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EDITORIAL

Science, Invention and Pasteur's Quadrant

New programs, initiatives, products and even books are customarily launched at public functions, providing photo opportunities and a chance for acknowledging the contributions made by many well wishers of the venture. As a minor (and available) functionary, I found myself roped into speaking at a gathering organized to unveil an 'electronic classroom', in a school for underprivileged children. A magical white board, with a touchscreen, brought the world of *Google* and *National Geographic* into a small and crowded classroom, filled with expectant children. The wonders of the communication age permitted the proceedings to be beamed live to two other schools, several kilometres away. In a very real sense, the children had a wide open window through which the world was suddenly visible. My brief was simple. I was to answer questions asked by the children, including those who viewed me on a screen at a distant location. I am still a novice at videoconferencing and feel most comfortable when a questioner confronts me in flesh and blood. Even as I wondered what the children might say, the first question was flung at me 'Have you invented anything?', asked a bright little boy, his voice eerily distorted by technology. My instant and instinctive response was to say 'No, I have not invented anything'; honesty is sometimes not only the best policy but also a default option in a stressful situation. On the long journey back to my laboratory, through Bangalore's crowded and chaotic streets, I came to the conclusion that there is much to learn from children. The image of the scientist in the public eye is a simple one; scientists are inventors who create wonderfully useful devices. They are puzzled about what most scientists do, since inventions (especially those that are widely applicable) come along very infrequently. In thinking about inventors, I could quickly conjure up images of Benjamin Franklin, Thomas Edison, Alexander Bell and Nikolau Tesla. Michael Faraday seemed more of a 'scientist', in the mold that most professional scientists look up to, although the induction motor may be as practical and applicable a device as any. J. C. Bose was another name that seemed to straddle two distinct worlds; one, a practical and inventive arena, while the other was a more academic and esoteric playing field. The little boy's penetratingly innocent query raised another question in my mind. Was 'invention' a restrictive word that excluded scientific 'discovery'? Was the hugely popular word 'innovation' a modern term that expanded and linked the more traditional words 'invention' and 'discovery'? And, in the background loomed that perennial issue: are 'pure' and 'applied' science as distinctly separated as Rudyard Kipling's East and West?

Basic research up to the middle of the 20th century was largely driven by the desire to understand the physical and natural world. Inventions were the result of creative genius, some of them spectacularly altering the human condition. Organized, government-supported research, involving large numbers of scientists, is really a post-World War II phenomenon. Vannevar Bush signalled a new era in research policy when he produced his much cited 1945 report *Science: The Endless Frontier*, which set the stage for large scale public funding of basic research in the United States. Bush was clear in his view that applied ('applicable' may be a more appropriate term) research can grow only out of basic research, creating a powerful argument for supporting 'pure' science. More than half a century after Bush argued persuasively for public funding of science, the world has changed beyond recognition. The debate on the utility of basic research has grown in intensity, as have the expectations on the practical outcomes of scientific research. It is in this climate that Donald Stokes advanced a new approach to viewing the interconnected world of pure and applied science. Stokes, a professor at Princeton died in 1997, the year in which his influential book *Pasteur's Quadrant: Basic Science and Technological Innovation* was published (Brookings Institution Press, Washington DC).

Stokes examined the legacy of the Vannevar Bush report in the context of 'the debates over science and technology policy in our own time – the increasingly troubled dialogue between science and government today'. He notes that: 'admiring as we all can be of the success of the paradigm view set out in *Science: The Endless Frontier* and its ushering in of the Golden Age of American science, the incompleteness of this view of the nature of basic sciences and its relationship to technological innovation has become increasingly clear'. Stokes discards the 'linear' view of a progression of science from a 'pure' zone at one end of the spectrum to an 'applied' region at the other. Stokes introduces a two dimensional conceptual plane in which the vertical dimension represents 'the degree to which a given body of research is motivated by the quest of fundamental understanding and the horizontal dimension the extent to which it is motivated by considerations of use'. Editorial columns are traditionally devoid of figures, but the Stokes Diagram is easy to visualize. Four distinct quadrants (varying dimensions may be useful) are marked on a square. The top left is the Bohr quadrant, capturing the space of basic research at its best, an unalloyed search for understanding. The bottom right quadrant honours Edison, symbolizing applied research and inventive ability of the highest order. The top right zone is Pasteur's quadrant, representing, in Stokes' words, 'use-inspired basic research'. Why did a professor of political science and public policy chose Louis Pasteur as the icon to capture the fusion of basic and applied research at the highest level? Stokes advances an interesting argument: 'There is no doubt that Pasteur wanted to understand the process of disease at the most fundamental level as well as the other microbiological processes that he discovered, but he wanted that to deal with silk worms, anthrax in sheep and cattle, cholera in chickens, spoilage in milk, wine and vinegar, and rabies in people. The melding of those motives in the work of the mature Pasteur is so complete that you could not understand his science without knowing the extent to which he had considerations of use in mind. *The mature Pasteur – not the crystallographer at the dawn of his career, the man who took on the enigma of racemic* (tartaric) *acid at the Ecole Normale – embarked on a pure voyage of discovery* (emphasis mine). But the mature Pasteur never did a study that was not applied while he laid out a whole fresh branch of science'. I was struck by Stokes' assessment as I might have placed the young Pasteur's resolution of tartaric acid in the mid-19th century, the starting point of all of organic stereochemistry and structural biology, right at the top of the Bohr quadrant. By Stokes' reasoning Pasteur would have been an anomaly in a one-dimensional view of research, appearing discontinuously at two ends of a continuous spectrum. The Stokes Diagram resolves this, with Pasteur exemplifying the highest ideals of science, while simultaneously powering the most breathtakingly practical innovations. The Edison quadrant is, undoubtedly, the region of Stokes' space that is easiest to appreciate for the lay public. In considering the race towards a major invention, Stokes notes that 'Edison never allowed himself or those working with him . . . five minutes to consider the underlying side of the significance of what they were discovering in their headlong rush to commercial illumination. Edison himself one night heated up a filament in a vacuum and observed what is now known in American physics as Edison's effect because he wrote it down in his notebook. . . if he had tried to consider its more fundamental implications, he might have shared the Nobel prize with J. J. Thompson for discovering the electron, but he went right on' (Stokes, D., Completing the Bush Model: Pasteur's Quadrant. Talk at a conference 'Science: The Endless Frontier' 1945–1995, 9 December 1994; http://cspo.org/products/conferences/bush/stokes.pdf).

Where do some recent advances fall in the Stokes Diagram? The work leading to the transistor or magnetic resonance imaging must surely belong in Pasteur's quadrant. So too must the work of Boyer and Cohen, which ushered in the recombinant DNA revolution; clearly an outstanding example of 'use-inspired' basic research, despite the absence of recognition by Nobel committees. The discovery of the polymerase chain reaction (PCR), which allows DNA to be copied with spectacular efficiency, has revolutionized biotechnology and might rightfully appear in Edison's quadrant. The Stokes diagram allows scientists and analysts to reflect on the position of their favourite advances in science.

What of the unnamed quadrant which lies to bottom left of the Stokes diagram, diagonally related to Pasteur's quadrant. This is probably the most densely populated region of Stokes' 'two-dimensional' conceptual plane. This is where I believe most of us work, attempting to move away from the origin in all directions. A little reflection suggests that the quadrants in the Stokes' plane are not separated by insurmountable barriers; indeed a seamless transition from basic to applicable research is readily achievable. The limiting factors will, of course, be the imagination and creativity of individuals and their passion and commitment to their chosen areas of work. I am sure if my young interrogator had been allowed to frame a supplementary question he might have asked: 'Why have you not invented anything useful?'. This is a question that must often appear in the minds of policy makers, charged with the task of reconciling financial inputs with scientific and technological outcomes. The Stokes analysis was stated in somewhat different terms more recently by John Marburger, the Director of the US Office of Science and Technology Policy. He recalled J. Robert Oppenheimer's observation that society supports science for two 'disturbingly different' reasons and added that: 'Science is useful, and the pursuit of science is ennobling. Perhaps, those qualities are complementary in the sense of quantum physics – narrowing the focus on one makes the other more uncertain. If so, funding the state in which both are optimized is a worthy goal of science policy' (*Physics Today*, June 2006, pp. 38–42).

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