The co-evolution of technoscientific knowledge: implications for future scientific methodologies

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Scientific knowledge has played an obvious and significant role in the advance of human technology; in turn, human technology has shaped powerfully the advance of scientific knowledge. One might even say that there is no standalone scientific method, but instead a technoscientific method in which science and technology are distinct but co-evolve synergistically.[1,2]

Recent progress in one technology – artificial intelligence (even in its "narrow" sense) – promises similar *quantitative* advances in the productivity of scientific research and development.[3] However, artificial intelligence of the future (as it becomes more "general") promises potential *qualitative* advances in the productivity of scientific research and development: (a) in the taking on itself of the execution of the technoscientific method (or at least pieces of it); and (b) in providing a test-bed for experimenting with various technoscientific method execution strategies so as to improve how humans themselves "do" technoscientific research and development.

We anticipate that shaping these qualitative (albeit likely long-term-future) advances in the productivity of technoscientific research and development will benefit from an understanding of *current* technoscientific research and development methodologies – an understanding of how humans *currently* do technoscientific research and development.

In this talk, we review two recent advances in that understanding and connect them to how technoscientific research and development might be done in the future. A first advance is our emerging hypothesis[4] about the nature of the full technoscientific research and development cycle, which includes pieces that have been long appreciated (e.g., hypothesis testing) but also pieces that are less well appreciated (e.g., exaptation, a term borrowed from evolutionary biology, in which solutions that have been adapted to solve particular problems are co-opted to solve new problems). A second advance is improved definitions[5] of two essential but very different flavors of technoscientific research and development: research, which maps to Kuhn's "revolutionary" science and Arthur's "radical" engineering"; and development, which maps to Kuhn's "normal" science and Arthur's "standard" engineering.[6,7]

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[1] V. Narayanamurti and T. Odumosu, *Cycles of invention and discovery.* Harvard University Press, 2016.
[2] V. Narayanamurti and J.Y. Tsao. "Nurturing transformative US energy research: Two guiding principles." MRS Energy & Sustainability 5 (2018).
[3] See, e.g., Symposium MT02 (Closing the Loop – Using Machine Learning in High-Throughput Discovery of New Materials) at the most recent 2019 Materials Research Society Fall Meeting.
[4] J.Y. Tsao and V. Narayanamurti, manuscript in preparation.
[5] J.Y. Tsao, C.L. Ting, and C.M. Johnson. "Creative outcome as implausible utility." Review of General Psychology 23, no. 3 (2019): 279-292.
[6] T.S. Kuhn, *The structure of scientific revolutions*. University of Chicago Press (4th Edition), 2012 (1st Edition published in 1962).
[7] B.W. Arthur, *The nature of technology: What it is and how it evolves*. Simon and Schuster, 2009.