An Analysis and Reflection on the Evolution of Science Communication Models and Their Interaction with Technological Innovation: Postprint

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Abstract

In an era of rapid technological advancement, science communication is intimately connected with technological innovation and constitutes a crucial factor influencing national technological competitiveness and securing global technological discourse power. This article analyzes the contemporary context of science communication along with its theoretical research and paradigm shifts, examines the mutually reinforcing relationship between science communication and technological innovation, and reveals the underlying mechanisms of their interaction. Building upon this foundation, the study investigates exemplary practices from major developed countries abroad in promoting science communication, and in conjunction with the current state of science communication in China, proposes strategic recommendations for advancing the science communication enterprise.

Full Text

Abstract

In today' s rapidly evolving technological landscape, science communication is intimately connected with scientific and technological innovation, representing a critical factor influencing national technological competitiveness and the contest for global scientific discourse. This paper analyzes the contemporary context of science communication alongside theoretical research and paradigm shifts in the field, examines the mutually reinforcing relationship between science communication and technological innovation, and reveals the underlying mechanisms of their interaction. Building upon this foundation, the study investigates exemplary practices from major developed countries in promoting science communication, and in light of China' s current situation, proposes targeted strategies to advance the nation' s science communication endeavors.

Keywords: science communication, science popularization, technological innovation, fundamental research

1 The Contemporary Context of Science Communication

The report from the 20th Party Congress emphasizes that innovation must occupy the core position in China' s modernization drive. Science popularization constitutes essential foundational work for achieving innovative development, establishing a solid scientific and cultural foundation for basic research and technological innovation. At the National Science and Technology Innovation Conference, the 18th Academician Conference of the Chinese Academy of Sciences, and the 13th Academician Conference of the Chinese Academy of Engineering and the 9th National Congress of the China Association for Science and Technology in May 2016, General Secretary Xi Jinping stated: "Scientific and technological innovation and science popularization are the two wings of innovative development, and science popularization should be placed on an equal footing with scientific and technological innovation." In July 2016, in his congratulatory letter to the Geological Museum of China, General Secretary Xi reiterated that "scientific and technological innovation and science popularization are the two wings of innovative development." In July 2023, in his reply to representatives of the "Science in China" academicians and experts, he further emphasized the importance of "widely disseminating scientific knowledge and promoting the scientific spirit, playing a very good role in advancing science popularization."

Science communication aimed at technological innovation helps promote science popularization, foster scientific spirit, and enhance public scientific literacy, thus carrying higher expectations and requirements in the new era. In developed countries, timely understanding of society's actual needs, concerns, and attitudes toward scientific and technological innovation, and formulating corresponding policies and measures accordingly, has become an important component of the national scientific and technological innovation system. To adapt to this developmental trend, China has formulated relevant science communication policies in recent years. For instance, the State Council' s 2018 "Several Opinions on Comprehensively Strengthening Basic Scientific Research" explicitly states the need to "fully leverage the important role of basic research in disseminating scientific ideas, promoting scientific spirit and innovation culture, and encourage scientists to popularize scientific knowledge among the public." The 2021 State Council "National Scientific Literacy Action Plan Outline (2021-2035)" calls for "building expert studios for science communication, formulating guidelines for the popularization of scientific and technological resources by category, and implementing a comprehensive media science communication capacity enhancement plan to achieve multi-channel, all-media dissemination of popular science content."

Against this backdrop, deeply exploring the interaction mechanism between science communication and scientific and technological innovation, and enabling

the public to better understand, participate in, and support scientific activities, represents not only the responsibility of scientists and the needs of the public and the nation, but has also become a significant issue in the field of Science, Technology, and Society (STS) studies. However, as China' s science communication started relatively late, current theoretical research in this area still lacks depth and extensive findings. Existing studies primarily focus on how scientists can effectively participate in science communication, while some scholars examine the role of science funding agencies in promoting researchers' engagement in science communication related to technological innovation. Nevertheless, domestic research lacks in-depth exploration of the interactive mechanism between scientific and technological innovation and science communication, particularly regarding how this interaction comprehensively enhances China' s basic research capabilities. This paper attempts to summarize the evolutionary process and paradigm shifts in science communication, analyze the mutual promotion between science communication and technological innovation, and examine practical cases from developed countries, with the aim of providing suggestions and references for the development of China' s science communication endeavors.

2 The Evolutionary Process and Paradigm Shifts in Science Communication

2.1 The Evolutionary Process of Science Communication

Communication is not merely a means of information and knowledge flow, but also a pathway for individual and group learning and interactive learning. With this understanding of "communication," we can view "science communication" as the flow pathway of scientific knowledge (and related knowledge) and as an interactive learning path centered on scientific knowledge and activities. This knowledge flow and exchange is not limited to the scientific community, but also encompasses interactions between the scientific community and the public, and even among the public themselves.

Traditional science communication research divides theoretical evolution into three stages (Table 1). The first stage is traditional science popularization explained by the "center-broadcast model," characterized by top-down, command-style one-way communication, transmitting science based on the premise of public ignorance of scientific information. The second stage is public understanding of science explained by the "deficit model," also top-down but educational in nature, aiming to educate the public through the dissemination of scientific information and knowledge. The third stage is reflective science communication explained by the "dialogue/participation model," which primarily encourages public participation in dialogue to build social consensus, emphasizing reflective two-way exchange and interaction.

Currently, as international theoretical understanding of science communication has shifted from the first-stage "center-broadcast model" to the third-stage "dialogue/participation model," China' s science communication practice has

completed the transition from traditional science popularization (first stage) to public understanding of science (second stage), and is now moving toward reflective science communication (third stage). However, during this process, the traditional "dialogue/participation model" has proven inadequate for China' s current science communication practice, causing Chinese science communication research to fall into a mechanistic and static predicament that hinders the dynamic development of practice.

After in-depth research and absorbing extensive theories and practical experience in science communication and technological innovation, Alan Irwin proposed a new three-stage model for science communication (Table 1). In this new model, both the center-broadcast model and the deficit model (first stage) are based on the premise that the public lacks necessary scientific knowledge and literacy, representing top-down, one-way communication driven jointly by government and scientists. This stage focuses primarily on scientific knowledge itself, encompassing both traditional scientific understanding and practice, sharing significant philosophical foundations and practical patterns. Irwin' s second stage shares many similarities with the traditional third stage, representing a two-way, bottom-up communication based on the "dialogue/participation"model that aims to balance "science-public" and "expert knowledge-lay knowledge." Irwin' s third stage emphasizes the decisive influence of socio-technical contexts on science communication practice. This contextual understanding clarifies that science and technology are constructed and developed within social, cultural, political, and economic backgrounds rather than in isolation. Consequently, all dissemination and reception of science and technology occur within specific socio-technical contexts, revealing the complexity and diversity of science communication practice.

2.2 Paradigm Shifts in Science Communication in the New Era

The world today is undergoing profound changes unseen in a century, and China is at a critical historical juncture in achieving the great rejuvenation of the Chinese nation. Following the Russia-Ukraine conflict, the comprehensive sanctions imposed by the US and Western countries on Russia' s science, technology, and economy have brought shocks and warnings to China' s scientific and technological development. Theoretically, any science communication practice faces unique social needs and technical backgrounds, and different countries, due to their particular socio-technical contexts, exhibit vastly different multi-stakeholder relationships and complex interactions in their science communication activities. Therefore, in this new era where technological competition and security concerns have become increasingly prominent, China' s social needs and technical backgrounds have undergone profound changes, and both theory and practice of science communication have likewise transformed significantly within the Chinese context.

Strengthening basic research and enhancing technological innovation capabilities from the source are urgent requirements for achieving high-level techno-

logical self-reliance and strength, representing the necessary path to building a world leader in science and technology. In this context, scientific and technological innovation, particularly breakthroughs in basic research, has become one of the important directions for science communication practice. In his speech during the 21st collective study session of the Political Bureau of the CPC Central Committee on February 21, 2023, General Secretary Xi Jinping emphasized: "Conducting basic research requires both material guarantees and spiritual incentives," while also pointing out the need to vigorously promote the scientific spirit of pursuing truth and scaling peaks throughout society, widely publicize exemplary models and deeds emerging from basic research, strengthen national science popularization capacity building, and disseminate scientific knowledge and showcase scientific and technological achievements through both online and offline channels. Consequently, the paradigm of science communication has shifted in this new era, urgently requiring further exploration of the interactive effects between science communication and scientific and technological innovation represented by basic research, in order to guide current Chinese science communication practice.

3 The Mutually Reinforcing Relationship Between Science Communication and Technological Innovation

Basic research is the source of technological innovation, primarily comprising curiosity-driven research and problem-driven research. The former has no foreseeable specific application or utility, while the latter aims to understand the fundamental knowledge of certain phenomena and facts. Precisely because of its high-level, profound, and novel characteristics, it is difficult for governments and taxpayers to intuitively understand where research funds are spent, which may consequently affect the material guarantees and spiritual incentives for technological innovation. Science communication and technological innovation mutually promote each other: on the one hand, to achieve high-level technological self-reliance and strength, China urgently needs to enhance its basic scientific and technological capabilities, which in turn requires science communication to improve the scientific literacy of the entire nation, awaken youth interest in scientific and technological innovation (especially basic research), and strengthen public understanding of the long-cycle, low-return characteristics of basic research. On the other hand, outstanding breakthroughs in technological innovation will provide new content support and development demands for science communication, offering richer research material for theoretical exploration in the field.

3.1 The Promoting Effect of Science Communication on Technological Innovation

The importance of science communication lies in its ability to transform knowledge flow from a natural process into a human-driven one. This includes identifying and overcoming barriers and bottlenecks in knowledge flow, exploring new

pathways for knowledge dissemination, and developing policies and methods that can optimize knowledge flow. Moreover, science communication helps inspire researchers' wisdom, expand their knowledge horizons, stimulate research inspiration, and promote the germination and deepening of interdisciplinary research. Science communication drives new demands for technological innovation, thereby promoting sustainable development in both science and society. Through science communication, society continuously identifies and generates new demands for technological innovation, a mechanism that not only drives continuous progress and iteration in basic research but also integrates it into a comprehensive innovation system encompassing new knowledge generation, dissemination, and application. Science communication also serves as an educational approach that can effectively enhance public scientific literacy, helping to cultivate a new generation of knowledgeable citizens with profound scientific and technological literacy and laying a solid foundation for the continuous development and progress of technological innovation. Through science communication, the public' s scientific understanding and technical capabilities are enhanced, further promoting the alignment between technological innovation and social needs, forming a positive and healthy innovation ecosystem.

3.2 The Promoting Effect of Technological Innovation on Science Communication

One important perspective on the motivation for science communication about technological innovation is that science communication represents scientists' own needs and social responsibilities. It is scientists' social responsibility to publicize the reasons, results, and impacts of their scientific research to the public. Specifically, technological innovation influences science communication in multiple ways: (1) Evolution of science communication content. New knowledge revealed by technological innovation continuously enriches and updates the content of science communication. Beyond the knowledge itself, various aspects of research activities, including the research process, research life, and research figures, have also become part of science communication. Presenting these elements visually to the public can more effectively help them deeply understand science. (2) Expansion of science communication teams. Researchers' active participation in science communication not only enriches human resources for science communication but also ensures the accuracy and forward-looking nature of the content disseminated. This enhances the authority of science communication and helps the public deepen their understanding of science in a trustworthy and accessible environment. (3) Strengthening of material foundations for science communication. The popularization of scientific and technological resources makes research facilities, equipment, and venues key resources for science communication. Integrating these resources into science communication can significantly enhance its material conditions, thereby strengthening its breadth and impact.

In summary, the interactive influence between science communication and technological innovation has three characteristics: (1) Complexity and diversity.

The interaction between technological innovation and science communication systems encompasses multiple elements, exhibiting obvious complexity and diversity. (2) Dynamic multiplicity. This interaction has both spontaneous natural attributes—for instance, the influence of science communication on research teams is largely a natural extension of knowledge transmission—while becoming more pronounced under external impetus. At least three forces affect this interaction: national will, tendencies of the scientific community, and public aspirations. (3) Win-win situation. From a broader perspective, through appropriate adjustment and optimization of the wills of the state, scientific community, and public, particularly through national policy guidance, this interaction generally presents a mutually beneficial and advantageous interactive state.

4 Analysis of Science Communication Practices in Developed Countries

Major global scientific research funding agencies attach great importance to science communication, strengthening the close connection between technological innovation and science communication in their organizational structures. They widely utilize internet, social media, and new media technologies such as video to achieve broader, faster, and more international science communication. Such strategies make scientific information more accessible to the public, narrowing the distance between research institutions, scientists, and the public. Developed countries possess profound historical backgrounds and research foundations in science communication, with diverse methods, rich content, highlighted key areas, and notable interdisciplinary characteristics. Their science communication experiences under specific social needs and technical backgrounds provide valuable guidance for improving China' s science communication practice as it moves toward Irwin' s third stage.

4.1 Explicit Integration of Science Communication Responsibilities into Major Science and Technology Programs

Taking the European Union as an example, public engagement with scientific and technological breakthroughs is a prerequisite for obtaining funding under the "EU Framework Programme." The EU encourages science communication through multimedia, exhibitions, educational materials, public debates, seminars, and other means. In January 2007, the "EU Seventh Framework Programme" specifically established a science communication component— "Science in Society" —within its "Research Capacity Building Programme," allocating a budget of €280 million for this purpose.

4.2 Establishment of a Public-Facing Scientific and Technological Reporting System

Many developed countries have relatively systematic and comprehensive scientific and technological reporting systems, through which research methods,

technologies, processes, data, and results generated from research activities are openly shared with the public. Simultaneously, science funding agencies provide support in terms of technology and communication channels. For instance, the U.S. Government Scientific and Technical Information (STI) system, one of the world' s most authoritative government science and technology reporting management systems, began its collection in 1958. It primarily includes scientific and technical reports produced during federally funded R&D activities, with sources including U.S. government agencies at all levels and their contractors, encompassing universities, for-profit and non-profit organizations, national laboratories, etc., covering dozens of disciplines including industry, agriculture, energy, transportation, military, and aerospace.

4.3 Integration of Science Communication Impact into the Evaluation System for Technological Innovation

In the UK' s current "Research Excellence Framework" (REF) evaluation metrics, research outcomes account for 60%, research environment for 15%, and research impact for 25%. This means that the impact of researchers' outputs on society and the public is also incorporated as a core indicator, demonstrating that effectively communicating technological innovation to the public and popularizing it to bring broader positive impacts to social life is equally important as technological innovation itself.

4.4 Policy-Level Promotion and Encouragement of Researchers' Integration into Science Communication

In 2008, the UK Research Councils and other major research funding agencies jointly signed an initiative to promote researchers and their academic institutions to actively participate in science communication activities. In March 2010, to further promote scientists' and academic institutions' participation, the UK Research Councils organized a working team composed of research funders and academic representatives to jointly develop the "Protocol for the Engagement of the Public with Research." This protocol aims to stimulate researchers, academic managers, and research institutions to more actively engage in science communication. Meanwhile, the German Research Foundation has, since 2000, promoted enhanced recognition and encouragement of researchers actively participating in science communication through specific incentive mechanisms such as the "Communicator Award," further stimulating broader participation among researchers.

5 Current Status of Interaction Between Science Communication and Technological Innovation and Recommended Strategies

Science communication is an evolving field that requires continuous updating and upgrading of its core concepts with the times, demanding that scholars com-

pare and explore various science communication models developed in different social environments. Regrettably, China' s current theoretical exploration of science communication has yet to meet practical needs. We still overly rely on the binary thinking of the "deficit model" and "dialogue/participation model," causing China' s overall science communication concepts to remain between Irwin' s first and second stages. On specific issues, we have begun transitioning toward Irwin' s second and third stages, but theoretical research on science communication remains insufficient during this process. While learning from the successful experiences of developed countries is necessary, we should also recognize that Chinese citizens have limited ability to acquire and master scientific knowledge, particularly when facing interdisciplinary and cross-disciplinary knowledge. Therefore, the effective popularization and widespread dissemination of scientific research results, especially basic research, are particularly crucial. Focusing on China' s current science communication status, the following recommendations are proposed to strengthen direct interaction with technological innovation.

5.1 Tailoring Science Communication to Different Groups to Enhance Public Scientific Literacy

Different public groups access science in vastly different ways—for instance, youth may prefer learning about science through social media or video platforms. We should conduct surveys on public knowledge and attitudes to understand audience needs and concerns, and based on these findings, formulate clear science communication strategies and objectives to ensure the direction and quality of science communication activities, while encouraging and supporting innovative science popularization projects. We should guide the public to actively participate in science communication activities such as science festivals and open days to improve their scientific literacy, strengthen science education to cultivate public scientific thinking and critical thinking abilities, and provide continuous education and training on science communication for researchers, educators, and science popularization workers to enhance their science communication capabilities. In science communication activities, we should establish cooperative relationships with news media, social media, and other online platforms to expand the reach of science communication.

5.2 Increasing Support for Science Communication Tasks in Research Projects

Scientific research, especially basic research within the "ivory tower," maintains a certain distance from the general public. To address this, funding agencies can, from a top-level strategic perspective, clarify the connection between research funding and science communication, incorporating science communication into the evaluation criteria for research management to normalize it as a regular task. Simultaneously, providing small, highly flexible grants to researchers for science communication of research outcomes, simplifying application procedures, and

enhancing funding timeliness will help support researchers engaged in cutting-edge scientific research to conduct public-facing science communication related to their projects.

For example, the following project types could be specifically supported: constructing a public-facing scientific and technological reporting system and related policy research; promoting exploration of new forms and pathways for integrating research and science communication; conducting regular surveys on the status of science communication resources and scientific and technological resources and research on science communication resource needs; drawing on developed countries' experiences to improve the policy and regulatory system supporting the integration of research and science communication; and exploring supporting conditions such as talent, projects, platforms, funding, and mechanisms for integrating research and science communication.

5.3 Elevating the Status of Science Communication Work and Promoting the Construction of Science Communication Teams

Science funding agencies can establish dedicated science communication awards or collaborate with other institutions to launch annual science communication awards for researchers, organizing award ceremonies and inviting renowned scientists as presenters to widely publicize these activities. This not only demonstrates funding agencies' support for science communication, alleviating researchers' concerns, but also sets examples, strengthens the scientific community' s identification with participation in science communication, and thereby enhances the recognition of science communication behavior within the scientific community. For instance, the China Science News Award, established by the China Science and Technology Journalists Association, aims to recognize outstanding individuals who have made significant contributions to science news and communication, further encouraging scientific and technological workers and citizens to participate in science communication and advancing China' s science communication endeavors.

5.4 Promoting the Establishment and Improvement of Digital Publishing Platforms for Scientific and Technological Innovation Achievements at All Levels to Strengthen Platform Construction

While learning from mature experiences in technologically advanced countries, we should attempt to establish digital open platforms or science popularization websites at various levels suitable for China' s national conditions, creating new media matrices with unified services, shared resources, and aggregated publishing and management. Through collaborative linkage and complementary functions among different accounts, we can expand the dissemination effect within the scientific community. Under the premise of ensuring that core research data is not disclosed, we should publish research progress and core achievements of various basic research projects in real time to enhance public engagement. Simultaneously, we should support researchers to transform relatively traditional

basic research outcomes into more flexible forms such as popular science audio-visual products, posters, and articles, presenting them in diverse formats to enrich the content. This approach publicizes research progress while promoting the scientific spirit and advocating academic ethics, helping audiences overcome reading fatigue.

5.5 Incorporating Researchers' Performance in Science Communication as an Important Reference in Scientific and Technological Evaluation

Since most major science funding agencies rely on public funds, guiding scientific research to be more responsive to social needs and strengthening the linkage between scientific research and society not only reinforces the justification for funding agencies to obtain public funds but also helps achieve their core missions. For example, the goal of the U.S. National Science Foundation is not only to promote scientific progress but also to "promote the health and prosperity of the nation and enhance the welfare of the people." Encouraging researchers to engage in science communication and increasing their interaction with the public is an effective way to understand social concerns and a key step for funding agencies to guide scientific research to pay attention to social needs. When implementing reforms to the science and technology management system, in addition to greatly encouraging researchers to engage in scientific research itself, we also need to revitalize outdated researcher evaluation index systems by incorporating researchers' performance in science communication work into the evaluation system, encouraging scientific and technological innovation to be more closely connected to public life and enabling the teaching and popularization of cutting-edge knowledge from basic disciplines to return to the core of scientific development.

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