Open Science: Drivers, Development Advantages, and Barriers (Post-print)

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Abstract

[Purpose/Significance] To examine the current international development of open science and provide theoretical support and references for its domestic advancement. [Method/Process] Through web-based investigation and literature review, this study synthesizes and introduces the connotation of open science, the factors driving its development, as well as the current advantages and obstacles in open science development. [Results/Conclusion] The concept of open science demonstrates diversity. The demands of scientific development, along with open science policies and practical programs from various institutions and nations, constitute the primary driving forces. The advantages of open science are increasingly evident, including enhanced speed and efficiency of research, facilitation of new research question discovery, increased visibility and engagement of research, promotion of academic rigor and research quality, and strengthened research collaboration and community building. Despite these advantages, several factors impede its development, such as the lack of incentive mechanisms including academic rewards, an independent research culture characterized by competitiveness, insufficient knowledge and skills in open science, and inadequate legal protection for intellectual property rights.

Full Text

Preamble

Open Science: Driving Factors, Development Advantages, and Obstacles

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Abstract

[**Purpose/Significance**] This study examines the current international development of open science to provide theoretical support and reference for the advancement of open science in China. [**Method/Process**] Through web-based and literature surveys, this paper reviews and introduces the meaning of open science, the factors driving its development, and the current advantages and obstacles facing open science. [**Result/Conclusion**] The concept of open science exhibits diversity. The demands of scientific development, along with open science policies and practical programs from various institutions and countries, constitute the main driving factors. The advantages of open science are gradually becoming prominent, such as improving the speed and efficiency of research, facilitating the discovery of new scientific problems, enhancing research visibility and engagement, promoting academic rigor and research quality, and strengthening scientific collaboration and community building. However, despite these advantages, several factors hinder its development, including the lack of incentive mechanisms such as academic rewards, an independent research culture and competitiveness, insufficient knowledge and skills for open science, and inadequate legal protection for intellectual property rights.

2. The Meaning of Open Science

The term "open science" was coined by Stanford University economist P. David to describe the attributes of scientific products generated by the public sector. He opposed extending intellectual property issues to information products, arguing that scientific knowledge produced through public research is a public good that should be freely accessible to everyone after public release to generate greater social benefits [10]. Currently, there is still no unified concept of open science, as different institutions, organizations, and individuals hold varying understandings. Wikipedia defines open science as a movement to make scientific research, data, and dissemination accessible to all levels of society, including both amateur and professional researchers. This encompasses practices such as open research publishing, the open access movement, open notebook science, and various activities that make scientific knowledge publication and academic communication easier [11]. The European Commission (EC) defines open science as transforming the way research is conducted and disseminated through digital tools, networks, and media. By providing new tools for scientific collaboration, experimentation, and analysis, and by making scientific knowledge more accessible, it promotes a more efficient, transparent, and effective scientific process that depends on both technological development and cultural changes affecting research collaboration and openness [12]. In its report *Open Innovation, Open Science, Open to the World*, the European Commission further defines open science as a new approach to research based on collaborative work and new methods of disseminating knowledge through digital technologies and collaborative tools. This concept systematically changes research practices over the past 50 years—from publishing research results in academic publications to sharing and using all available knowledge early in the research process [13]. The Organisation for Economic Co-operation and Development (OECD) defines open science as efforts by researchers, governments, funding agencies, or the scientific community to make publicly funded research results (publications and research data) digitally accessible with minimal or no restrictions, thereby enhancing research transparency and promoting collaboration and innovation [14]. J.D.K. Smith, Director of the Office of Copyright and Scholarly Communication at Duke University, believes that open science involves all aspects of openness, with "transparency" permeating the entire research process, including scientific methods, observations, data collection, data access, communication, collaboration, and research tools. Rather than merely removing restrictions on access to scientific publications, the entire process should be shared with all potential users, collaborators, and derivative users [15].

Although these definitions differ in their descriptions of open science, all emphasize public access to research content and broader communication. The reason open science has not formed a unified concept lies in its complex and extensive content, with different institutions, organizations, and individuals holding different perspectives on "openness." Understanding of "openness" can vary based on different angles: it may represent the democratic right to access knowledge (such as open access publications) or the need to involve the public in research (such as citizen science), or it may involve using tools to promote research collaboration and sharing. B. Fecher et al. argue that open science encompasses numerous assumptions about future knowledge creation and dissemination. Through extensive literature review, they propose that the current discourse on open science consists of five major schools of thought: the infrastructure school (concerning technical frameworks), the public school (concerning accessibility of knowledge creation), the metrics school (concerning altmetrics), the democratic school (concerning knowledge access), and the pragmatic school (concerning collaborative research). The specific content of these five schools is shown in Figure 1 [Figure 1: see original paper].

Based on a comprehensive review of open science definitions and these five schools of thought, the authors argue that modern open science combines concepts, tools, platforms, and media to promote knowledge creation and dissemination in a free, open, and more inclusive manner, thereby generating greater benefits from research, as shown in Figure 2 [Figure 2: see original paper].

3. Driving Factors of Open Science Development

Open science has gained widespread attention and rapid advancement due to multiple influences: (1) the intrinsic demands of scientific development in the new research information environment; (2) the explosive growth of global open science policies, providing important theoretical guarantees; and (3) the continuous emergence of open science practice programs supported by these policies, which further propel open science forward.

3.1 Intrinsic Demands of Scientific Development for Open Science

The inherent needs of scientific development itself constitute an important driving factor for open science. In a research environment filled with new tools, platforms, and media, the ways research is conducted, its outputs, and its participants have also changed. J.C. Burgelman et al. propose that scientific development currently exhibits three important trends: (1) new research methodologies are emerging—in a data-intensive environment, large datasets are accessible and can be processed using simulation software and high-performance computing; (2) exponential growth of research outputs—including not only open access to research data but also the reproducibility of scientific discoveries, which means researchers can access methods, tools, data, and articles, fostering new pathways for collaboration; and (3) diversification and growth of those who create research outputs—including not only conventional researchers but also citizen scientists [18]. From this perspective, trends in scientific development create intrinsic demands for open science.

3.2 Open Science Policies Promoting Development

Open science policies serve as a crucial driving force for the rapid implementation of open science. In recent years, many institutions and countries have introduced various open science policies to vigorously promote its progress (open science encompasses extensive content, so these policies also include targeted policies on open access and open data proposed by various countries, which this paper does not specifically address), which are vital for accelerating open science development.

On September 29, 2014, the Association of European Research Libraries (LIBER) released the "LIBER Statement on Enabling Open Science." LIBER believes that moving toward open science will bring greater research transparency, higher quality, and increased citizen participation, while also accelerating the pace of scientific discovery through data-driven innovation. LIBER fully supports open science policies and actions at the European level across all disciplines and recommends that the European Commission support open science through policy and leadership, advocacy and recognition, legal frameworks, open infrastructure, roles and responsibilities, and skills [19].

Between 2014 and 2017, Finland's Ministry of Education and Culture implemented the Open Science and Research Initiative (ATT), aiming to make Finland a global leader in open science by 2017 and ensure its widespread utilization. One of its goals was to make publicly funded research results and data openly accessible and to clarify the methods of openness. This strategy recognized that openness increases opportunities for everyone to participate in scientific development and makes it easier to share research results [20]. Building on ATT, on November 25, 2014, the Ministry released *The Open Science and Research Roadmap 2014–2017*, reaffirming Finland's goal to become a global leader in open science by 2017 [21].

In April 2016, the Netherlands hosted a two-day open science conference in Amsterdam, where EU member states and representatives from research, publishing, and higher education institutions across Europe discussed the importance of open access. The conference launched the "Amsterdam Call for Action on Open Science," which, in addition to 12 detailed action items, set two main goals: (1) achieving 100% open access to publicly funded scientific publications by 2020, and (2) making open data a standard for publicly funded research [22]. On February 9, 2017, the Netherlands formally proposed the National Plan Open Science, with objectives to: (1) fully achieve open access to research publications by 2020; (2) establish clear, recognized technical and policy prerequisites, including providing necessary expertise and support to promote research data reuse; (3) consider open science as a metric for evaluating and rewarding researchers, research groups, and research proposals; and (4) create an information repository for all available research support information. To encourage necessary collaboration and demonstrate and monitor implementation progress, national education, culture, and science and technology departments jointly signed the "Dutch Declaration on Open Science" and launched the "National Platform Open Science," aiming to demonstrate the important impact of open science on research and society as a whole and to implement a systemic shift toward open science at the national level [23].

3.3 Open Science Practice Programs Accelerating Progress

In addition to actively formulating and implementing open science policies, many institutions and countries have launched relevant practice programs, such as the Budapest Open Access Initiative (BOAI), the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities, the 21st Century Open Science Declaration, and *The Open Science and Research Roadmap 2014–2017*, which have promoted the popularization of open science concepts. Software and platforms such as the Open Science Framework (OSF), Open Science Organization (OFO), Figshare, and arXiv support open science development, while institutions like the Open Knowledge Foundation (OKF) and the Allen Institute for Brain Science support open science through project funding. These open science practice programs serve as important accelerators for open science development by implementing and validating policies and theories.

The following sections introduce several representative EU practice projects to illustrate their role in advancing open science.

3.3.1 FOSTER Project FOSTER (Facilitate Open Science Training for European Research) is a two-year project funded by the European Union's Seventh Framework Programme (FP7), launched in February 2014 by 11 partners from 6 EU countries. It developed the FOSTERportal e-learning platform, which aggregates many of the best training resources on open science and strategies and skills for implementing open science practices in daily workflows. The platform targets stakeholders including funders, policymakers, researchers, managers, librarians, data managers, and graduate students. Its primary goal is to enable European research personnel to make genuine and lasting changes to their research practices, ensuring that open science becomes the norm [24].

To better conduct training on open science and related content, the FOSTER project team constructed an open science taxonomy (see Figure 3 [Figure 3: see original paper]) to classify thematic areas of open science. The taxonomy serves multiple purposes: helping users navigate and browse FOSTER content; providing a framework for users to subscribe to updated content; identifying experts in specific fields; linking and recommending open science-related content in the portal; serving as a thematic map to introduce learners to various areas of open science; ensuring that FOSTER training covers all areas of open science; and providing a framework for FOSTER project consulting services. In 2014, the FOSTER project funded 28 open science training activities, and in 2015, it supported 24 community training activities in 18 countries [25]. Currently, FOSTER has launched FOSTERPlus, which will expand existing training materials and create new content. These resources will be tailored to specific disciplines and developed in collaboration with experts and organizations in life sciences, social sciences, and humanities, with results that can be directly applied to researchers' daily practices. FOSTER is significant in helping users quickly understand various aspects of open science, track and locate knowledge and experts in specific fields, and integrate open science concepts into daily research and work.

3.3.2 Open Science Monitor The Open Science Monitor (see Figure 4 [Figure 4: see original paper]) is part of the EU's research and innovation program—Open Science. Commissioned by the European Commission's Directorate-General for Research and Innovation, the monitor was developed by RAND Europe with support from Deloitte, Digital Science & Research Solutions, Altmetric.com, and Figshare. It aims to track open science trends, identify the main drivers, incentives, and constraints of open science development, and provide policymakers and stakeholders with up-to-date data and development trends on open science [26].

The monitor tracks three aspects of open science: open access to publications, open research data, and open scholarly communication. Each monitoring feature includes several indicators presented in the form of a wheel (see Figure 4 [Figure 4: see original paper]). Each indicator contains at least one type of data—for example, the "open peer review journal policies" indicator provides relevant data on open peer review journal policies (see Figure 5 [Figure 5: see original paper]), and clicking on this data presents its visualization trend chart (see Figure 6 [Figure 6: see original paper]). The Open Science Monitor maintains real-time tracking of the latest developments in open science from these three perspectives, visually demonstrating the growth of open science practices through charts and providing the latest data and development trends for decision-makers and stakeholders.

3.3.3 European Open Science Cloud Europe is the world's largest producer of scientific data, but inadequate infrastructure and data fragmentation have prevented the full utilization of big scientific data. On April 19, 2016, the European Commission announced a blueprint for promoting cloud services and building world-class data infrastructure to ensure that Europe's science, business, and public services can benefit from the big data revolution. The Commission plans to establish a new "European Open Science Cloud" (EOSC) by enhancing existing research infrastructure and promoting interconnectivity. The EOSC will provide a virtual research environment for 1.7 million researchers and 70 million science and technology professionals across Europe, facilitating convenient data storage, sharing, and reuse. By deploying necessary high-speed broadband networks, large-scale storage facilities, and supercomputers, the cloud ensures effective access to and processing of large datasets stored in cloud space. The European Open Science Cloud provides crucial infrastructure support for researchers to fully utilize scientific big data and serves as an important platform for promoting open science development, making research more efficient and effective. It will enable countless researchers to share and analyze research data in a trusted environment that transcends technology, disciplines, and national borders [29].

4. Advantages and Obstacles of Open Science Development

Supported by modern information technology and driven by forward-thinking scientists and research institutions, open science has made significant progress. Compared with traditional scientific development, which suffered from slow research cycles, restricted access to research results, low research transparency, lack of oversight in research processes, rampant academic misconduct, and insufficient research collaboration, open science possesses inherent developmental advantages. However, open science remains an unachieved goal and inevitably faces various problems during its development. This section analyzes the positive impacts of open science on research and the factors hindering its development to inform the formulation and adjustment of relevant policies and strategies.

4.1 Advantages of Open Science Development

4.1.1 Improving the Speed and Efficiency of Research Cycles Open science can enhance the speed and efficiency of research cycles. For example, reusing others' project data avoids repetitive work and saves time, labor, and financial costs associated with data collection, organization, and processing. Reusing open standards in project data recording reduces tool development costs. A typical example is in astronomy, where high data collection costs and the need for expensive instruments to reduce data collection time have created a culture of sharing raw data.

4.1.2 Facilitating the Discovery of New Research Problems When researchers reuse data and materials created by other researchers, integrate and reanalyze data from diverse sources, and apply them to new research projects with new perspectives and methods, they can generate new research results and support the development of "data-intensive science."

4.1.3 Enhancing Research Visibility and Engagement Sharing research processes and results with users increases research transparency. Open science encourages more people to participate in research, including not only conventional researchers but also other groups such as "citizen scientists," providing the public with opportunities to engage in research processes and outcomes. Citizen science offers ordinary citizens ways to contribute their strengths while providing more solutions for scientific research.

4.1.4 Ensuring Academic Rigor and Research Quality Academic ethics is an important concern in academia. Making research processes and results as open as possible essentially subjects research to public supervision. Reviewers and ordinary users can verify experiments and reproduce data through the author's clear and complete research data, methods, and protocols, further demonstrating the reliability and quality of published research results. Such a supervisory system also creates a self-review and self-monitoring mechanism for authors themselves, ensuring academic rigor and research quality.

4.1.5 Strengthening Research Collaboration and Community Building Open science provides researchers with more opportunities for collaboration and exchange. Open science infrastructure can help researchers quickly find research communities interested in the same research areas without being limited by institution, country, or discipline. Through shared research questions, mutually beneficial cooperative relationships can be established to share knowledge and expertise, reduce duplicate research, and accelerate research progress.

4.2 Obstacles to Open Science Development

4.2.1 Lack of Incentive Mechanisms Such as Academic Rewards Open science requires researchers to invest more time and energy than in traditional research environments. If they cannot obtain obvious benefits through open science—such as improved ability to secure funding, greater recognition from peers, or enhanced career development—they may be unwilling to bear these costs. Traditional academic reward systems focus primarily on academic evaluation, using published research papers as the main evaluation criterion. Such an academic environment lacks any reward mechanism for researchers who share their research processes and results, inevitably becoming an important factor hindering further development of open science.

4.2.2 Unique Research Culture and Competitiveness Different disciplines have different cultures, and the nature of disciplines themselves can create difficulties for interdisciplinary collaboration. Some disciplines have frequent research collaboration, while others rarely collaborate. Additionally, fierce competition exists in all industries, and the research field is no exception. Researchers are often both partners and strong competitors. The key elements to ensuring competitive advantage are publishing articles, papers, and monographs. Many researchers view the data and other resources generated during their research processes as intellectual capital to be utilized and mined to create new research results. Researchers are unwilling to share any research-related data before formally publishing their results because they fear losing control over outcomes and worry about the risk of their research results being stolen by others.

4.2.3 Lack of Knowledge and Skills for Open Science Many open science stakeholders—including funders, policymakers, researchers, administrators, and librarians—lack awareness, relevant knowledge, and skills for open science. For example, developing, maintaining, and utilizing open science infrastructure requires researchers and related personnel to master new skills and make significant efforts, especially when there are no unified standards or guidelines for managing new types of resources. This represents a huge challenge for researchers. This also explains the necessity of implementing projects like the EU's FOSTER, but the lack of relevant knowledge and experience among stakeholders remains a widespread phenomenon.

4.2.4 Lack of Legal Protection for Intellectual Property Rights and Other Issues Open science advocates for the openness of research methods, processes, data, results, and infrastructure, but many researchers worry that their results may be plagiarized—a significant issue that cannot be ignored in open science development. Researchers making their results publicly available does not mean they no longer enjoy corresponding intellectual property rights; rather, they should receive greater protection. Otherwise, promoting open science to drive research innovation and scientific and technological progress would be empty talk. Additionally, for resources that are personal, confidential, or protected by commercial or third-party licenses, public sharing is nearly impossible. Researchers or their funders, institutions, and partners wish to restrict access to research results and related materials to protect commercial secrets and prevent commercial exploitation. The relationship between such restrictions and the requirements of the U.S. Freedom of Information Act remains a contradiction in the research community.

Conclusion

This paper has reviewed the meaning of open science, the main factors driving its development, and the current advantages and obstacles facing open science through web-based and literature surveys. Although open science has a long development history, its concept remains diverse due to its complexity. In the new generation information environment, the intrinsic demands of scientific development, along with open science policies and practice programs from various institutions and countries, constitute the main driving factors. Open science is receiving increasing attention because its advantages are gradually becoming prominent, such as improving research speed and efficiency, facilitating the discovery of new research problems, enhancing research visibility and engagement, promoting academic rigor and research quality, and strengthening collaboration and community building. However, despite these advantages, open science faces significant resistance during its development, including the lack of incentive mechanisms such as academic rewards, unique research culture and competitiveness, insufficient knowledge and skills, and inadequate legal protection for intellectual property rights.

Open science is the inevitable path forward, but it is also a long journey. Addressing the problems and obstacles in its development requires joint efforts and cooperation from all stakeholders. For example, conducting training and advocacy on open science through projects like FOSTER can enhance open science awareness and encourage more researchers and institutions to participate. Funders and government departments should formulate policies to promote open science development and improve research evaluation systems to safeguard open science progress. Additionally, establishing infrastructure such as cloud platforms and scientific big data service platforms can enhance data processing, computing, and storage capabilities, providing researchers with convenient platforms for data storage, sharing, and reuse.

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Author Contributions

Chen Xiujuan: Collected, organized, and analyzed research materials; drafted and revised the manuscript.
Zhang Zhiqiang: Proposed the research idea; participated in manuscript revision.

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