Implications of New-Era Research Paradigm Transformation and Responses to Postprint

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Date: 2023-08-12T00:00:00+00:00

Abstract

This article conducts a comprehensive investigation into the main connotations and important impacts of the transformation of research paradigms from both theoretical and practical perspectives. At the theoretical level, starting from Kuhn and his representative work "The Structure of Scientific Revolutions", it explores the logical essence of the concept of "paradigm". At the practical level, through questionnaires, interviews, and other forms, it investigates and distills three aspects of the connotation of research paradigm transformation in the new era: solving systemic complex problems has become the main driving force for research paradigm transformation in the new era, simulation modeling and data science may become effective breakthroughs for promoting research paradigm transformation, and organizational innovation in research activities has become the foundation for promoting research paradigm transformation. On this basis, it analyzes the existing problems in China's current response to research paradigm transformation and proposes corresponding policy recommendations.

Full Text

Preamble

Connotation and Countermeasures of Scientific Research Paradigm Transformation in the New Era

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Abstract

This study comprehensively explores the main connotation and important impact of scientific research paradigm transformation from both theoretical and practical perspectives. At the theoretical level, beginning with Thomas Kuhn and his seminal work *The Structure of Scientific Revolutions*, we examine the logical essence of the concept of “paradigm.” At the practical level, through questionnaires, interviews, and other methods, we identify three core dimensions of research paradigm transformation in the new era: (1) solving systematic and complex problems has become the primary driver of transformation; (2) simulation and data science may serve as effective breakthrough points for advancing paradigm change; and (3) organizational innovation in research activities has become the foundation for promoting such transformation. Building on this analysis, we examine current challenges in China’s response to research paradigm transformation and propose corresponding policy recommendations.

Keywords: research paradigm, scientific community, complexity, simulation, data science, organization of research activities, discipline

Today, science and technology have become key variables shaping and influencing the global economic and political landscape. Governments worldwide continuously adjust and refine their science and technology policies, increasing investment in priority areas to secure advantageous positions in international competition. Despite growing societal emphasis on and investment in science and technology, accompanied by rising numbers of publications and patents, disruptive achievements have become increasingly rare [1]. Major discoveries are more difficult to attain, requiring greater personnel, time, and financial investment than before, posing challenges to the path of scientific development [2].

From the perspective of current science and technology development trends, the continuous integration and mutual penetration of science and technology with economic and social development, alongside deepening interdisciplinary convergence, are driving profound transformations in research paradigms. In particular, Jim Gray, a Turing Award laureate, proposed the concept of a “fourth paradigm”—data-intensive scientific discovery—based on experimental induction, model deduction, and simulation in his keynote speech at the U.S. National Research Council’s Computer Science and Telecommunications Board (CSTB) conference in January 2007 [3]. This has gradually made research paradigm transformation a hot topic in the global scientific community [4]. We must seize the opportunities presented by this transformation to explore more effective ways to address global challenges such as climate change, major diseases, natural disasters, and economic and social governance systems [5]. This urgently requires the scientific community, government, and society at large to actively plan for and adapt to research paradigm transformation to find solutions to these problems.

To better promote scientific and technological development, we need to understand the connotation and trends of global research paradigm transformation and proactively respond to these changes. This will provide strong support for building China into a science and technology powerhouse and achieving high-level self-reliance in science and technology, particularly by optimizing knowledge production pathways to facilitate major scientific breakthroughs and solutions to global problems. To this end, this paper first clarifies the logical essence of the "paradigm" concept, analyzes the basic trends of research paradigm transformation in the new era based on empirical research, examines the challenges China faces in responding to this transformation, and proposes knowledge production-related policy recommendations.

1. The Logical Essence of the "Paradigm" Concept

The concept and theory of "paradigm" were proposed and systematically elaborated by the renowned American historian and philosopher of science Thomas Kuhn (hereinafter referred to as "Kuhn") in his *The Structure of Scientific Revolutions* [6]. Since its introduction, the influence and application of "paradigm" have extended beyond the philosophy of science to other disciplines.

Kuhn earned his bachelor's, master's, and doctoral degrees from Harvard University in 1943, 1946, and 1949, respectively, all in physics. His doctoral advisor was Nobel laureate John van Vleck. A fortuitous opportunity in 1947 proved decisive for Kuhn's academic career when he was invited to deliver a series of lectures on the origins of 17th-century mechanics. This prompted him to temporarily suspend his dissertation preparation and delve deeply into the mechanical theories of Galileo, Newton, and Aristotle. Kuhn discovered that Aristotle had advanced many seemingly absurd arguments about motion in his *Physics*, and what particularly struck him was that numerous subsequent researchers had considered these erroneous views correct for a considerable time. Kuhn suddenly realized that the subject matter of Aristotle's *Physics* was fundamentally different from that of modern physics, which explained why certain content appeared completely absurd when examined through the lens of Kuhn's contemporary academic perspective. Once readers shifted their analytical framework back to Aristotle's own knowledge domain and logical structure, the content that would later seem "absurd" or even "wrong" immediately acquired internal coherence [7]. Kuhn thus attempted to understand the author's intentions by adopting Aristotle's own mode of thinking, rendering Aristotle's theories comprehensible [8]. Kuhn found that both the new and old mechanical theoretical systems could solve certain practical problems during their respective historical periods, yet their explanations of the same observed facts were entirely different. This was true for the relationship between Aristotelian and Newtonian systems, as well as between Newtonian and Einsteinian systems. Consequently, Kuhn concluded that the traditional view of scientific progress as cumulative and characterized by continuous knowledge accumulation did not reflect the reality revealed by historical research.

How does science develop? This is the core question Kuhn continuously explored in *The Structure of Scientific Revolutions*. In fact, it was the introduction of "paradigm" that formed the book's fundamental research framework: normal science is characterized by a "paradigm" that ensures the legitimacy of research questions for the scientific community. If all goes well, this can continue until anomalies emerge that cannot be resolved by the methods determined by the paradigm. A crisis then arises and persists until new scientific achievements begin to guide new research and form a new "paradigm." The essence of scientific revolution is the transformation and replacement of "paradigms" [9].

In *The Structure of Scientific Revolutions*, "paradigm" serves as the core concept throughout the book. Kuhn [6] stated: "In its established usage, a paradigm is an accepted model or pattern… I have adopted this term to suggest that certain accepted examples of actual scientific practice—examples which include law, theory, application, and instrumentation together—provide models from which spring particular coherent traditions of scientific research." For Kuhn, a paradigm represents fundamental commitments to ontology, epistemology, and methodology—the totality of hypotheses, theories, criteria, and methods jointly accepted by a scientific community, which become the shared beliefs of scientists. In other words, Kuhn regarded the collectively recognized scientific achievements of a scientific community as a "paradigm" that tells scientists what to do, what questions to ask, and how to conduct observations and experiments. Kuhn believed these scientific achievements could "attract an enduring group of adherents away from competing modes of scientific activity" and be "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve" [6].

However, the concept of "paradigm" in *The Structure of Scientific Revolutions* is not a precise term; it possesses flexibility, hierarchical structure, and diversity, with paradigm shifts varying in importance across different levels. Therefore, the logical starting point of this study aligns with Kuhn's concept of "paradigm," aiming to identify effective knowledge production methods that promote scientific breakthroughs and address current global major problems and challenges. This effectively unifies paradigm transformation with knowledge production methods (such as those supported by the National Natural Science Foundation). When seeking such effective knowledge production methods, we can make judgments from two starting points: first, from the perspective of the scientific community—knowledge production methods in a specific discipline or interdisciplinary field that are global and have certain universality; second, from a social perspective, examining the organization of scientific activities, such as topic selection and social needs, resource allocation, etc., which are often closely related to national science management models.

2. Main Manifestations of Research Paradigm Transformation in Specific Disciplines in the New Era

Since the birth of modern science, knowledge has been continuously created and developed, forming systematic theories and methods to become disciplines with specific paradigms. Disciplines continuously evolve, change, and differentiate with knowledge growth, replacement, and differentiation, forming different branches and developing into a spectrum of knowledge growth. To this end, this research is divided into two parts: analyzing international strategic research findings in relevant disciplines, focusing on development trends in physics and biology, and examining discipline development and changes in knowledge production methods; and conducting a special survey on research paradigm transformation by the National Natural Science Foundation of China, administering questionnaires to strategic scientists across 18 disciplines.

2.1 International Strategic Research Findings in Relevant Disciplines—Exemplified by Development Trends in Physics and Biology

(1) Physics. 2005 was designated as the International Year of Physics. To commemorate this occasion, the international physics community published two important works: *Physics in the Twentieth Century* and *New Physics for the Twenty-first Century*. From *New Physics for the Twenty-first Century* [10], we can also discern clues and trends in the frontier development of physics and understand some changes in knowledge production methods. Physics is the science of matter and energy. Current physics has become more complex and is diverging along different directions. Content related to future physics research paradigm transformation can be summarized in three aspects: First, new synthesis. The universe is vast, yet ultimately composed of extremely small entities. On large scales, the universe is described by relativistic gravitational theory, while on small scales it is described by quantum physics. For many years, these two descriptions remained isolated from each other, but by the late 20th century, new understanding emerged—the universe was created in a big bang, with quantum gravity playing a major role. Such research achievements foreshadow a new synthesis, as scientists have gained deeper understanding of both the universe's microstructure and its big bang, subsequent evolution, and large-scale structure. Second, simplicity and complexity. Traditionally, physicists have pursued "simplicity" as their goal, yet the real world exhibits complexity. Current physics needs to reconcile these two aspects and coordinate with the ability of various objects to "organize" themselves into self-sustaining structures. When dealing with mathematical problems that cannot be solved analytically, such as nonlinear systems, computer modeling and simulation provide alternative and possibly entirely new levels of understanding. Third, sophisticated experimental techniques. Experimental physics is rooted in sophisticated technology, and new physics discoveries often result from technological breakthroughs and instrumentation innovations.

(2) Biology. Between September 2008 and July 2009, the U.S. National Research Council, at the request of the National Institutes of Health (NIH), Department of Energy (DOE), and National Science Foundation (NSF), established the “Committee on a New Biology for the 21st Century.” After extensive research and thorough discussion, it produced *A New Biology for the 21st Century* [11]. In this report, content related to changes in biological knowledge production methods can be summarized in three aspects: First, knowledge integration. The essence of the new biology is the reintegration among various biological disciplines and the integration of biology with physics, computational science, mathematics, engineering, and other disciplines. Knowledge integrated from these various disciplines promotes deeper understanding and cognition of biological systems. Second, moving beyond reductionism. Traditional research methods generally start from reductionism, effectively guiding researchers to reveal the most fundamental molecular, cellular, physiological, and ecological processes in living organisms. Reductionist approaches to biological research will continue. However, biologists have begun to study interactions among various components at single levels of biological organization and to simultaneously study multiple components, integrating this knowledge. Such approaches, which move beyond reductionism, enhance understanding of how these components work together in a living system. Third, setting grand goals and letting problems drive scientific progress. For projects that are interdisciplinary, system-level, and computationally demanding, traditional funding channels and institutional structures are no longer suitable. There is a need to establish challenging grand goals and coordinate relevant resources from existing academic, public, and private institutions to maximize returns across most fields.

2.2 Special Survey on Research Paradigm Transformation by the National Natural Science Foundation of China

This special survey involved 57 scientists, primarily strategic planning leaders from 18 disciplines covered in the National Natural Science Foundation of China’s 14th Five-Year Development Plan, as well as scientists with strategic vision recommended by various departments of the NSFC. The survey aimed to understand scientists’ perspectives on the main manifestations of research paradigm transformation in the new era, its impact on research, and how to respond. A total of 57 questionnaires were distributed, with 31 valid responses collected (a 54.4% response rate). Valid respondents covered 16 disciplines, representing 88.9% disciplinary coverage. In addition to the questionnaire survey, interviews were conducted with some scientists.

To more comprehensively examine strategic scientists’ understanding of research paradigm transformation, our team conducted word cloud analysis of the survey results [Figure 1: see original paper]. The analysis shows that keywords of relatively high concern among strategic scientists include: discipline, foundation, organization, data, problem, complexity, system, field, interdisciplinary integration, model, demand, society, mechanism, collaboration, holism, etc. Based on this, our team also analyzed the structural relationships among keywords [Figure

2: see original paper], where big data, problems, direction, society, complexity, and organization occupy relatively central positions.

3. Main Trends of Research Paradigm Transformation in the New Era

From the specific survey content, different disciplines have their unique research objects, methods, and theoretical systems, and thus the main manifestations of research paradigm transformation are not entirely consistent. Nevertheless, the survey results reveal some common themes, concentrated in the driving forces of transformation, research methods, and organization of research activities.

3.1 Solving Systematic Complex Problems as the Primary Driver of Research Paradigm Transformation

Solving systematic and complex problems has become the main goal of current scientific development, leading to gradual changes in research content, methods, and scope within existing disciplines and forming the fundamental characteristics of multi-level, multi-scale, and dynamic scientific research. These systematic complex problems typically exhibit three features:

(1) Emphasis on holistic properties. A whole is composed of parts, but its properties are not simply the sum of the parts' properties. At each level of scientific research, there are new, effective, and universal laws that often cannot be derived from more fundamental levels using reductionist methods. Reductionism has been and remains key to obtaining useful information in scientific research activities. Gallagher and Appenzeller [12] noted that understanding more and more about less and less, and the continuous differentiation of subdisciplines, may create certain barriers to information flow and communication.

(2) Complexity. When examining the relationship between parts and the whole, the characteristics of complex systems inevitably emerge, including interactions, feedback, phase transitions, and other properties. Examples include climate issues and chronic complex diseases in clinical medicine. First, climate issues are generally dominated by solar radiation feedback. These feedbacks may be influenced by system nonlinearity and future change patterns, but the magnitude of influence is uncertain and difficult to predict. Climate issues may forever remain complex: there is determinism within chaos and unpredictability within understanding [13]. Second, chronic complex diseases such as cardiovascular and cerebrovascular diseases, metabolic diseases, tumors, and neuropsychiatric disorders have become the greatest threats to China's population health. These diseases involve numerous pathogenic factors, and their pathogenesis remains largely unclear, posing major challenges for diagnosis, treatment, and new drug development strategies. One scientist in our survey noted, "Looking back at the history of human understanding of chronic complex diseases, research on major diseases has undergone historical transitions from macroscopic disease phenotypes to microscopic molecular subtypes. However, research on the pathogenesis of complex diseases has mainly focused on local tissue lesions themselves, largely ignoring the systemic changes of the organism as a whole, as well as the comprehensive impacts of current ecological environmental changes, changes in patients' lifestyles, and increased social pressure. In recent years, understanding of chronic complex diseases has begun to expand from local lesions to the whole organism. People have gradually realized that chronic complex diseases are not only abnormalities of local tissues and organs but often involve the joint participation of various systems of the organism, are closely related to natural environmental and social psychological factors, and result from multi-factor, multi-link, and multi-organ interactions."

(3) Multidisciplinary integration. These problems are often related to major issues and challenges encountered in economic and social development and cannot be solved by single-discipline research alone, requiring disciplinary integration to find solutions. For example, effectively responding to large-scale epidemics in the 21st century necessitates the integration of multiple disciplines including epidemiology, social sciences, social media, vaccine development, diplomacy, logistics, and crisis management [14]. As another scientist noted in survey interviews, "For chronic complex diseases, we need to establish a 'holistic research perspective' focusing on microecology, immunity, metabolic disorders, and neuroendocrine imbalance stress as core content. We should build spatiotemporal regulatory networks within cells, between cells, between cells and organs, and between organs under disease states; establish connections and correspondences between pathophysiological characteristics and clinical phenotypes; analyze common mechanisms and key factors of diseases; integrate cutting-edge technologies such as multi-dimensional omics and artificial intelligence; develop new technologies and models; establish multi-dimensional holistic evaluation systems based on common pathological foundations; and then construct holistic diagnosis and treatment systems based on both common pathological foundations and individual disease characteristics."

3.2 Simulation and Data Science as Potential Breakthroughs for Driving Research Paradigm Transformation

(1) Computer simulation is demonstrating enormous value in the future development of disciplines. Since the birth of modern science, experimental induction and model deduction have been the main methods of scientific research. With the development of computers, simulation technology began to emerge, initially mainly applied in military fields. In the 1980s, with the rapid development of computer technology, simulation entered a new era of computer simulation technology, which began to be applied on a large scale in various aspects of production and life such as simulation training, instrumentation development, virtual manufacturing, and electronic product design, and has increasingly become a necessary supplement to experimental induction and model deduction. First, in astronomy, at the beginning of the 21st century, some cosmologists skilled in computer modeling began to simulate the 14-billion-year history of the universe on supercomputers. The IllustrisTNG project achieved unprecedentedly fine-grained simulations of various forces in the universe, enabling scientists to observe how galaxies form, evolve, grow, and facilitate new star formation over a 14-billion-year timescale. These cosmologists have built and utilized this model to further reveal the influence of black holes on dark matter distribution, how heavy elements are produced and distributed, and the origin of magnetic fields. Second, in biology, in 2012, Karr et al. [15] published an article in *Cell*, simulating for the first time the entire life cycle of *Mycoplasma genitalium* and constructing a whole-cell computer model covering all molecular components of the bacterium and their interactions. This whole-cell computer model contains interpretations of all gene functions and can be validated across multiple datasets, enabling calculation of every biological reaction step in a dividing bacterial cell [16] with applications in multiple aspects of biological research. Third, in Earth science, computer simulation has also made significant progress recently. In June 2021, the "Earth System Numerical Simulation Facility" (hereinafter referred to as "Huan"), led by the Institute of Atmospheric Physics of the Chinese Academy of Sciences, was completed and put into operation in Huairou Science City, Beijing. "Huan" can predict Earth's climate and environmental changes in greater detail and integrate massive simulation data to produce detailed "Earth databases" for global and surrounding regions. It aims to enhance understanding of interactions and evolution patterns among various spheres of the Earth system and establish a scientific predictive foundation for global climate and environmental changes. As one scientist noted in our survey, "With the development of supercomputing and artificial intelligence, and the rapid advancement of computer data processing capabilities and speeds, making full use of high-performance computing and scientific simulation to achieve new forms of experimentation, induction, and deduction is about to become an effective breakthrough for research paradigm transformation."

(2) Data science is demonstrating enormous potential. Massive data, substantially improved computing power, and the development of the digital economy are continuously catalyzing the emergence of data science [2]. Particularly driven by artificial intelligence (AI), AI for Science achievements such as AlphaFold 2 have continuously refreshed the scientific community's cognition. Consequently, many scientists have proposed that data science will be an effective breakthrough for driving research paradigm transformation. We believe that research paradigm transformation driven by data science is still developing and requires focused attention in two aspects: First, currently, there is still no rigorous definition or academic consensus on the connotation and extension of data science, but it can generally be explored from methodological and ontological perspectives. From a methodological perspective, the research paradigm driven by data science is what Jim Gray called the fourth paradigm, discovering new patterns, knowledge, and even new laws through direct data analysis that previous scientific research methods had not discovered [17]. From an ontological perspective, data is a symbolic reflection of the natural world. Since the natural world objectively exists and follows universal scientific laws, the data space reflecting the natural world may also contain general laws independent of specific domains [18]. Second, data science has only just begun, and its establishment and effectiveness require a long process. Currently, active exploration is needed in three areas [ ]: solving data acquisition, quality, storage, transmission, management, and application scenario issues through the establishment of data platforms; promoting the integration of mechanisms and data to enhance the effectiveness of algorithms and models; and establishing the foundation of data science in fundamental mathematics such as discrete geometry, discrete topology, graph theory, and combinatorics.

4. Problems in China's Response to Research Paradigm Transformation

4.1 Serious Problem of Disciplinary Isolation and Field Fragmentation

(1) The innovation chain has further expanded, evolving from the traditional linear model of basic research, applied research, and product development to a coexistence of linear and reverse models. For example, reverse-model technological innovation is common in the information field. Unlike the traditional forward model where basic research innovation is first transmitted to product development, the reverse innovation form and diffusion path from specific to general is frequently observed in the information field, such as in software engineering. This reverse innovation research process refers to "innovative products and services specially developed by enterprises for specific markets, which then drive product iteration and optimization through basic research discoveries oriented toward problems, following the reverse research law from specific to general" [19]. One scientist in our survey noted that Google serves as a typical example of reverse innovation: "Google AI research teams have always been committed to combining basic research with systems engineering. Most of the team's work provides research support for different products to complete tasks faster and more effectively, thereby spawning breakthroughs in basic research in natural language understanding, perception research, algorithms and theory, software systems, AutoML, TPU, etc., which are then widely applied to products through collaboration with different product teams."

(2) Disciplinary boundaries have become increasingly rigid. China's current disciplinary structure suffers from rigid management and excessive subdivision. Different countries have different disciplinary management systems and mechanisms. For example, the United States' disciplinary classification mainly focuses on statistics, surveys, and guidance, allowing universities and research institutions to set up and adjust their own disciplines according to their own and societal needs. In China, disciplinary setup serves as a basic management tool for disciplinary development and scientific research. Management agencies' excessive emphasis on the management function of disciplinary division is not conducive to giving full play to the initiative of universities and research institutions, preventing them from fully adapting to economic and social development and the needs of scientific development. Against this background of rigid disciplinary management, China's excessive disciplinary subdivision neither conforms to the nature of things nor facilitates solving practical problems, thereby exacerbating the fragmentation of academic activities and creating "disciplinary barriers."

4.2 Inadequate Inter-Agency and Inter-Institutional Coordination and Sharing Mechanisms

(1) Research topics tend to follow rather than lead, with few original questions and more applied problems than comprehensive ones. How to transcend institutional and departmental interests, propose highly challenging scientific goals, and establish corresponding coordination and management mechanisms to let problems drive scientific progress remains a major challenge.

(2) Systemic "barriers" urgently need to be broken. Due to systemic reasons, the segmentation among various departments and institutions creates obstacles to knowledge production and flow. The reasonable sharing of research results is far from adequate, which is extremely detrimental to the formation of original ideas.

(3) A diversified sharing ecosystem and mechanisms for research data urgently need strengthening. The open sharing of research data is of great significance, and diverse research data sharing ecosystems have already formed abroad. Examples include Academia.edu for free sharing of research papers, ResearchGate for sharing research results, Science Exchange for research experiment outsourcing services, Kaggle for data science communities, InnoCentive for crowdsourced innovation research platforms, and IdeaConnection, the world's largest crowdsourced open innovation intermediary platform. However, China's current data sharing remains sporadic and independent, with very limited capacity to manage and serve research data, and mechanisms for research data sharing need further improvement.

4.3 Need for Greater Diversification in Research Management

Exploring a system that combines central macro-control with diversified free research, establishing an institution with both a "big science" hard core and a "small science" soft periphery, is the necessary path for China to become a world science and technology powerhouse. Currently, due to various issues in China's evaluation system, institutions, and mechanisms, there are obvious deficiencies in pure basic theoretical research, scientific and technological infrastructure support capabilities, and the construction of academic societies and journals that need urgent improvement.

(1) How to develop pure basic theoretical research remains an important issue. Pure basic theoretical research often originates from interdisciplinary studies and usually has no direct application value, but it can provide new research perspectives and intellectual inspiration for solutions to major mission tasks. Meanwhile, the more cutting-edge and original the question, the higher the research risk. However, China's current academic incentive mechanisms and research culture tend to be relatively conservative toward risk.

(2) There are serious deficiencies in basic capabilities such as professional software and instrumentation. For example, China's high-end scientific research equipment and professional software are almost monopolized by international giants. Once foreign suppliers stop providing or maintaining these products, China faces not only the problem of lacking domestic alternatives but also the possibility of a comprehensive stagnation of domestic scientific research. In recent years, the disabling of Matlab software developed by U.S.-based MathWorks in some Chinese universities has demonstrated the severity of this problem.

5. Policy Recommendations

Research paradigm transformation involves changes across the entire scientific system. Considering the complexity of this transformation and the practical needs of current scientific development, this paper focuses on optimizing knowledge production methods, particularly regarding the management of scientific funding, and proposes four policy recommendations:

(1) **Reform disciplinary management models and explore new management models for interdisciplinary studies.** Clarify the relationship between government and universities/research institutions, expand the autonomy of universities and research institutions, and explore effective mechanisms that actively adapt to economic and social development and conform to the laws of education and research development. Strengthen overall planning and dynamic adjustment to gradually promote balanced and coordinated development of the disciplinary system. Encourage the creation of new types of academic organizations for interdisciplinary studies and explore effective operational mechanisms to promote interdisciplinary integration.

(2) **Strengthen pure basic theoretical research.** Continuously establish and improve the guarantee, incentive, and evaluation systems adapted to pure basic theoretical research, increase the proportion of guaranteed funding for research units, and establish and improve a stable system and mechanism to support free exploration, providing institutional guarantees for the spirit of "willing to sit on a cold bench for ten years."

(3) **Strengthen mission-oriented research and promote disciplinary integration at a deeper level.** Conduct normalized selection and iteration of scientific questions oriented toward the frontiers of world science and national major needs; strengthen mission-oriented research with multi-disciplinary collaboration and multi-stakeholder participation; enhance top-level design and overall coordination; and seek diversified management model pathways with corresponding departmental coordination

mechanisms as well as personnel, financial, and material management systems.

(4) **Strengthen scientific and technological infrastructure support capabilities and data platform construction.** Establish a special fund for scientific and technological infrastructure support capabilities to support the construction of computing software, high-end instrumentation, and related infrastructure; explore long-term mechanisms for establishing corresponding evaluation and management systems; improve institutional norms for data sharing; and build third-party platforms to meet data sharing needs.

Acknowledgments

We thank the Bureau of Academic Divisions of the Chinese Academy of Sciences and the Bureau of Planning and Policy of the National Natural Science Foundation of China for their guidance, as well as the scientists who participated in the survey and interviews for this project.

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Note: The 18 disciplines surveyed were mathematics, physics, mechanics, astronomy, chemistry, biology, nanoscience, Earth science, resources and environment, agricultural science, energy science, materials science, marine science, space science, information science, engineering science, medicine, and economics and management science.

Note: Figure translations are in progress. See original paper for figures.