Research on the Collaborative Mechanism of Stakeholders in Open Scientific Data: Postprint

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Abstract

[Purpose/Significance] Open scientific data represents an inevitable trend in scientific and technological innovation, as well as economic and social development. Clarifying the collaborative dynamics and operational mechanisms among its stakeholders facilitates the efficient implementation of national open-sharing initiatives. [Method/Process] This study identifies and categorizes the stakeholders involved in scientific data openness, analyzes their functional positioning and interest appeals, and subsequently summarizes the driving forces underlying multi-stakeholder collaboration. Furthermore, drawing upon synergetics theory, we construct a dynamic system model for stakeholder collaboration in open scientific data to explore the interrelationships among actors. [Results/Conclusion] Corresponding recommendations for promoting collaborative work are proposed from two dimensions: stimulating endogenous motivation and strengthening exogenous drivers, thereby providing theoretical guidance for the practice of scientific data open sharing in China.

Full Text

Preamble

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Research on Collaborative Dynamics and Mechanism of Stakeholders in Open Scientific Data

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Abstract: [Purpose/Significance] Opening scientific data is an inevitable trend in scientific and technological innovation, economic and social development. Clarifying the collaborative dynamics and mechanisms of its stakeholders is essential for the efficient implementation of national open sharing initiatives. [Method/Process] This paper identifies and summarizes the stakeholders involved in scientific data opening, analyzes their functional positioning and interest demands, and on this basis, summarizes the driving forces for multi-stakeholder collaboration. Then, drawing on synergetics theory, it constructs a collaborative dynamic system model for open scientific data stakeholders to explore the cooperative relationships among them. [Result/Conclusion] Finally, corresponding recommendations are proposed from two aspects: stimulating endogenous motivation and strengthening exogenous motivation, providing theoretical guidance for the practice of scientific data opening and sharing in China.

Keywords: scientific data; opening and sharing; stakeholders; collaborative dynamics; mechanism

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1. Introduction

Scientific data, as a strategic resource with significant research, social, and economic value, has gained widespread international recognition for its importance in management and utilization [**?**]. Implementing open sharing of scientific data has become a crucial strategic policy for countries to maintain national competitiveness. The further development of the scientific data opening movement requires promoting the depth and breadth of exchanges and cooperation among various stakeholders [**?**]. Understanding the interest demands of stakeholder entities and analyzing their dynamic mechanisms for coordination and cooperation is vital for promoting the efficient implementation of scientific data opening initiatives.

Currently, academic research on stakeholders in scientific data opening and sharing mainly focuses on four areas. First, investigation and analysis of data opening policies at home and abroad. Cui Yan summarized the main content of data policies for data centers [**?**], publishers [**?**], and research funding agencies [**?**] based on text content analysis. Y. Socha [**?**] elaborated on existing data citation policies of organizations related to data opening and sharing based on data citation practices in international organizations. Lü Na [**?**], Wang Dezhuang et al. [**?**], and Jiang Xin et al. [**?**] respectively established frameworks for effective division of labor and cooperation from system and stakeholder perspectives, highlighting key points such as effective participation of identified entities, multi-level comprehensive layout, and achieving incentive and balance of rights and interests for all stakeholders.

Second, discussion of relationships and balance mechanisms among stakeholders. Chen Yuanyuan et al. [**?**] and Huang Ruhua et al. [**?**] constructed interactive re-

lationship models among stakeholders in scientific data management, analyzing the interactive relationships between key stakeholders and those with libraries as the core. Zhu Ling et al. [?] summarized that the main points for establishing effective division of labor and cooperation frameworks among scientific data opening and sharing entities include: effective participation of identified entities, multi-level comprehensive layout, and achieving incentive and balance of rights and interests for all stakeholders. Guo Shilin [?], Gong Yunfei [?], and Si Li et al. [?] introduced stakeholder theory to analyze the interest demands of various entities participating in open scientific data and discussed interest balance issues.

Third, research on stakeholder roles, responsibilities, and motivations. L. Lyon [?], M. S. Mayernik [?], and P. U. K. De Silva et al. [?] respectively described the roles, responsibilities, and contributions of different stakeholders in data citation and open sharing. Sheng Xiaoping et al. analyzed the responsibilities and roles of 10 types of stakeholders in scientific data opening [?] and explored the participation motivations of different entities [?]. C. L. Borgman [?] discussed four motivations for data sharing from the stakeholder perspective: reproducing or verifying research, providing funded research results to the public, enabling others to ask new questions of existing data, and promoting research and innovation.

Fourth, research on stakeholder opening and sharing behaviors, mainly including influencing factors and evolutionary game analysis. Liu Guifeng et al. [?] used grounded theory to analyze five major factors affecting research data sharing behavior from a stakeholder perspective: individual, organizational, resource, institutional, and technical factors. Wang Xiaowen et al. [?] conducted game analysis on stakeholders involved in university scientific data management services, proposing that optimizing service paths requires strengthening top-level cooperation design, building coordinated cooperation networks, cultivating an open sharing culture, and establishing cooperative quality evaluation systems.

From the above research, it is evident that although scholars have noticed the cooperation issues among stakeholders in open scientific data, there remains a lack of in-depth analysis of key elements for multi-stakeholder collaboration and the roles and functions of each participant. In view of this, this paper aims to clarify the motivations of various stakeholders participating in scientific data opening and sharing, identify the collaborative dynamics and interaction mechanisms among multiple stakeholders, and propose targeted strategies to ensure smooth collaboration, thereby enhancing the level of scientific data opening and sharing in China.

2. Analysis of Open Scientific Data Stakeholders

2.1 Definition and Positioning of Open Scientific Data Stakeholders

Stakeholders are defined as "individuals or groups who can affect or are affected by the achievement of organizational objectives" [?]. Stakeholders in scientific

data opening involve multiple roles including data producers, funders, organizers, publishers, disseminators, managers, and users [**?**]. Current methods for identifying stakeholders mainly include brainstorming, the Mitchell scoring method, and literature analysis [**?**]. This paper adopts literature analysis, starting from the concept and extension of scientific data opening to retrieve relevant policies, reports, and media materials from domestic and international websites. Using search queries "TI=('scientific data' OR 'research data') AND SU=('stakeholder' OR 'subject')" and "TI=(scientific data OR research data) AND TS=((open sharing OR open access) AND stakeholder?)" in CNKI and Web of Science Core Collection respectively, 29 valid articles were identified as of May 1, 2020. After merging and deduplication, 10 stakeholders were determined: government, research institutions, researchers, funding agencies, publishers, libraries, data centers, industry associations, enterprises, and other users.

The scientific data opening process mainly involves four stages: data creation, data storage, data publication, and data access. Different stakeholders have varying participation methods and approaches at each stage, and clear functional positioning helps optimize resource allocation. Based on functional attributes, stakeholders in open scientific data can be roughly divided into four categories: social, research, technical, and user organizations, as shown in Table 1 .

Research organizations are the most important producers of scientific data and, as significant users, obtain shared scientific data from data intermediaries for analysis and research to achieve data reuse.

Social organizations have certain public welfare attributes and undertake the role of regulators and policymakers. Government, funding agencies, publishers, libraries, data centers, industry associations, and others establish guiding principles and norms for scientific data opening from top to bottom.

Technical organizations participate throughout the entire process of scientific data opening, responsible for providing storage, discovery, and permanent access services for scientific data; establishing relevant technical and data standards to ensure data accessibility; and providing data management training and consulting services. Research institutions participate in data organization, preservation, and management through infrastructure construction and services.

User organizations only participate in the utilization stage of scientific data, aiming to create value based on open data. They are direct beneficiaries of the scientific data opening movement. Open data is not only used for academic research by research organizations but also helps enterprises and other users develop data products or support decision-making.

2.2 Analysis of Multi-Stakeholder Interest Demands in Open Scientific Data

Marx believed that everything people strive for is related to interests [**?**], and the pursuit of interests drives their activities. Therefore, identifying the interest demands of different stakeholders can provide direction for strengthening cooperation willingness and reference for research practice and data management. In the scientific data opening system, each stakeholder' s interest demands include economic benefits, research interests, and social benefits, as detailed in Table 2 .

3. Analysis of Multi-Stakeholder Collaborative Dynamics

3.1 Exogenous Driving Forces for Multi-Stakeholder Collaboration

Collaboration in the open scientific data process involves managing behavioral activities and interdependent relationships to enable stakeholders to utilize resources more effectively and improve efficiency [**?**]. Materialist dialectics holds that changes and development of things result from the combined action of internal and external factors. Therefore, the driving forces for stakeholders to adopt collaborative behaviors should also include both internal and external aspects, with endogenous and exogenous forces jointly promoting the cooperative development of scientific data opening.

Exogenous driving forces refer to forces from the objective environment that directly or indirectly affect stakeholders'willingness and behavior. As social organizations, stakeholders in open scientific data are inevitably influenced by various objective factors including economic level, policy systems, ideological culture, and social environment [**?**]. Based on previous analysis, the main environmental factors affecting stakeholder participation in coordination and cooperation are institutional environment, social environment, technical environment, and organizational environment [**?**], with their interaction process shown in Figure 1 [Figure 1: see original paper].

Institutional Environment Guidance: Any activity requires institutional guidance. The institutional environment for open scientific data mainly consists of policies, laws, and regulations proposed by social organizations, which can be divided into macro, meso, and micro levels. National macro-framework policies not only provide important basis and principles for regional data opening but also promote and publicize the open data movement at the national level. Horizon 2020' s "Guidelines on Open Access to Scientific Publications and Research Data" [**?**] requires EU and member states to take legal and financial measures to promote extensive cooperation in data opening. China' s State Council issued the "Measures for the Management of Scientific Data" [**?**], requiring storage and accumulation of scientific data from research projects and open sharing with society and relevant departments. Meso-level institutional policies at the departmental and agency level refine and supplement macro policies, addressing deficiencies in disciplinary standard formulation, such as the UK Medical

Research Council requiring funded institutions to share clinical trial data [?]. Micro-level policies mainly include data submission, preservation, and management policies during data storage, with renowned journals like PLoS ONE and Nature requiring authors to submit data involved in their papers [?]. Macro, meso, and micro-level institutions constitute the overall implementation framework for open scientific data from top to bottom, under which the scientific data opening movement is orderly promoted.

Social Environment Driving Force: Social organizations are regulators and coordinators of the social environment. Supervision from higher authorities, social evaluation, media and public opinion, and public demands for the right to know collectively form significant pressure affecting their behavior. On the other hand, with increasing academic commercialization, research results and copyrights are mostly controlled by societies and commercial publishing institutions, creating information gaps and severely hindering knowledge exchange. In this context, libraries, data centers, funding agencies, industry associations, and other social organizations hope to break barriers through open data. Additionally, for some technical and user organizations competing in the market, social pressure also stems from competitor threats. To alleviate industry competition pressure and gain market advantages, various stakeholders actively seek external exchanges and cooperation, innovating service models and adjusting development strategies through the open movement to avoid elimination. The UNESCO Science Report: Towards 2030 [?] points out that open data will have a tremendous impact on future sustainable development and is an inevitable trend of social development. Under social environmental pressure, various stakeholders actively seek change and cooperation in openness, positively promoting collaborative exchanges among open scientific data entities.

Technical Environment Support: Rapidly developing information technology lays the foundation for open sharing and value-added innovation of scientific data, enabling the smooth development of the scientific data opening movement under the guarantee of data storage and sharing technical facilities. Various stakeholders including social, research, technical, and user organizations can freely exchange information through internet technology, allowing policy systems issued by social organizations to be widely disseminated and rapidly implemented, while facilitating the orderly flow of scientific data among these entities. The successful implementation of modern information classification standards, information organization standards, metadata standards, digitization standards, and other software and hardware standards helps technical organizations provide more standardized, high-quality data organization, preservation, and management services. Numerous domestic sharing projects and platforms, such as the Chinese Academy of Sciences Data Application Environment Construction and Service Project [?] and the National Science and Technology Infrastructure Platform [?], have designed and issued sharing-related metadata standards during construction to promote scientific data sharing. In terms of data analysis and utilization, developments in cloud computing, linked data, and data mining have enhanced the data processing and analysis capabilities of research and user

organizations, effectively promoting the value realization of open scientific data.

Organizational Environment Support: The open scientific data system is a cooperative network constructed by multiple stakeholders to achieve opening goals, with multi-level, multi-dimensional connections existing among all parties. Any change in a single relationship affects the stability of the entire network. The organizational environment for open scientific data includes the maintenance of collaborative relationships among different types of organizations and organizational culture and atmosphere within organizations. Current collaborative relationships in research work mainly stem from trust relationships among multi-stakeholders across systems [**?**]. Social and technical organizations can establish stable trust relationships with research or user organizations by providing scientific and reliable policies or services, ensuring accurate implementation of management policies and data standards. Organizational culture includes organizational values, beliefs, missions, spiritual outlooks, as well as conflict management and behavioral norms among organizations [**?**]. A positive sharing culture and atmosphere can provide lasting motivation for organizational members to carry out work. Open scientific data involves numerous stakeholders with a complex internal organizational environment, where conflicts and contradictions easily arise due to unbalanced interest distribution. Establishing a good organizational environment can mobilize participants' initiative to cooperate with other collaborative entities, promote effective organizational operation and development, and enhance the efficiency of organizational value creation.

3.2 Endogenous Driving Forces for Multi-Stakeholder Collaboration

The goal of multi-stakeholder collaboration in open scientific data is to achieve a win-win situation for both public and stakeholder interests through integration and optimal allocation of resource elements, creating a "1+1>2" effect. Endogenous driving forces refer to motivation factors generated based on internal needs that make stakeholders willing to participate in open scientific data collaboration. Therefore, unifying public and individual interests is the endogenous driving force promoting synergy among multiple stakeholders in the open scientific data system. Recognition and pursuit of public interests are prerequisites for stakeholder participation in collaboration, and common goals can strengthen cooperation willingness. The public interest of the open scientific data system is to create an environment with low-cost data acquisition, barrier-free data dissemination, and high-timeliness data publication, which is closely related to each stakeholder' s own interests. In a good open scientific data environment, social organizations can achieve institutional innovation, promote academic exchange and cooperation, accelerate scientific and technological development, and enhance economic benefits; research organizations can overcome scientific data acquisition barriers and improve the timeliness of their research output publication; technical organizations can unify data citation standards, standardize data management, and improve data service quality; user organizations can more easily access massive data to facilitate product design and

improvement, etc. Additionally, the "rational actor" nature also drives each stakeholder to continuously pursue its own interests while achieving public interests. The pursuit of interests causes continuous conflicts and coordination during system operation, requiring attention to balancing interests among parties, narrowing interest gaps, and establishing flexible cooperation networks.

4. Multi-Stakeholder Collaborative Mechanism

4.1 Multi-Stakeholder Collaborative Dynamics Model

Synergetics holds that competition is the fundamental interaction mode among subsystems, while synergy can be understood as another dimension of competitive interaction, representing a dialectical unity of opposites [**?**]. Stakeholders in open scientific data are in a state of competition and cooperation during system operation, playing games between pursuing their own interests and achieving public interests. Stakeholders make choices and adjust their behaviors based on benefit assessment and feedback. For example, researchers will refuse to share if they believe benefits from open data cannot offset their risks, and vice versa. When interests achieve a win-win situation, stakeholders adopt coordinated actions based on cooperation, forming a basically stable system structure. Moreover, as the scientific data opening system is an open ecosystem, changes in the external environment such as policy changes, public sentiment, and other stakeholders' behaviors will affect collaboration. Therefore, the effects of institutional, social, organizational, and technical environmental factors must be considered. These driving forces interact, couple, and promote each other, ultimately converging into a driving force for stakeholder collaborative development.

Based on the above analysis, this study has constructed a multi-stakeholder collaborative dynamics system model for open scientific data, as shown in Figure 2 [Figure 2: see original paper]. The model demonstrates the basic process of collaborative dynamics formation among multiple stakeholders in open scientific data. Under the coupling effect of dynamic elements (institutional environment guidance, social environment driving force, organizational environment support, technical environment guarantee, and interest win-win pulling force), various stakeholders undergo continuous competition and cooperation processes, ultimately reaching a balanced state of collaborative development and common progress. The model expresses the mechanism of multi-stakeholder collaborative dynamics in open scientific data, including both the effects of dynamic elements on stakeholders within the system and interactions among stakeholders.

Due to the numerous stakeholders in the scientific data opening system, the interaction relationships among them are relatively complex. To more intuitively and clearly display the positions and roles of different stakeholders in the system, this paper mainly studies the collaborative relationships among four types of organizations (research organizations, technical organizations, social organizations, and user organizations) with different functional attributes.

4.2 Multi-Stakeholder Collaboration Process

Figure 3 [Figure 3: see original paper] provides a supplementary expression of the collaboration process among the four types of organizations in the collaborative dynamics system model. As shown, open scientific data sharing first requires transforming scientific data into open scientific data that can be freely accessed by others, which involves stages including data creation, data storage, and data publication. Subsequently, through accessing open data for scientific research or developing data products and applications, the goal of creating value using scientific data is achieved. In the process from data publication to utilization, the four types of organizational roles occupy different positions and play their respective roles.

(1) **Research organizations** are the core roles in the scientific data opening and sharing process, responsible for producing original scientific data and providing it to intermediaries such as data centers, libraries, and publishers, sometimes also undertaking data preservation and management tasks. The "ERC Open Access Guidelines for Research Results" [**?**] states that funded scientists have the responsibility to retain data generated through observation, analysis, and other activities in scientific research, and should disclose it to other researchers to ensure reusability.

(2) **Technical organizations** serve as bridges connecting research organizations and user organizations, managing, storing, and disseminating scientific data obtained from research organizations, and ultimately providing it to users for research and development. As the most important supporting force in the scientific data opening and sharing process, they provide support and guarantee for professional services and technical facilities throughout the entire process. "Open Data in a Big Data World" [**?**] directly points out that libraries and data centers should formulate and provide corresponding technical standards and data services for scientific data storage and curation to ensure data accessibility. Publishers are responsible for centralized collation and standardization of data and building service platforms for storing datasets supporting their academic publications.

(3) **Social organizations** are responsible for creating a favorable external environment for scientific data opening and sharing, supervising, guiding, and supporting the behaviors and activities of various stakeholders in all stages. Their responsibilities include formulating relevant policies, regulations, and industry standards, standardizing and encouraging scientific data opening behaviors, and providing macro-control and action guidelines for various tasks. Additionally, they can provide financial or activity support for scientific research activities, possessing functions such as research education, exchange services, standardization and coordination, and incentive demonstration.

(4) **User organizations**, as direct beneficiaries of scientific data opening and

sharing, need to explore the potential value of scientific data, obtain shared scientific data through data access, and process it to obtain or develop corresponding academic achievements or data products and applications. Allowing users to freely share scientific data is the main purpose of the open scientific data movement [**?**], and therefore, user demand feedback for free acquisition, dissemination, development, or utilization of data can promote further participation of nations and institutions in scientific data opening and sharing.

5. Recommendations for Promoting Multi-Stakeholder Collaboration

By activating and coordinating key dynamic factors, efficient system operation can be achieved, thereby quickly and accurately reaching organizational goals. Based on the above research on collaborative dynamics and mechanisms among multiple stakeholders in open scientific data, we believe that enhancing stakeholders' willingness to participate in collaboration and improving collaborative effects in scientific data opening system work should start from the following two aspects:

5.1 Stimulating Endogenous Motivation for Collaboration

(1) **Improve participants' interest compensation and incentive mechanisms.** Win-win of public and individual interests is key to ensuring active stakeholder participation in collaboration. Effective incentive measures can enable participating entities to obtain higher individual benefits from opening, such as: Funding agencies establishing special funds to encourage open sharing behaviors in scientific research; Higher authorities establishing awards to recognize outstanding projects or units in open sharing practices; Incorporating open sharing of data results as an important key indicator in project assessment or professional title evaluation; Using open sharing assessment results as reference basis for funding allocation or performance income, etc. Through multiple measures including funding, awards, and assessment, the opening and reuse of scientific data and research results can be jointly promoted.

(2) **Encourage scientific data application and value-added services.** The "Measures for the Management of Scientific Data" issued by the General Office of the State Council [**?**] states that "legal entities should analyze and mine scientific data according to needs, form valuable scientific data products, and carry out value-added services." Encouraging enterprises and other legal entities to develop market-oriented value-added services helps transform open data into economic benefits, ensuring the enthusiasm of users to develop and utilize scientific data while attracting more stakeholders to participate, such as: Using government funds as guidance to promote the formation of a data value-added industry chain through

project investment, venture funds, and fiscal subsidies; Constructing a scientific data value-added product service standard system including safety standards and quality standards to improve the efficiency of scientific data value-added utilization; Establishing a legal system guaranteeing scientific data application and value-added services to maintain stable market operation.

(3) **Improve stakeholders' interest balance mechanisms to alleviate conflicts and contradictions.** Achieving interest balance and incentives among relevant stakeholders can provide continuous endogenous motivation for scientific data opening development. During system operation, conflicts often arise among various stakeholders due to the distribution of rights, responsibilities, and interests, such as copyright conflicts in scientific data opening and conflicts between personal privacy rights and public right to know. Alleviating these conflicts requires balancing rights and responsibilities, following the principles of "who owns, who is responsible" and "who opens, who benefits" [**?**], clarifying property rights 归属 in scientific data reuse, defining transferable data rights types in data reuse, and clarifying rights and obligations of both parties during data submission, to effectively safeguard the legitimate rights and interests of stakeholders through policy and legal measures.

5.2 Strengthening Exogenous Motivation for Collaboration

(1) **Enhance technical support in scientific data opening.** Currently, China has achieved preliminary results in open scientific data practice, but there remains room for improvement in key technological breakthroughs and application of standards and norms [**?**]. Therefore, the technical environment needs optimization, such as: Increasing investment in infrastructure construction such as high-level comprehensive resource supply and data service platforms to fully leverage the supporting role of data opening platforms; Establishing universal data standards, network technology standards, and information technology paths to improve interoperability among data platforms and resolve technical obstacles in scientific data submission and preservation; Focusing on metadata provision and management, establishing a data quality assessment and control system to strictly control data quality; Strengthening professional technical education and training for data personnel to enhance their data management service capabilities.

(2) **Strengthen organizational communication and organizational culture construction.** Good communication among organizations can facilitate collaborative work exchanges and resource allocation, while a good organizational culture can effectively promote sharing behaviors, and cultivating common vision and values can strengthen members' willingness to cooperate. Measures that can be taken include: Establishing diverse communication and feedback forms among stakeholders, such as

holding thematic academic conferences with speakers and interactions from different types of organizations, and encouraging exchanges and discussions within academic communities; Producing posters or holding presentations to popularize the social benefits of scientific data opening, explaining the benefits of scientific data sharing in work and research to internal personnel or relevant parties, and forming an organizational culture of scientific data opening and sharing.

(3) **Establish and improve relevant policy and legal systems.** The practice of scientific data opening requires guidance from national policies and laws. China' s existing institutional system stipulates general principles for scientific data management, but the following issues remain: Lack of data management systems for various stages in scientific data opening project practice; Need for further specification of responsibilities for scientific data opening and sharing stakeholders, clarifying duties of various personnel and making specific requirements for their division of labor; Intellectual property definition. Currently, there is no specific regulation in China to resolve conflicts between intellectual property protection and scientific data sharing, and concerns about risks have become the biggest obstacle for researchers to share data. Therefore, there is an urgent need to establish intellectual property achievement 归属 laws that conform to actual conditions and combine the characteristics of scientific data opening.

Conclusion

Scientific data opening is an ecosystem encompassing numerous stakeholders, and collaboration can achieve overall benefit maximization in the multi-stakeholder participation process. To understand the multi-stakeholder collaborative mechanism in scientific data opening, this paper first reviewed existing research on scientific data opening stakeholders to identify a comprehensive list. It then classified stakeholders according to their functional attributes, analyzed and summarized each stakeholder' s participation methods and interest demands in the data opening process. Next, based on stakeholder positioning and demands, it summarized the driving forces for multi-stakeholder collaboration (interest win-win pulling force, institutional environment guidance, social environment driving force, organizational environment support, technical environment guarantee). Finally, it constructed a multi-stakeholder collaborative dynamics model for scientific data opening, clarified the mechanism of collaborative dynamics and cooperative relationships among stakeholders, and proposed targeted recommendations for effective multi-stakeholder collaboration to provide a basis for promoting scientific data opening in China and a reference for future research on inter-stakeholder cooperation.

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Author Contributions

Hu Jiaqi: Literature research, paper writing and revision;
Lu Ying: Discussion of research ideas, guidance on paper revision.

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