Deepen supply-side reform of science popularization resources and build high-quality and highly efficient modern science and technology museums

Xiaoming Wang
Shanghai Science and Technology Museum, China

Abstract
Standing at the starting point of the 14th Five-Year Plan (2021–2025), China’s modern science and technology museum system faces both new opportunities and challenges, and urgently needs supply-side reform of science popularization resources. The reform should maintain the direction of promoting public participation, strengthening cross-sector integration, applying emerging technologies, promoting the science popularization industry and deepening international cooperation. The aim of the reform is to optimize exhibition levels and quality, deepen the diversity and innovation of educational resources, refine the detection of and response to visitor demands, and strengthen academic research and the transformation of research achievements. Such efforts will serve to cultivate the capacity for holding popular exhibitions, enhancing science communication, delivering targeted services and driving innovation, and will promote the development of high-quality and highly efficient modern science and technology museums.

Keywords
Modern science and technology museums, supply-side reform, science popularization

1. Introduction
During the 13th Five-Year Plan period (2016–2020), the number of science and technology (S&T) museums in China continued to increase, resulting in a wider range of visitors and a growing capacity of science popularization services. The modern S&T museum system created in this process has become a new highland for promoting science popularization and science, technology and innovation (STI), as well as supporting the early-stage cultivation of STI professionals.

The launch of the 14th Five-Year Plan (2021–2025) marks the beginning of a new journey and brings new opportunities for the modern S&T museum system. In 2021, the first year of the plan’s implementation, several new policies and
regulations were introduced, which shows the importance of S&T museums in the education community made up of families, schools and society. This also provides a wider space for the development of S&T museums and gives them greater social responsibilities. For example, the Opinions on Further Reducing the Burden of Homework and After-School Tutoring for Students in the Stage of Compulsory Education (the ‘Double Reduction’ policy) issued by the General Office of the CPC Central Committee and the General Office of the State Council has turned S&T museums and other public institutions into a major component of extracurricular education. Government departments in various localities have also raised specific requirements in this regard. In the National Action Plan for Scientific Literacy (2021–2035) issued by the State Council, creating a modern S&T museum system has been identified as one of three major science popularization infrastructure projects (the other two are strengthening the systematic planning and guidance of science popularization infrastructure and building science popularization bases). The document also underscored, together with the Outline for the Development of Children (2021–2030), that S&T museums as informal science education providers should be better aligned with in-school education. The Law of the People’s Republic of China on the Promotion of Family Education clearly states that S&T museums and other public cultural service institutions and patriotic education bases should guide and support family education and develop public cultural products for that purpose. This clarifies the role and responsibility of S&T museums in family education.

That said, with opportunities also come challenges. First, while S&T museums can benefit from new ways of education enabled by digital technologies and the opportunities created by the Double Reduction policy, problems such as the insufficient supply of science popularization resources make it difficult for museums to cope with the increased demands of people. Second, the COVID-19 pandemic has profoundly reshaped the pattern of social development, and S&T museums must consider how to transform their development pattern after the pandemic. Third, visitors to S&T museums have also undergone changes in various aspects, such as increasingly diverse and layered new demands. Su (1997) once observed that ‘the modernization of museums is a historical process, and the development of museums follows in the footsteps of the development of social production and social life’. Therefore, facing dramatic changes in social production and life, S&T museums should improve their supply of science popularization resources to keep pace with the level of social productivity and people’s growing demands for a better life.

Given the background of the new era, the 14th Five-Year Plan for the Development of the Modern Science and Technology Museum System (2021–2025) issued by the China Association for Science and Technology (CAST) is highly relevant and well targeted. Most notably, by identifying supply-side reform as a priority of future work, the plan has introduced the economic concept of supply-side structural reform to the area of S&T museums and indicated the direction for their transition from quantity-based to quality-based development. The year 2022 marks the 10th anniversary of the CAST proposal on building a modern S&T museum system. It is therefore imperative for us to explore, from a new historical starting point, how to advance supply-side reform of science popularization resources and promote the development of higher quality, more efficient S&T museums, thus contributing to the improvement of the modern S&T museum system.

2. Common directions of supply-side reform

2.1 Public participation: Driving new progress in science communication

Fundamentally, the social and national demands for science communication are all related to the demands of the public (Ren and Zhai, 2014). The development of science communication has undergone a change from the deficit model (which regards the public as knowledge recipients and involves science literacy and public understanding of science) to public engagement, science and society, citizen science and other paradigms. Considering those changes, the public’s initiative in science communication has been given greater
emphasis. Therefore, S&T museums should respond to the demands of the public, change the mindset of one-way dissemination of scientific knowledge, and become platforms for promoting equal-footed dialogue and connection between the public and the scientific community. In addition, the museums should improve their accessibility and equally accommodate the needs of special groups such as the elderly, the disadvantaged and people with disabilities. This will enable more public participation in the whole process of science popularization.

2.2 Cross-sector integration: Giving rise to new forms of science popularization resources

Due to the openness, sharing and high efficiency of the internet, various subjects and elements of science popularization resources have developed ubiquitous connections and synergies, making cross-sector integration a distinctive feature of our times. S&T museums should work with stakeholders such as governments, research institutes, enterprises, media and public welfare organizations in all aspects of cross-sector cooperation. While reinforcing the support of various subjects for the construction of S&T museums, such cooperation also paves the way for the sharing of information, the connectivity of resources and the complementarity of strengths (Wang, 2021), thus generating synergy for development by pooling the efforts of multiple subjects. In addition, the museums should work towards multifaceted integration across different regions and sectors and actively explore new models, industries and ways to activate and promote science popularization resources.

2.3 Empowerment of science and technology: Pushing for changes in science popularization

In the digital age, technological achievements such as 5G, big data, cloud computing, artificial intelligence (AI) and blockchain have transformed every aspect of our daily lives, allowing physical S&T museums to evolve towards digitization and intellectualization, and even producing digital twin forms in the virtual space. More importantly, the concept of the metaverse has introduced infinite possibilities for future scenarios and forms of science popularization. More new scientific discoveries and the creation of new technologies will occur in the future. It is therefore imperative for S&T museums to embrace all possibilities for change and move along the path of digital transformation. First, they should apply recent scientific discoveries and technologies in museum-based education, constructing a big-data system for museum-based education to collect real-time data on learning feedback, provide appropriate learning resources, promote cooperation with schools and other institutions and enhance the productivity of the big-data system of science culture. Second, they should apply recent scientific discoveries and technologies in museum management, taking steps to update their management modes, improve safety and establish smooth workflows, and use intelligent connections to promote the sharing of resources among S&T museums and between S&T museums and the outside world, thus ensuring the effective operation of science popularization. Third, they should apply recent scientific discoveries and technologies in visitor services to strengthen public participation, enhance the visiting experience and promote learning. Finally, they should also apply recent scientific discoveries and technologies in academic research to deepen the study of objects, update analysis tools, promote the establishment of new links and new ideas and lay the foundation for improving public services.

2.4 Shifting growth drivers: Unleashing new potentials of the science popularization industry

Science popularization conducted through S&T museums is a public-welfare undertaking aimed at providing inclusive and equalized public cultural services. Together with other cultural programmes, it serves the purpose of meeting the public’s basic cultural needs. However, with the enhancement of public consumption and the development of the science popularization industry, providing unique products and services has engendered a new direction for building the modern S&T museum system, and the museums’ demand for science popularization products has further stimulated the development of the science popularization industry (Ren and Li, 2020). S&T museums should make full use of their
collections, exhibits, exhibitions and educational, academic and personnel resources. They should also adopt a market-oriented approach to develop high-quality, branded, systematic and distinctive products and services such as science videos, science games and study tours to facilitate the transformation of science popularization resources and meet diversified, personalized and differentiated public needs. This will enable science popularization to move forward along the dual tracks of public undertaking and commercial operation.

2.5 International cooperation: Opening new prospects for science popularization exchanges

Engaging in extensive exchanges and cooperation with S&T museums and related personnel in other countries and regions is a process of mutual communication, understanding and reciprocity across regions, cultures, ideas, experiences and resources. S&T museums should broaden their vision, cultivating an international perspective and establishing a long-term mechanism for international cooperation. They should act on the Belt and Road Initiative and continuously enhance the depth and breadth of cooperation and exchanges in science popularization. This can be achieved through co-organizing exhibitions, issuing calls, incubating projects, establishing brands and other methods of cooperation, as well as by organizing international forums and promoting mutual visits. In this context, we need to adopt the ‘bringing in’ strategy to learn from the advanced concepts and best practices of other countries. In addition, now that China has increased its comprehensive national strengths and the modern S&T museum system has displayed its distinctive features and effects, we should also actively ‘go out into the world’ to make China’s voice heard and promote China’s experience. This will enable people in other countries to experience, enjoy and embrace the excellent science popularization products and services developed by Chinese S&T museums, as well as further amplify China’s voice in the world and enhance the country’s soft power and the cultural confidence of the Chinese public. These positive interactions with the world can facilitate the efficient allocation of scientific popularization resources worldwide, promote cross-cultural understanding and equal-footed dialogue and contribute to the vision of a community with a shared future for humankind.

3. The practical path of supply-side reform

In order to meet public demand and conduct supply-side reform of science popularization resources, the modern S&T museum system should continue along the route of public participation, cross-sector integration, S&T empowerment, industry cultivation and international cooperation. S&T museums should effectively reform their four basic functions of exhibition, education, research and collection, and develop science popularization products and services based on available science popularization resources and tailored to the needs of visitors.

3.1 Raise the level and quality of exhibits and displays to make exhibitions more attractive

1) Create hybrid exhibitions to open up new fields of science popularization. S&T museums should improve the quality of physical exhibitions, explore innovative exhibition ideas, themes and content, and use digital media, indoor positioning and recognition and sensing technologies to promote visitors’ interaction with exhibits and enhance their sense of participation and immersion. In addition, S&T museums could open up online exhibitions. They could design the content and forms of interaction of virtual exhibitions based on physical exhibitions, exhibits and collections while considering the characteristics of virtual exhibitions, targeted visitors and the available exhibition platforms and technical conditions. Doing so would thus eliminate physical exhibition limitations in terms of space, cost and information capacity. Moreover, the museums should open up their digital resources as much as possible and adjust the content on demand at any time. They could retrieve visitors’ visiting history or conduct social media surveys to provide segmented services or even personalized recommendations. The linkage between online and offline exhibitions should also be strengthened, so that visitors to both...
exhibitions are interchangeable, thus truly achieving an integration of online and offline exhibitions.

(2) Present STI achievements in dynamic forms and build cutting-edge display platforms. S&T museums should keep pace with the progress of S&T, maintain cooperation with scientific research institutions and S&T enterprises and become dynamic platforms for displaying cutting-edge S&T accomplishments. They could hold temporary exhibitions when new achievements are reported by extracting related sections of permanent exhibitions or collecting related exhibits. In such exhibitions, they should encourage the participation of scientists, S&T workers and researchers in the development and implementation of exhibition and education activities so that visitors can obtain basic information about new achievements as they expand their knowledge. This will also bring visitors closer to scientists and researchers and boost visitors’ scientific literacy and interest in STI.

(3) Establish sound working mechanisms and build professional curatorial teams. S&T museums should establish regular working mechanisms to update and renovate basic displays and conduct temporary and touring exhibitions. They could develop new exhibition methods and concepts and eliminate out-of-date exhibits or content by tracking the latest S&T progress and practical experience at home and abroad and by considering the needs expressed in visitor assessments and studies. In addition, S&T museums should also establish dynamic curatorial teams in the form of project systems, which include not only exhibition planners and designers but also professionals with academic backgrounds or experience in education and pedagogy, science communication and other disciplines related to specific exhibition themes. Other professionals who meet the requirements of the modern S&T museum system are also required. For example, museums could employ virtual exhibition development and network maintenance technicians to design online exhibitions and educational activities and meet the demands of digital transformation. There is also a need for marketing personnel with the mindset and expertise in market operations to establish exhibition brands and promote the commercial operation of science popularization and for professionals with cross-cultural perspectives and the ability to communicate in multiple languages to develop domestic and overseas touring exhibitions and meet the demands of global cooperation. In addition to recruiting and training specialists, S&T museums could also hire part-time workers or engage volunteers to increase workforce strength and flexibility.

3.2 Deepen the diversity and innovation of educational resources to boost the power of science communication

(1) Develop science popularization videos and unlock the potential of the science popularization industry. Combining the characteristics of the internet age, S&T museums could engage in the innovative development of science popularization videos to increase the social and economic benefits of such videos. First, they could develop new content. The changing demands of present-day audiences should be taken fully into account. If knowledge-based narration can no longer attract audiences, the content could be made more entertaining, including fashion icons where possible, provided the videos do not deviate from science. In that way, viewers no longer just receive information from the programmes but also join programme designers to create video products. Second, museums should consider new scenes. The viewers of science popularization videos are now moving from cinema and television to new spaces, such as mobile devices. Products should be developed considering this factor. While continuously improving image clarity (8 K) and enhancing the viewing experience of cinema and other traditional spaces through the use of virtual reality (VR) and augmented reality technologies, it is also important to adjust the content and format of the products and related services of other target scenes. Third, museums could use new channels. As distribution channels for science popularization videos become increasingly diversified, the videos should be posted on social media and other platforms and promoted through the media matrix. In the age of big data, following the logic of data flow is the sure way to accurately deliver content to the target audience and expand the content’s reach and influence.
(2) **Strengthen the development of original educational programmes and build brands with influence.** S&T museums should pay attention to the combination of exhibition and education, promote the integrated development of resources inside and outside museums and form a system of original education programmes that are thematic, systematic and diversified and comprise exhibition education, outreach education and comprehensive education. Museums should meet the needs of school, family, social and lifelong education with sufficient resources and, in particular, develop educational products for both in-class teaching and after-school services to support the implementation of the Double Reduction policy. In addition, museums should explore the new frontier of online education, digitize existing educational resources, provide additional digital resources, develop digital cultural and creative products (such as online interactive courses and popular science games), and bring audiences into the process of content production using big-data and AI technologies to upgrade education models and enrich learning experiences. Moreover, museums could create educational brands and develop and market the brands together with other social forces such as schools, enterprises and the media, thus complementing each other’s strengths and resources and expanding the impact of the brands. The public should be seen as a major contributor to the development and implementation of educational programmes. It is therefore important to promote equal-footed dialogue between the public and the scientific community and encourage public participation in science popularization.

3.3 **Refine the detection of and response to visitors’ demands and build up the capacity for targeted services**

(1) **Promote integrated online and offline communication to serve the entire museum visit process.** S&T museums should increase the breadth and depth of information dissemination in both physical and virtual museums, fully utilize the internet and AI to conduct online communication beyond onsite visits, and strengthen online and offline linkages, thus eliminating the time and space limitations of traditional communication and providing all-weather, all-directional and whole-process information services. Before visits, museums could provide comprehensive, easy-to-access and well-designed information pages on various online platforms, explore visitor types and their characteristics based on their browsing data to provide them with customized information, and answer visitors’ questions using AI assistants. During visits, museums could use various types of devices to assist visitors in exploring and learning and push content to their devices using technologies such as indoor positioning. They could also analyse onsite visiting data through facial-recognition and eye-capture technologies and study visitors’ online browsing data using big-data and other technical means to create visitor profiles. This requires museums to pay appropriate attention to ethical issues such as visitor privacy protection. After visits, museums could push content that may be of interest to visitors based on the visitor profiles produced during their visits or browsing. This would help to prolong the visiting experience and generate repeated visits.

(2) **Build a dynamic and open communication system to cultivate loyal visitors.** Efforts should be made in four areas to cultivate loyal visitors. First, expand the scope of science communicators. S&T museums should cultivate professional science communicators among their staff while also attracting science fans and enthusiasts with a variety of knowledge and communication abilities from among visitors to join their communication teams. They should also work on science communication with the government, researchers, media and individuals from various sectors, thus broadening the perspective and boosting the professionalism and innovative power of science popularization. Second, optimize the content of communication. Museums should collect visitors’ expectations, preferences, opinions and suggestions through extensive and effective online surveys, give substantive feedback and make targeted adjustments, thus developing communication content that is welcomed by the public. Third, refine the means of communication. Museums could set up fan communities on social media platforms for their frequent visitors to maintain active interactions and enhance visitors’ loyalty (or ‘stickiness’). On that basis, museums should look for breakthroughs in the membership system under the
current framework. Based on feedback from online users and the interactive behaviour of offline visitors, museums could be able to recommend personalized content for visitors to raise the efficiency of communication targeted at segmented and even pinpointed visitors. Fourth, build a communication matrix. Museums should increase communication input on popular platforms such as websites, WeChat and Weibo. They should also expand their engagement on other platforms and emphasize interactions among various platforms and between online and offline channels. They could also seek to expand the scope and influence of communication based on the characteristics of the various communication channels, but should guard against the undesirable tendency to place visibility before quality.

3.4 Strengthen academic research and the transformation of academic achievements and boost the driving force of innovation

(1) Consolidate foundational academic resources to cultivate a scientific research system with distinctive features. Based on their mission and their goal of education, S&T museums should establish their own distinctive features by enriching their collections, improving their collection systems and developing digital collections. They should encourage the opening and use of collections for academic research and perform their exhibition and education functions by providing strong academic support. Museums should determine their research priorities based on their mission, features, resources and conditions, cultivate research and innovation teams in every direction and build platforms for key research projects. They could either focus on theoretical research to provide support for national strategic research projects, such as the study of the scientist spirit, or focus on applied research to explore how technology can be used to reshape exhibitions, reconstruct education, revitalize collections and represent history, providing science popularization solutions for S&T museums.

(2) Integrate high-quality social resources to promote the innovative transformation of science popularization results. S&T museums should make good use of the networking function of organizations such as the Alliance of Chinese Science and Cultural Venues and the Chinese Association of Natural Science Museums to promote the connectivity of academic resources, thus promoting new progress in interdisciplinary research and enriching research results. They should deepen cooperation with research institutions, S&T enterprises and other social entities to jointly develop exhibits, exhibitions, educational programmes and projects on the transformation of research results. They should also encourage the use of market mechanisms to develop science-derived products and services, explore new mechanisms and models (such as government procurement of public services) and establish systems combining online and offline operations.

4. The practical effect of supply-side reform

The Shanghai Science and Technology Museum and its branch museums (the Shanghai Natural History Museum and the Shanghai Astronomy Museum) have developed a unique model of ‘science centre + museum’ cluster, aiming at aligning with first-class international science museums and the strategy of innovation-driven development. In the 20 years since its opening, the Shanghai Science and Technology Museum has pursued supply-side reform centred on the core functions of exhibitions, education, research and visitor services and has made notable progress in building up the capacity for pooling science popularization resources, supporting innovation-driven development and promoting the international science popularization industry.

4.1 Improving the quality of exhibitions

The Shanghai Science and Technology Museum and its branch museums have improved their exhibition quality by combining online and offline exhibitions. First, the museums continuously updated their approach to holding offline exhibitions, planning and designing basic exhibitions based on the needs of visitors and the technologies available in different periods. From the theme-based exhibition of the Shanghai Science and Technology Museum opened in 2001, to the open/cluster-based exhibition of the
Shanghai Natural History Museum opened in 2015 and the immersive exhibition of the Shanghai Astronomy Museum opened in 2021, the museum cluster has completed the process of self-iteration. Second, the online–offline integrated exhibition system has been enriched. While introducing numerous excellent exhibitions, the museum cluster has enhanced its own exhibition capacity and established an exhibition supply system consisting of permanent exhibitions, original exhibitions, imported exhibitions, temporary exhibitions and virtual exhibitions. Third, the themes of exhibitions are converging. Exhibitions such as the ‘Qing Palace Animal Genealogy’ science and technology + traditional culture exhibition, the ‘Ten Thousand Years of Rice Farming’ science and technology + agricultural science exhibition, the ‘Twelve Chinese Zodiac’ science + humanities exhibition and the ‘Light and Shadow Magic’ science + art exhibition have revolutionized the curatorial concept of traditional S&T exhibitions. Fourth, the experience of exhibitions is being upgraded. The extensive use of digital media technologies in physical exhibitions has created an immersive experience for visitors to interact with the exhibits. For example, the Shanghai Astronomy Museum uses VR technology to virtually recreate the surface of the Moon, where visitors can experience a ‘moon walk’ with professional VR instruments. In addition, the opening of virtual exhibition halls gives visitors a different experience from that of the offline exhibitions. For example, the online ‘Solar Eclipse Special Exhibition: Phantom of the Sun and Moon’, instead of representing the original look of the exhibition hall, sets the scene in a specially designed planetarium building. The visitors’ routes and the positions of the exhibits have all been rearranged so that visitors can wander through and freely explore the museum, making the visit more immersive and entertaining.

4.2 Enhancing multisource innovation in education

The Shanghai Science and Technology Museum and its branch museums have strengthened their innovative education through efforts in two areas. First, they have created new channels for promoting science popularization videos. Many documentaries, such as *Endangered Species in China*, and 4D science films have been produced and promoted through domestic and foreign public television channels, mainstream new media websites, the internet and mobile terminals, which has increased the communication speed and impact of science education.

Second, they have broadened the composition and methods of the science education system. The museum cluster has established an education system with distinctive features underpinned by a complete content framework, covering all types of visitors and combining online and offline exhibitions. The museums have developed educational activities tailored to the features of different visitor groups and cultivated several branded programmes, such as the ‘Explorers Alliance’ for palaeontology enthusiasts over age 16, the ‘Wild Child’ programme for families with children aged 3–6 years and the ‘Nature without Hurdles’ programme for visitors with physical disabilities. The museums have also launched a variety of products to serve the home-school-society educational community, such as the museum-based curriculum and online courses developed to support the teaching of primary and secondary students and resource packages tailored for after-school services in the context of the Double Reduction policy. Moreover, the museums have contributed to expanding museum accessibility and educational equity. For example, the ‘Shanghai–Tibet–Xinjiang’ session held under the ‘Shanghai Science Communication Forum’ brand activity has yielded fruitful social benefits. The museums have also developed a large volume of online educational resources and have regularly hosted live-streaming events such as exhibition hall lectures and guided tours of S&T hotspots. Recognizing the importance of popular science games, the museums have developed such games either based on their own collections and permanent exhibitions, by combining with temporary and touring exhibitions and educational activities, or by co-branding partnerships. In 2021, the Shanghai Science and Technology Museum held the first China Science Games Conference and issued the *Declaration on the Development of the Science Games Industry*, charting the course for the development of the industry. Moreover, the museum cluster has worked with other museums and scientific
research institutions to jointly create popular science works and has involved the public in science education. For example, the ‘My Magic Box of Nature’ project launched by the Shanghai Natural History Museum invites citizen scientists from all over the country to participate in nature exploration activities.

4.3 Completing the public communication system

To expand the scope of communicators, the Shanghai Science and Technology Museum and its branch museums have cultivated a team of professionals who are good at communicating science through performances, written articles and science games. They have maintained close cooperation with researchers and other members of the scientific community to promote the popularization of S&T resources. In addition, they have used innovative content, methods and channels to communicate science. For example, the ‘Museum at Fingertips’ project provides new interpretations of the history, collections and principles of nature and S&T with 14 sections of content and invites top scientists to tell the history of nature and the history of S&T. The programmes under the project have been posted on a matrix of new media platforms, including Xue Xi Qiang Guo, a WeChat official account and video channel, Weibo, Bilibili and Zhihu, and have attracted more than 20 million views online to date.

4.4 Forming a special scientific research system

The Shanghai Science and Technology Museum and its branch museums have established a system of collections with the characteristics of nature, science and technology, and astronomy museums, and more than 55,000 items have been converted into available digital resources. More than 80,000 scientific research samples of various types have been collected, including nearly 200 samples provided by Chinese and foreign scientists, which have provided the basis for academic research in the museums. In addition, a collection research centre has been established to strengthen the support of scientific research for science popularization.

To cultivate a high-quality workforce of professionals, the museum cluster has constructed a ‘1+5 +X’ framework of research organizations consisting of an academic committee, five specialized research institutions, including the Science Communication Centre, and other in-house research teams. In 2021, the museums set up one research innovation team (the Cultural and Creative Products Research and Promotion Team) and two research innovation platforms (the Science Popularization Think Tank and the Ecological Security and Biodiversity Protection Laboratory of the Yangtze River Delta City Cluster), and identified six special research priorities, putting in place the initial structure of an expanded research system. The proposed ‘core + opening + co-constructed’ science popularization think tank aims to support science popularization by building platforms and pooling advantageous resources and to promote two-way interaction between science popularization and STI.

The museum cluster has established a distinctive research and development (R&D) platform and won honorary titles such as the ‘National Class-A Museum’, ‘5A Tourist Attraction (Spot)’, ‘National Demonstration Base for Culture and Science and Technology Integration’, and ‘National Model Base for Study Tours’. It has been actively involved in the construction of science game laboratories. The Shanghai Natural History Museum has built three basic research laboratories, and the Shanghai Astronomy Museum has established an astronomical research centre. Thus, a unique and influential R&D experimental platform has taken shape.

4.5 Extending external cooperation and exchange

The museum cluster has promoted external cooperation and exchange in three areas. First, it has actively engaged in international cooperation and exchanges. For example, the museums have organized or co-organized international conferences such as the International Forum for Natural History Museum Directors and the first International Symposium on the Development of Science Museums under the Belt and Road Initiative. This presents China’s effort to take the initiative to introduce Chinese S&T museums to the international...
academic arena and provide Chinese experience to science museums around the world to deal with COVID-19 and other crises.

Second, the cluster has promoted cooperation and exchanges in the domestic context. For example, the Shanghai Science and Technology Museum and several other science museums have jointly initiated the establishment of the Yangtze River Delta Science Museum Alliance, signed the *Consensus of the Yangtze River Delta Science Museum Alliance*, and jointly planned the ‘Beauty of Jade: Special Exhibition on Chinese Ethnic Culture and Mineral Treasures’. The Shanghai Science and Technology Museum also joined the Alliance of Chinese Science and Cultural Venues and cooperated with the Palace Museum, a fellow member of the alliance, in organizing the ‘Qing Palace Animal Genealogy’ exhibition, providing a concrete example of collaboration among the alliance members.

Third, the museums have pursued cross-sector cooperation and exchanges to promote the coordinated development of museums, enterprises, research institutes and educational institutions. For example, the Shanghai Science and Technology Museum has cooperated with Boeing, BASF and other well-known international institutions to develop and implement science popularization projects, in addition to establishing museum–school cooperation with more than 200 schools in various districts of Shanghai to promote the joint development and sharing of science popularization resources.

5. Conclusion

The *14th Five-Year Plan for the Development of the Modern Science and Technology Museum System (2021–2025)* has specified the direction of development for the S&T museum system. However, the current S&T museum system still has many problems compared to the plan: The core functions of S&T museums have yet to be fully activated, and the two-way interaction between the supply of science popularization resources and the demands of visitors has not yet been fully established. It is therefore imperative to deepen supply-side reform. S&T museums should focus on their core functions and improve the quality and level of their exhibitions, education, academic research and visitor services in the direction of promoting public participation, strengthening cross-sector integration, using emerging S&T, integrating science popularization industries and deepening international cooperation. They should cultivate the capacity to hold popular exhibitions, enhance science communication, deliver targeted services and drive innovation. In addition, science communication should be aligned with national strategies and serve the strategic tasks of promoting the scientific spirit and scientist spirit, pursuing common prosperity, implementing the ‘Double Carbon’ policy (peak carbon emissions and carbon neutrality), and promoting mass innovation and entrepreneurship.

Internationally, S&T museums have evolved into their fourth generation (Pedretti and Iannini, 2020). In addition to their core functions, modern S&T museums have developed multiple functions involving science, culture, education, society, politics and economics (Achiam and Solberg, 2017) and gradually acquired more expanded functions. This implies more social responsibility and provides possible directions for future S&T museums. First, S&T museums should strive for equality and inclusion, taking fully into account the diversity of visitors in terms of gender, economic conditions, physical conditions and digital literacy, to give them equal opportunities to enjoy science education. Also, the museums should aim to support educational equity by promoting dialogue on education policies among governments, educational institutions and other stakeholders. Second, S&T museums should serve as a platform for communication on key global challenges and crises, giving their own voice to global issues such as COVID-19, climate change, emerging technologies and gender equality, in order to facilitate public discussion and help address such challenges and crises. Third, S&T museums should be able to stimulate STI, not only as demonstrators, advocates and users of STI, but also as producers of innovative knowledge. Fourth, S&T museums should become platforms for the free exchange of scientific information, cultivate science communication professionals, convey scientific information through various means, promote exchanges between scientific research institutions and researchers and the public, and link society to advanced S&T.
Declaration of conflicting interests
The author declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding
The author received no financial support for the research, authorship and/or publication of this article.

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Author biography
Xiaoming Wang is a professor and the director-general of the Shanghai Science and Technology Museum. His research interests include science communication, museum management, population biology and ecology.