Survey of the Pasteur's Quadrant Model in the Planning of Research and Technical Education

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Abstract

This paper reports the results of the survey on (a) use-inspired basic research also known as Pasteur's quadrant, in which research pursues both goals of understanding and use, and (b) the effort of U.S. Department of Education to innovate science, technology, engineering, and math (STEM) education by adoption of Pasteur's quadrant.

Keywords : Use-inspired basic research, Pasteur's quadrant, STEM, ARPA-ED.

Introduction

Donald E. Stokes in his 1997 book, Pasteur's Quadrant : Basic Science and Technological Innovation, divides scientific research into four quadrants by dual dichotomy on whether a given body of research quests for fundamental understanding and whether the research is guided by consideration by use. The models derived are the pure-basic research solely for understanding and hence called Bohr's quadrant, the pure - applied research solely for application and hence called Edison's quadrant, the use - inspired basic research which pursues both understanding and use as illustrated by Pasteur's work toward both goals - hence called Pasteur's quadrant, and the last model inspired neither by understanding nor use.[1]

The use-inspired basic research model is quite realistic in today' view, as witness such organizations as National Institutes of Health (NIH) and Defense Advanced Research Projects Agency (DARPA) have long made efforts to extend the frontiers of understanding but also pursued practical use on one hand, and many nations have virtually conducted academic research pursuing both goals on the other. But in view of American postwar paradigm of science policy in which basic research and applied research have been separated for decades, Stokes' Pasteur's quadrant and his proposal of new compact between science and government have been perceived as a quite new idea.

Quite recently, in April 2015 issue of Scientific American, Russell Shilling, executive director of STEM at the U.S. Department of Education (USDE) has given a commentary on the Advanced Research Projects Agency for Education (ARPA-ED) with background explanations such as social demands to improve STEM skill among the workforce and the advantage of seizing rapidly advancing information technology (IT).[2] ARPA-ED, created by the President's 2012 budget, pursues technical breakthroughs that advances methods of teaching and learning for 21st-century workforce.[3] It is noted that Shilling emulates DARPA to use Pasteur's quadrant as a means to succeed their mission especially at the intersections of science and technology.[4]

Once the adoption of Pasteur's quadrant by US government into the strategy of research and development planning is publicly known, it is plausible that the subjects of Pasteur's quadrant and its application will be discussed further in many fields and places.

This paper delineates, first, American postwar paradigm of science policy, in which basic and applied research are distinctly separated. Second, the model of scientific research named use-inspired basic research, or known as Pasteur's quadrant is described. The contents of above two subjects are extracted from the Stokes' book. Third, on the STEM education initiated by ARPA-ED, the comprehensive approach and projects where the role of Pasteur's quadrant is expected, are briefly introduced from publicized USDE documents.

American Postwar Paradigm of Scientific Policy

The view of basic science and its relation to technological innovation, which was set out in 1945 in Vannevar Bush's report, Science - The Endless Frontier, submitted to the President, became a foundation of the U.S. scientific policy for decades after WWII.[5] Bush's view of basic research was, first, that "basic research is performed without thought of practical ends," and "its defining characteristic is its contribution to general knowledge and an understanding of nature and its laws." He saw an inherent tension between understanding and use as goals of research, and by extension, argued the separation between them.[6]

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Bush's second view was that "the basic research is the pacemaker of technological progress," a powerful dynamo of technological progress as applied research and development convert the discoveries of basic science into technological innovations. Furthermore, he asserted that "a nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade."[7]

Bush's paradigm has recently exhibited limitation. As witness, instead of pursuing one or the other of goals of understanding and use, a number of government organizations such as Department of Agriculture, NIH and DARPA have shifted the emphasis toward scientific basic research inspired by the applications and or technological use because of realistic necessity. Also on the technological harvest from science, it has been observed that technologies first developed in America have been commercially exploited elsewhere in the world.[8] Realities have induced question on the prevailing paradigm.

Quadrant Model of Scientific Research

Definition of model

With the example of Louis Pasteur, Stoked modeled scientific research based on the goals of understanding and use. It is well known that Pasteur sought a fundamental understanding of microbiological processes but also applied this understanding to prevent spoilage in vinegar as an example.[9]

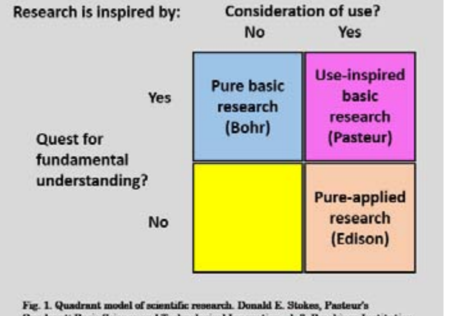

Fig. 1. Quadrant model of scientific research. Donald E. Stokes, Pasteur's Quadrant: Basic Science and Technological Innovation, ch 3. Brookings Institution Press, 1997. (Redrawn)

The resultant model is shown in Fig. 1. The upper-left cell or quadrant (Stokes uses cell and quadrant interchangeably) includes research that is guided solely by the quest for understanding without thought of practical use, so that it is called Bohr's quadrant.

The lower right-hand cell includes research that is guided solely by applied goals without seeking a more general understanding of the phenomena, so that it is called Edison's quadrant.

The upper right-hand cell includes basic research that seeks to extend the frontiers of understanding but is also inspired by consideration of use, so that it deserves to be known as Pasteur's quadrant. This category is wholly outside of the Bush's framework. Stokes explains that the fundamental research of the Manhattan project and Irving Langmuir's surface physics are included in this category.

The lower left - hand cell includes research that is inspired neither by goal of understanding nor by the goal of use. The example is birdwatching which results in Peterson's Guide to the Birds of North America, and birdwatcher might want to call this Peterson's quadrant. This quadrant can be important precursors of research in Bohr's quadrant.[10]

According to the survey on the breakthroughs in the ten most important clinical advances since 1940s, Bohr's, Pasteur's, and Edison's quadrants included, respectively, 37%, 25%, and 21% of the key articles. The remaining 17% were development (15%) or "review and synthesis" (2%).[11]

Revised Dynamic Model

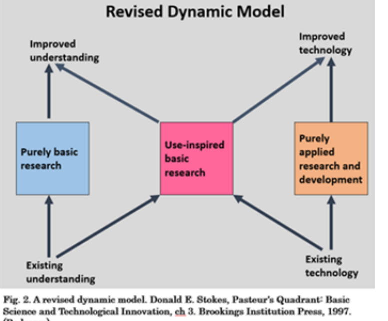

Fig. 2. A revised dynamic model. Donald E. Stokes, Pasteur's Quadrant: Basic Science and Technological Innovation, ch 3. Brookings Institution Press, 1997. (Redrawn)

Science moves from an existing to a high level of understanding by pure research in which technological advances play little role. Similarly technology moves from an existing to an improved capacity by targeted research in which fresh advances in science play little role. But each of these trajectories is at times strongly influenced by the other, and this influence can move in either direction, with use-inspired basic research often cast in the linking role. Such interactive dual and upward trajectories are depicted in Fig.2.[12]

One of the most important factor in converting pure scientific knowledge to application is “time to application.” As Pasteur quickly applied the knowledge gained by his own fundamental work in microbiology to industrial and public health, as much of the fundamental work in molecular biology is quickly applied in biotechnology today. It is important to see that some advances of fundamental science have near-term applications, and the use-inspired basic research can easily find a good timing of the conversion.[13] The feed-back and feed-forward coupling between science and technology, along with time factor, enables continuous research and development possible until completion, and hence use-inspired basic research is quite efficient process.

Advanced Research Projects Agency for Education (ARPA-ED)

U.S. government created ARPA-ED by the President’s 2012 budget to support research on innovative and emerging forms of education and learning technology, with the goals of improving students’ academic performance, more specifically the skill of STEM.[3] The requirements for ARPA-ED are:

(1) Identify and promote advances in learning, fundamental and applied sciences, and engineering that may be translated into new learning technologies;

(2) Develop, test, and evaluate new learn- ing technologies and related processes; and

(3) Accelerate transformational techno- logical advances in education.[14]

The pathways leading to these goals are (a) Basic and Applied Research, (b) Field Scan/Field Innovation, and (c) Directed Development. Basic and Applied Research is a creative engine for breakthrough innovation in learning technologies and is proceeded by the use of Pasteur’s quadrant. The goals of this category are “digital tutors” as effective as personal tutors, “the virtual learning laboratory” for use by more students, and educational videogames capable of complex collaboration in multi-player game. Also included is the theoretical cognitive modeling foundations of today’s cognitive tutors. Field Scans of efforts by practitioners and others throughout education can help identify and support the most successful, ideally resulting in the spread of effective ideas.

Directed Development provides the ability to pursue a small number of high - impact projects, from concept through demonstration or prototyping. Directed development projects begin with a specific end goal. It is noted that Directed Development focuses on advancing beyond the state-of-the-art that the activities of the field are unlikely to produce the desired outcome in the prescribed time frame.[3]

Concluding Remarks

Pasteur’s quadrant was implemented in practice after fifteen years since the Stokes’ book was published. Many cases will follow in future. It is reasonable to conjecture that the search for optimum solution of structure and execution will continue, and the Stokes’ original concept will evolve for better as experiences accumulate.

References

Donald E. Stokes, ***Pasteur’s Quadrant : Basic Science and Technological Innovation.*** Brookings Institution Press, 1997. Stokes died of acute leukemia in 1997, after having put the final touches on this manuscript. At the time of his death, he was professor of politics and public affairs in the Woodrow Wilson School of Public and International Affairs at Princeton University.

Russell Shilling, ***“The Case for Education Moon Shots”.*** Scientific American, Vol. 312, No. 4, pp. 10, April 2015. Shilling is executive director of STEM at the U.S. Department of Education. He and his group have publicized articles on ARPA-ED and Pasteur’s quadrant.

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