

# CURRENT SCIENCE

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GUEST EDITORIAL

## Academic and post-academic research, and national development

Useful arts, that is tools and crafts, developed by early civilizations, have evolved to become present day technologies. Archaeologists have given us evidence of the use of tools and practice of crafts by humans belonging to ancient civilizations, but it is difficult to say when and where the concept of scientific inquiry originated. Attribution of its origin to any particular civilization can be challenged. However, one attribute, that is delinking of scientific inquiry from practical arts, is common across all ancient civilizations. Practical arts were pursued by those who were dependent on them for their livelihood, while well-off elites were pursuing knowledge for the sake of knowledge. Only physicians were in a different category. They studied human anatomy and physiology with the objective of developing cures for diseases and surgical means for healing wounds and fractures.

Dominant thought was that pursuit of knowledge is civilizing, and has its own intrinsic value. A parallel thought, which looked at the utilitarian case of knowledge emerged during 14–17th century, when trade guilds became powerful in Europe, and Italian Renaissance, saw coupling of knowledge and its application in various ways. Interest in practical arts amongst elites grew when they realized that experimental observations are necessary for the growth of knowledge, i.e. science.

Francis Bacon opined that the roads to human power and human knowledge lie close together and are nearly the same. Royal Society was set up in 1660 and its second charter issued in 1663 endorsed this relationship by including in it the words ‘further promoting by the authority of experiments, the sciences of natural thing, and [the] useful arts...to...the advantage of human race’. A significant fraction (40–60%) of scientific discoveries during 17th century was for solving problems in navigation, mining, etc.

Despite increasing visibility of utility of knowledge, developments in technology continued independent of science. Individuals like James Watt and Thomas Edison were inventing products based on knowledge of technology and systematic and intuitive approach followed by them for development. Technologists had no formal education, and topics then comprising science, which was considered a part of philosophy, had no particular relevance to their trade. Universities were established, but

separation between science and technology (S&T) continued.

Shift in the relationship between S&T started during 19th century after science was emancipated from philosophy. The work done by Maxwell and Oliver Heaviside on the development and use of Maxwell’s equations is one example. Interchange between S&T became intense because of emergence of scientist-engineers such as Lord Kelvin, or engineer-scientists like Joseph Henry, Sadi Carnot, Alexander Bach, and Willard Gibbs. Chemical industry realized the importance of research with the synthesis of aspirin (in 1899) by Adolf von Baeyer and progressed rapidly.

Practical arts have evolved into engineering and technology, and are continuously advancing. For prosperity and well-being of mankind, technologies have to be developed and deployed. To select topics for research, encourage industry to innovate, and advise governments to formulate policies, one has to study the relationship between S&T. After the Second World War, the President of the USA set up a panel chaired by Vannevar Bush to advise on future research. His report, submitted in 1945, said that basic science is performed without thought of practical ends. This gave rise to the linear model, that is basic research leads to applied research, which after design and development leads to deployment.

We know that: the steam engine came before thermodynamics; the aircraft came before aero-space sciences; construction of structures and buildings started before the subject of strength of materials; and technical tools helped in experimentation leading to developments in science. For most part of the history, technology has developed independent of science, and has accelerated advances in science. The linear model was thus challenged and the reverse linear model, that is ‘new scientific possibilities are created by technology’, was proposed.

A project ‘Hindsight’ was funded by the Department of Defence, USA in early 1960s to study the development history of 20 defence systems, which were improved versions of earlier systems (Sherwin, C. W. and Isenson, R. S., *Science*, 1967, **156**(3782), 1571–1577). The most significant finding was that the improvement in performance or reduction in costs is largely due to the synergistic effect of a large number of scientific and technological

innovations of which only 10% had been made at the time the earlier systems were designed. Developments during the period intervening between the new and the old systems were called as ‘events’. Of the events, only 9% were classified under science, 91% under technology; only 0.3% came from undirected science. The most obvious way in which undirected science enters technology is the organized form of a well-established clearly expressed general theory included in handbooks, textbooks and university courses.

There were more surveys and the reverse linear model that is ‘technology is knowledge’ gained strength. Ultimately, a meeting on the relationship of S&T in 1972 is considered by historians as the ‘extended funeral’ of the linear model (Wise, G., *OSIRIS*, 1985, 1, 229–246). Donald Stokes opined that quest for knowledge and consideration for use can exist simultaneously or independently (Stokes, D. E., *Pasteur’s Quadrant: Basic Science and Technological Innovation*, Brookings, 1997). The basic issue is: if science develops technology, the money should be spent on science; and if technology drives both itself and science, the money should be spent on technology (Price, D. S., *Res. Policy*, 1984, 13(1), 3–20).

Continuing studies indicate that there are multiple facets of S&T relationship; S&T have similarities and differences. Both are progressing based on systematic approach. Technology is now an enterprise much larger than science and views about the relationship have evolved from hierarchical models (the linear and the reverse linear models), to non-hierarchical models which include ‘technology and science are mirror image twins’, the continuum model that is ‘science-technology complex’ or ‘military-industrial complex’. There is also a blurring of distinction between S&T in fields where an intuitive approach alone is not enough like in computer science, genetic engineering and fusion energy.

Undirected research thrives on governmental funding. It has become so large that governments in most countries including India are not able to provide resources. Simultaneously despite all round advances, problems that are facing humanity are multi-disciplinary, cannot be solved by individuals living in silos, and may have local, regional or global context. Solving such problems needs large multi-disciplinary teams which may be located in universities, or work places such as national laboratories, industries, consulting companies or non-governmental organizations. Researchers now are accountable to multiple agencies: the employing organization, peers, the funding agency, the regulator, public, and global bodies through international treaties. Evolution of the relationship between S&T, problems now facing humanity and multiple accountabilities for research, call for a relook at the classification of research. Following some other researchers, I endorse a simple terminology for classification that is Academic Research (AR) and Post-Academic Research (PAR) (Grover, R. B., *Indian J. Hist. Sci.*, 2019,

54(1), 50–68). PAR is invariably aimed toward and accompanied by development. There is a large overlap between AR and PAR, i.e. the two are fully intertwined. Both need prior knowledge and prior technology as input. Both generate new knowledge and new technology. It is most efficient to carry out PAR and AR at the same place or in very close collaboration, else there is a danger that results of AR will never be used or exploited.

Intertwining of AR and PAR has messages: for researchers in universities, the message is that one must pursue early-stage PAR while doing AR; for researchers in national laboratories, the message is that while one starts with PAR to address a given problem, it might require contextual AR for arriving at an efficient solution and that must be pursued. This has implications for the structure of the research establishment in a country and policies followed for science, technology, innovation and education (Grover, R. B., *Curr. Sci.*, 2019, 117, 1140–1147).

For the advancement of the country, research must lead to development of products and processes and therefore, the country needs both AR and PAR. To paraphrase William Shockley (Nobel lecture, 1956), researchers should have a healthy respect for both AR and PAR. While one cannot brush-off long-range value of AR into new areas where useful outcomes in the future cannot be foreseen, resource allocation for AR not contextually linked to PAR will invariably be governed by resource position.

Researchers should prioritize working on problems facing the employing organizations, their country and also work for deployment of results. The organizations and the country should create an ecosystem to facilitate such deployment. Topics selected based only on literature survey would fill the knowledge gaps, but might have to wait for a long time before deployment of results. Doctoral programmes where a part of the research is done in the industry should be cultivated. Through a strong interaction with industry via the medium of internships and consultancy, academia should help the governments in creating an ecosystem where industry looks forward to employing highly qualified individuals with the objective of accelerating innovations. University faculty should inculcate a respect for PAR in students and re-examine increasing academic valorization of highly specialized knowledge. The word ‘research’ in the manifesto ‘unity of education and research’ should be interpreted to include both AR and PAR. To achieve all above, the leadership in academia should incentivize working on national problems (Elkana, Y. and Klopper, H., *The University in the Twenty-First Century*, CEU Press, 2016, 184).

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