Engineering 19 (2022) 22–23

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

Science for This Age: Paradigm Shifts and Global Challenges

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Whether the goal is to meet global challenges or to enable a paradigm shift, it is always essential for science to move beyond conventional thinking. Moreover, the mutually beneficial interactions between global challenges and paradigm shifts require a great deal of effort. To this end, it is imperative for the scientific community not only to respond to major challenges by shifting paradigms in science but also to drive paradigm shifts in science by responding to major challenges. This aim sets a higher bar for scientists as, in order to achieve it, we must properly identify the scientific questions in research and better utilize existing knowledge. At present, however, we are not paying sufficient attention to this aim, nor are we sufficiently competent in this regard. It is essential for the global scientific community to pay more attention to these interconnected issues of global challenges and paradigm shifts.

1. Meeting major challenges by shifting a paradigm in science

A paradigm shift is understood here as a fundamental change in the various processes by which science is conducted, understood, and accomplished. Paradigm shifts in science have gradually become a major focus of attention among academic communities. Some researchers hold the opinion that data-intensive research is the fourth scientific paradigm, while others suggest that the application of artificial intelligence (AI) also represents a new scientific paradigm. Of course, both are important future directions; nevertheless, a consensus has not yet been reached regarding the direction and fundamentals of the anticipated paradigm shift in science.

In our view, the scope for a substantial paradigm shift in contemporary science should be both broad and intrinsic. For example, at a minimum, more attention should be paid to the common principles underlying the complexity of today's world (including big data and AI), because the ability to deal with major challenges and achieve the generality and full impact of AI depends heavily on breakthroughs in principles of complexity. In fact, the landscape of knowledge systems—like our complex world—is characterized by multiple levels and scales. A study of the principles of complexity at each level, especially the formation and evolution of dynamic structures at the corresponding mesoscale and the interconnectivity of complexity at different levels, will inevitably be a significant entry point in promoting a paradigm shift to address global challenges.

Two relevant points should be stressed: The first concerns the convergence between reductionism and holism. With the increasing complexity of scientific problems and the growing attention being paid to spatiotemporal structures, the focus of scientific research is gradually shifting from the element-scale details and system-scale behaviors of each level to the relationship between them—that is, to mesoscale complexity as a bridge between these scales. The second aspect concerns exploring the "simplexity" that can be distilled from complexity at different levels by reducing dimensionality and generalizing the common principles within diversity. Unlike simplicity, simplexity involves achieving complementarity between simplicity and complexity and deriving commonality from the diversity of complex systems.

Both aspects require not only a transdisciplinary approach but also a call to identify the missing links in order to arrive at an integrated view of the knowledge system and the responses to major challenges. Evidence-based discussions about these two aspects may be an important step in promoting paradigm shifts in science. In this context, the scientific community should proactively explore the possible direction of such a shift and reach consensus step by step, thereby bringing in global efforts to respond effectively to major challenges through a fundamental shift.

2. A paradigm shift in science driven by tackling global challenges

How do we address common global challenges such as the 17 Sustainable Development Goals (SDGs) in a coordinated way [1]? How do we respond to climate change, while maintaining a balance between achieving carbon neutrality and ensuring socioeconomic development? How do we deal with epidemics and pandemics in a scientific and effective way to protect human life and health? These are examples of highly complex problems that are socially, economically, industrially, and technologically relevant. Only scientific advancement, built on a paradigm shift in science, can open optimal pathways and provide the necessary scientific fundamentals for achieving adequate solutions.

https://doi.org/10.1016/j.eng.2022.05.002

Our understanding of nature, human beings, and human activities of production has been extended to the molecular and atomic levels within the time and space range of the whole universe. However, in scientific development, scientists from various fields still encounter difficulties due to their inability to deal with the challenges of complexity. This suggests that there are gaps in the existing knowledge system and, more particularly, in our ability to utilize existing knowledge. For example, in our fight against the coronavirus disease 2019 (COVID-19) pandemic, we have seen how rapid advances in science and technology have played major roles; yet we have also encountered problems in understanding the multilevel interaction between the virus, the human body, and society at large.

In achieving global carbon neutrality, one of the remaining unsolved and complicated issues is that of systematically optimizing strategies at different phases and levels [2] and, in so doing, providing evidence-based policy guidance. All of these issues involve the regulation and optimization of multilevel dynamic networks in complex systems. It is necessary to integrate reductionism and holism and to derive common laws from different complex cases in various fields—both of which call for a new paradigm in science. In view of these challenges, long-term exploration through typical cases will certainly become an effective driving force in shifting the paradigm and creating an important path toward meeting major challenges.

Previous paradigm shifts have taught us that the process of reaching consensus can be lengthy and complex. Nevertheless, science has now entered an era of global openness and collaboration, and the developments that accompany a paradigm shift can be driven by the common challenges faced by different fields. Thus, once the shift in direction is clarified, change will take place more rapidly. As a result, it is critical to seize the opportunity, identify the direction, and work toward consensus! The joint efforts of various disciplines are needed and this calls for an enhancement of globalization and transdisciplinary science.

3. Identifying scientific questions as a bridge between challenges and paradigms

Whether it is to truly understand the nature and relevant mechanisms of major challenges, to meet these challenges through paradigm shifts, or to fill in the gaps in the knowledge system through scientific development itself, the key is to identify the intrinsic scientific questions as accurately as possible. This is the essence and starting point of scientific research, and often determines the value, progress, and achievement of research work. For basic research, the fundamental goal is to put forward scientific questions and resolve them. Such questions may derive from the frontiers of science or the needs of socioeconomic development. In any case, exploration, creativity, and originality are essential in all cases.

What is a scientific question? On the one hand, it is difficult to establish a universally agreed-upon definition of a scientific question, due to variations in the origin of scientific problems and the complexity of the cognitive process. On the other hand, scientists with long-term professional training have their own tacit understanding based on the commonality and diversity of each scientist's academic activity. The combination of complexity, commonality, and diversity makes the definition and identification of scientific questions complicated. Therefore, it is necessary to discuss common characteristics of scientific questions in order to achieve the maximum level of commonly agreed-upon tacit understanding among scientists, which will in turn facilitate the derivation of generalized simplexity and commonality from complexity and diversity.

For a possible common understanding of scientific questions, whether described by philosophy as knowable-unknowns or interpreted by scientists in actual research activities, the intrinsic common nature of the questions should be definite, regardless of the variety of formulations. It is reasonable to say that proposing scientific questions is the process of exploring the origin of knowledge, and that any scientific question should reflect what is to be complemented, improved, or extended in the current knowledge system. Sometimes, in practice, problems that can be explained with existing knowledge are confused with what remains unsolved. We cannot afford to ignore this issue. Likewise, while basic and applied research should interact with each other, care should be taken not to turn basic research into applied research without goals, or to turn applied research into basic research of low quality.

The steps in identifying scientific questions are closely related to the characteristics of the subject field. Generally speaking, however, they can be summarized as follows: ① to raise problems about matter or phenomena; ② to explore and elucidate these problems from a scientific perspective; ③ to analyze the gap in existing knowledge that needs to be bridged from that specific perspective; ④ to determine the specific direction toward bridging the gap; and ⑤ if possible, to think in an in-depth way about the common principles that may be involved in the overall research programme. Through this process, scientific questions will gradually be identified, and the case studies that come into play can contribute to a paradigm shift due to their common intrinsic nature.

In conclusion, the ability to identify scientific questions is vital in order to meet major challenges. This ability is also the glue of transdisciplinary convergence and the driving force toward a paradigm shift in science. Different analyses can be made from different perspectives. While the questions raised may differ, prioritizing the identification of scientific questions will certainly contribute to encouraging an academic culture that is conducive to achieving major scientific breakthroughs. Young researchers, with their enormous creativity and curiosity, are least likely to be influenced by conventional thinking and most likely to enjoy the greatest potential in this regard. Shifting the paradigm in science and tackling global challenges urgently require concrete scientific action. A change in mindset is a primary step, while the key to progress is to identify significant scientific questions from a new perspective. Among various alternative directions, it is of paramount importance to focus on the aforementioned principle of multilevel complexity. Hopefully, this focus can be realized—although it is likely to be possible only when different disciplines make joint efforts to address global challenges by deducing the simplexity from diverse complexity through case studies.

Acknowledgments

We appreciate the financial support from the International Partnership Program of Chinese Academy of Sciences (122111KYSB20170068). We would like to thank Manfred Horvat for his comments, suggestions, and polishing of the text; Jie Shen, Jin Xu, Rongda Tang, and Liyao Zou for their help in preparing the English version of the manuscript.

References

[1] Fu B, Wang S, Zhang J, Hou Z, Li J. Unravelling the complexity in achieving the 17 Sustainable Development Goals. Natl Sci Rev 2019;6(3):386–8.
[2] Huang W, Li J. Optimizing the roadmap to carbon neutrality with a new paradigm. Engineering 2021;7(12):1678–9.