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GUEST EDITORIAL

Fundamental and applied research for the 'Make in India' programme

There are always discussions in the media regarding the role of science for the benefit of the society. This has become particularly relevant in view of the current emphasis on the 'Make in India' programme. In this year's Indian Science Congress, the issue was raised as to whether India should be investing in research in fundamental science or in applied science. Whenever there is a successful advancement in fundamental research, its outcome in any branch of science takes decades or more, before it can be of societal value. A good example is Einstein's famous equation $E = mc^2$ proposed in 1905. Decades later, this idea resulted in controlled nuclear energy to produce electricity. This delay between research in fundamental science and its application to the enrichment of the society is unpredictable. However, such a delay is by no means a deterrent to the development of the technology emanating from the research in applied sciences.

Advancement in technology stems from a rigorous understanding of the established relevant basic science. In most cases it is not related to the contemporary advances in the fundamental science areas. As an example, consider the development in communications and information access that has transformed the world today. It is the invention of the transistor and the subsequent hardware miniaturization which has made it possible. The current astonishing developments in hardware are primarily due to developments in materials technology. The essential science fundamentals to this development, i.e. quantum and statistical mechanics were established well before Bardeen–Shockley–Brattain (BSB) discovered the way to control the flow of charge in solids in 1947. The later development is through applied research. With priority, India needs urgent technology developments for the 'Make in India' programme to succeed, and the current research in fundamental sciences cannot be used as the input to such technology progress. Thus, it is not the new developments in fundamental science, but the thorough understanding of the established basic principles that will drive the innovations. Such a development should form the basis of the 'Make in India' campaign initiated by the Prime Minister.

A noteworthy article by Nobel Laureate David Gross in *Indian Express* (15 January 2016) brings out the need for 'discover in India' and 'innovate in India' as essential ingredients for the 'Make in India' programme. How can one increase the potential for discoveries and innovations in India? While the difference between innovation and discoveries is debatable, we would like to restrict ourselves to workable definitions of the two. Innovation is a product of the efforts to create a solution to a known problem or a new way of looking at known processes, while discovery happens due to a deviation (already thought about or serendipitous) from a routine protocol in an experiment or procedure, introduced intentionally or unintentionally. Innovation is thus a corollary to discoveries in various subject areas such as applied sciences, economics and behavioural and social sciences. In other words, while exploring nature's secrets, one should be capable of grasping the moment of discovery, as and when it occurs. On the other hand, continuous efforts are needed to innovate in all the fields relevant to the society. It is during these efforts that discoveries may also show up. To crystallize these definitions let us refer back to Bardeen's example. BSB were working on the problem posed by Bell Labs to replace the vacuum tube by a solid state device, a challenge to innovate. The transistor was invented during these efforts, which led the trio being honoured with the Nobel Prize for discovering the transistor effect. This innovation was possible because of the earlier discovery of the doping effect in semi-conductors by Ohl (Riordan, M. and Hoddeson, L., *IEEE Spectrum*, 1997, **34**(6), 46). This was an outcome of the applied research by researchers who had a thorough understanding of basic sciences (John Bardeen received his second Nobel Prize for explaining the low temperature superconductivity in metals).

What is constricting or restricting such innovations and discoveries in India?

The article in *Indian Express* mentioned that 0.9% of GDP is allocated to research and development in India. It was suggested that this needs to be augmented for improvement in the present scenario for indigenous technology development. Although the percentage of GDP by advanced countries allocated for R&D is supportive of this idea, it does not seem to be the only way of attaining the goal. Consider the special boost given for research in high temperature superconductors (HTS) in the late eighties. In 1986 J. G. Bednorz and K. A. Muller declared the discovery of HTS material during the pursuit of exploring oxides that had exhibited higher superconducting transition temperatures, compared to metals. In 1988–89 HTS were on the research agenda with priority for many countries. In those years, in spite of the debilitating FOREX reserves in India, a substantial amount was allocated for research in HTS. In this field, the list of top ten cited papers between 1999 and 2009 does not contain any Indian originated paper (data available on *ScienceWatch* website). Further, most of the patents bought by HTS-related manufacturers are other than Indian in origin. This goes to show that funding alone will not salvage India's lack of innovative drive. There is a more important consideration which must be recognized and acted upon urgently and that is, getting the right type of human resource in research.

Being in a research environment, we have had several occasions to review presentations and attend scientific seminars and conferences in India. Based on our experience, we find the following problems in the Indian science and engineering work force: (i) Lack of understanding of fundamentals in the subject of their work; and (ii) lack of appreciation in the cross-disciplinary subjects, in particular, science and engineering. Lack of understanding of the fundamentals in the given area of research restricts a person's ability to invent new methods or ways while attempting to find solutions to a problem. Such a person cannot predict changes that might occur when parameters in a given procedure or experiment are changed. An innovator does several experiments in the mind by anticipating correctly the possible variations in the experimental output under assumed changes in the input parameters. This allows him to narrow down the parameter space and choose the correct path. This may be compared with a chess player who anticipates many moves and its results in his/her mind to determine the safest and the best move. The innovator should also be able to communicate and help engineers develop products out of his innovations.

Considering the above lacunae, we must exercise extreme care while selecting the most suitable manpower. It is also necessary that a vibrant research environment be created in the labs for these persons to contribute maximally. It is expected that mission-oriented research can lead to certain deliverables to the society. This idea is already implemented in China for ensuring advancements in fundamental research, associated applied research and practical deliverables to the market. It often involves several institutions which are all funded towards this time-bound objective. Greater governmental initiatives in India in this respect are likely to lead to beneficial results.

How do we bring about this important objective? Taking a cue from the Chinese model, we suggest proceeding as follows: (i) Identify nationally relevant problems in various fields; (ii) create budgetary resources for such problems; (iii) entrust the task to the science and engineering academies of finding the relevant expertise available inside (and even outside) the country in fundamental research institutes, accredited Universities, IISERs, IITs/NITs, and industry, etc. in order to form task forces; (iv) provide resources and define time limits for finding solutions to the posed problems. These are not new ideas, but have been suggested earlier. The problem, always, has been that there is no universal commitment to solving the problems identified by the concerned group of experts and the resources are finally frittered away in various ways, not leading to actual deliverables. This is the crux of the problem. Unless we get over this bottleneck, the 'make in India' programme cannot succeed. To be specific, let us suppose that a group of scientists is identified to tackle and find innovative solutions to a technology issue. They may need to spend a significant part of their time and effort to arrive at a solution. During this process, their rate of publication in the relevant fields may suffer. Their parent institutions should have a mechanism which evaluates the efforts made by them so that their career progression is not affected. Similarly, agencies like NAAC and NBA should give due credit to the efforts made by these institutions (universities, colleges, etc.). As Gross mentions, 'India does not lack brilliant young people who can create the science of the future, but they need to be given appropriate opportunities, visibility and engaged in decision-making'. We would like to replace 'science' in the above line by 'science and technology'!

In the long run, for the sustainability of such endeavours, there is a need to revamp the competitive examination patterns in India. 'Innovative science education should begin at the schools to ignite the minds of the young' (Lavakare, P. J., *Curr. Sci.*, 2016, **110**(1), 10). It is therefore imperative for maintaining the initiative for innovations that new types of tests be designed that cannot be mastered by thriving coaching classes.

Thus, if we are to become strong in innovations in the country, we need young minds who are curious, who have clarity on basic fundamentals, have abundant enthusiasm to follow a chain of reasoning, have persistence and can dream about targeted areas for innovations in applied science and technology. This is apart from their aptitude and ability to write useful academic papers, publish them, etc.

At the Government level, funding for research in thrust areas must be integrated with the deliverables other than the publications. The thrust areas can be further divided into missions with well-defined outcomes and milestones. Even while the Government should continue to support basic sciences at the existing level or better, applied science needs large additional support and a shift in manpower resource strategy with a clear mandate to innovate socially relevant developments. Concomitantly the examination pattern of the competitive examinations deserves a serious reconsideration.

Development of good human resource and proper motivation to such persons to innovate can make the PM's enthusiasm for 'Make in India' a reality.

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