroad. The green revolution initiated in the late sixties is an example of the latter, where the dwarf wheat varieties from abroad made a very valuable contribution. Papers published in these areas may not be of great interest to the already developed countries.

There is also overlap, of course, among these categories of R&D.

I remember, when I was the Director of the Physics Group at BARC in the late 80s, telling my colleagues that their work should satisfy the criterion of 'relevance or excellence, preferably both'. Either it should be relevant to the nuclear programme, or of such a high quality that nobody would be able to question the relevance of it; of course, the ideal situation is when both the criteria merge. P. Medawar[8] has put it differently: 'Always work on important problems!'. Advising young scientists; he says: 'It is not enough that a problem should be *interesting* – almost any problem is interesting, if studied in sufficient depth . . . the problem must be such that it matters what the answer is – whether to science generally or to mankind'.

From a national point of view, is there a sharp border between what has been called conventional science and strategic science? I do not think so. In my own area of high pressure physics, when we work on the fascinating 5*f*-metal thorium, one could call it conventional science. But when we

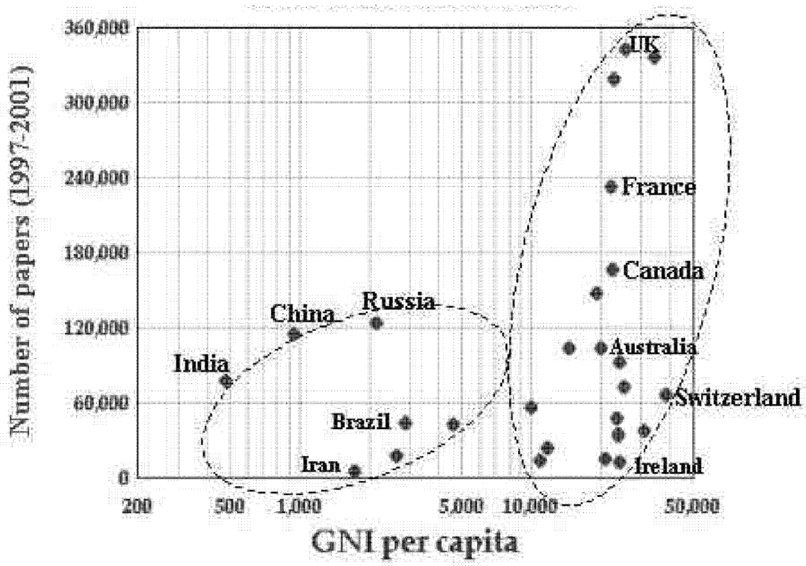

Figure 2. Relationship between GNI per capita and publications (1997–2001) for 26 selected countries (data from King[5] and WDR[6]).

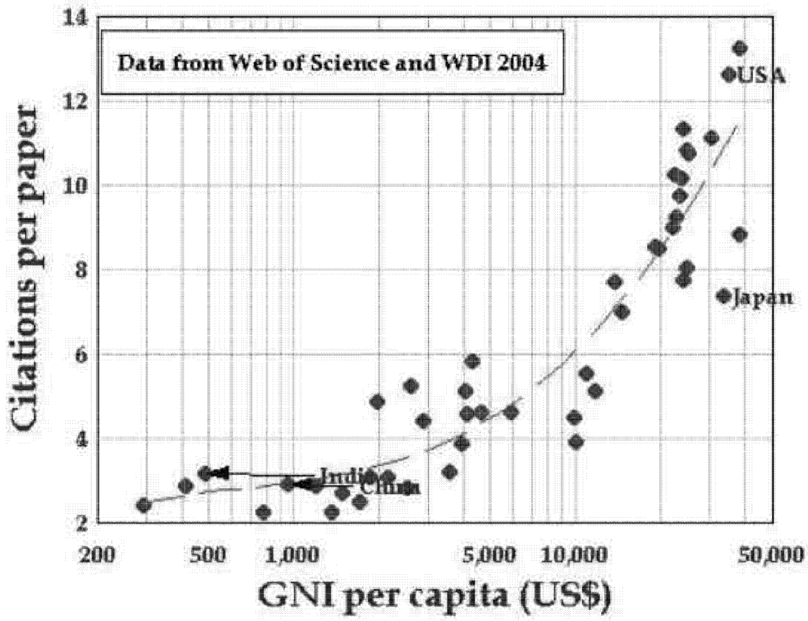

Figure 3. Citations per paper versus GNI per capita for 45 countries (Sikka and Gupta unpublished).

work on plutonium, a few atomic numbers up the periodic table – knowledge of its equation of state under high pressures is needed to predict exactly the yield of a nuclear weapon – one could call it strategic science. The same condensed matter theoretical techniques and powerful computational resources are needed for both.

If one then asks a general question: 'what kind of R&D is important for India?', I would say: (i) Globally competitive basic research, without too much concern about its impact on Indian technology; and (ii) R&D, which feeds Indian technology – for the needs of industry and of critical technologies, and of societal requirements.

The boundary between the two of course, is often fuzzy. High-T_c basic research, for example, was often mistaken for technology development. An understanding of the phase diagram and electronic structure of the entire actinides series from a basic research standpoint, is helpful when you are looking at uranium and plutonium in the context of nuclear weapon design.

In measuring progress in S&T, therefore, you cannot take a blinkered view. The next ten or hundred publications in *Physical Review* or *Journal of American Chemical Society* are important, but they are not the only measure of science. S&T for benefit to society – for national development and national security – is equally important.

Careers in science

I remember reading forty years back a 'Letter to the Editor' in a leading UK journal, which claimed – somewhat tongue-in-cheek – that the author had looked at the publication rate from UK laboratories and had come to the following conclusion: 'The number of papers published from a laboratory is independent of the number of scientists and is directly proportional to the number of typists!' Remember those were pre-word processor days and the secretaries who typed the papers did wield quite a bit of power! Speaking more seriously, I have postulated the following theorem, with which most scientists I have talked to are in general agreement. 'Given a certain number of senior scientists, the output of the laboratory is directly proportional to the number and quality of research students.'

This is the root cause we have to address and the publication rate problem will take care of itself. Steps have to be taken to attract talented young people into careers in science after the (10 + 2) stage and, of course, to increase the funding for basic research.

There has been a feeling in the country that nowadays the talented and bright young persons do not opt for careers in science. Steps have, therefore, to be taken to reverse this trend. A sub-committee of the Scientific Advisory Committee to the Cabinet (SAC-C), headed by N. Mukunda, has suggested creation of Centres of Academic Excellence to attract young students after the 10 + 2 stage; one of the recommendations is that leading R&D institutions like IISc and TIFR must have attached to them undergraduate teaching institutions[9].

The industry also has to contribute. At the end of several academia–industry interaction meetings last year in the Principal Scientific Adviser's Office, we came up with a series of recommendations. Very often people with degrees in engineering do not go in for research and technology development, even though they may have a talent for it, but opt for jobs in IT, management, or just go abroad. Of course, many of the young people who have gone abroad have come back later with substantial experience to enrich our development efforts or support Indian S&T efforts from their countries of residence. But it would be better today if we can create an environment to retain them in the country. One of the recommendations was that the industry could send some fresh employees (from among those they recruit during placement interviews in academic institutions) – the most talented among them – to do research in institutions and with professors whom the industry respects and pay them company salaries. The young research student thus hired would be treated no differently from any other student in that institution. He/she might not be addressing the company's problems consciously, but subconsciously the company's products would manifest in his (or her) thoughts and actions in all professional interactions. Over a period of 4–5 years, he/she could evolve into someone useful for the company's product or process development. Also, the company could gain important knowledge even during this period, because information access is free when academics from India and abroad meet. Doors are firmly shut when industry R&D professionals from various countries meet and IPR issues dominate.

Measures of progress in S&T

The indicators for measuring this progress seem to be well developed only for basic research and industry-related research. For the former, these include a count of publications, citations, awards earned and the prestige gained in terms of keynote and plenary talks, etc. The biology community, in a project called 'Faculty of 1000', is suggesting a value-based peer review mechanism as an alternative to impact factors. Count of patents, count of new products and processes and value

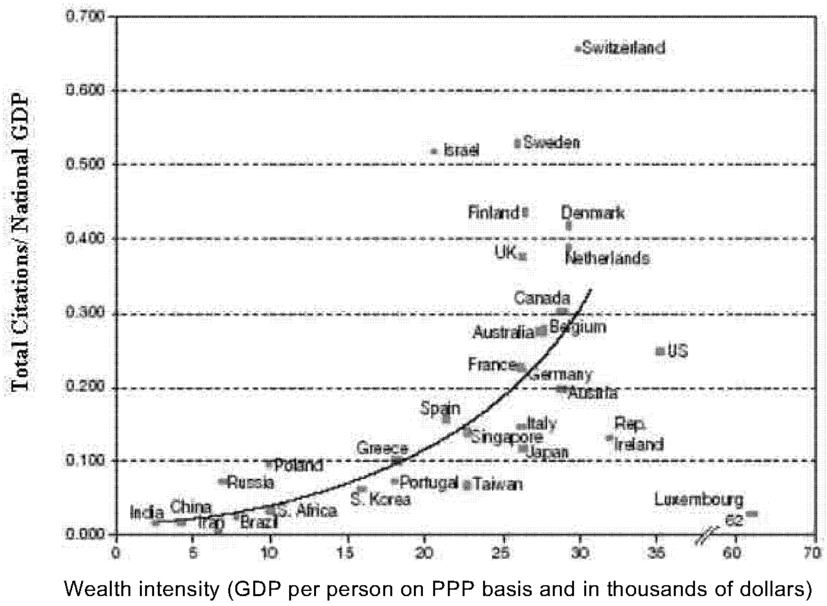

Figure 4. Total citations/National GDP versus national wealth (from King[5]).

additions resulting from these are some of the measures to evaluate the industry-oriented research. For mission-oriented research, how do you measure the progress in S&T, in building and utilizing indigenous nuclear power plants and communication satellites, for example, and the consequent self-reliance developed in the context of existing technology control regimes? The work done by the mission-oriented agencies for national security is also not easily quantifiable.

At a meeting in December 2002, with a 'Group of Scientists' (consisting of M. G. K. Menon, V. L. Chopra, R. A. Mashelkar, V. S. Ramamurthy, R. Natarajan, T. Ramasami, R. C. Mahajan and S. K. Sikka) to discuss the issue relating to the perceived stagnancy in science in India since the 1980; Subbiah Arunachalam made a presentation, which observed that a mere count of publications does not capture correctly the progress of the S&T system of the country, especially for the following: (i) Mission-oriented agencies, DAE, DOS, DRDO; (ii) Progress of research in industry-related applied research; here the measures, as already mentioned above, are patents and innovations leading to new products and processes. How do we quantify the latter? (iii) Country-specific applied research; (iv) Application of S&T for rural development and societal needs. Much of science required is well-known science, though the latest advances in science are also needed.

The Group of Scientists recommended conducting of studies on the following issues: identifying and spelling out parameters to quantify and to evaluate sector-wise progress of S&T in India during the last decade; evolving Indian *SCI* databases to capture all parameters specific to India; finding out the areas of decline/stagnation in progress in S&T in India with reasons; and suggesting broad guidelines for taking up remedial action and for evolving policy interventions.

Office of the Principal Scientific Adviser (PSA) to GOI placed the issue before SAC-C at its meeting held on 26 March 2003 and SAC-C recommended that a study should be conducted on measures of progress of S&T in India. The office has taken up, so far, the following three projects as a first step.

1. 'Analysis of Indian patenting activity in international and domestic patent system' to be done by National Institute of Science, Technology and Development Studies (NISADS), Council of Scientific and Industrial Research (CSIR), New Delhi.
2. 'Measures of Impact of Science and Technology in India: Agriculture and Rural Development' to be done by M.S. Swaminathan Research Foundation, Chennai.
3. 'Measures of Progress of S&T in India: An analysis of the Publication Output in S&T' to be done by NISTADS.

We are also considering projects to measure achievements in high-technology and in country-specific research (some overlap with # 2 above).

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2. Arunachalam, S., *Curr. Sci.*, 2002, **83**, 107–108.
3. Web of Science, Thomson Scientific, http://www.isinet.com
4. Gupta, R. P., *Curr. Sci.*, 2004, **86**, 1195–1197.
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