ISSN 2096-6083
CN 10-1524/G

Culture Of Science

cos.cnais.org.cn

2022

Volume 5 . Issue 1 . March

NAIS
National Academy of Innovation Strategy
China Association for Science and Technology

Cultures of Science
cos.cnais.org.cn

Honorary Director of Editorial Board

Qide Han, Chinese Academy of Sciences, China Association for Science and Technology, China

Director of Editorial Board

Yanhao Xu, China Association for Science and Technology, China

Editors-in-Chief

Jinsheng Shen, National Academy of Innovation Strategy, China
Bernard Schiele, Université du Québec, Canada

Associate Editors

Zhiqiang Hu, University of Chinese Academy of Sciences, China
Zhengfeng Li, Tsinghua University, China
Daya Zhou, China Association for Science and Technology, China

Invited Editor of Current Issue

Hui Luo, China Association for Science and Technology, China

Director of Editorial Office

Xuan Liu, National Academy of Innovation Strategy, China

Managing Editor

Ji Zhao, National Academy of Innovation Strategy, China

Coordinating Editor

Yanling Xu, National Academy of Innovation Strategy, China

Data Editor

Bankole Falade, Stellenbosch University, South Africa

Copy Editor

James Dixon, Institute of Professional Editors, Australia

Editorial Board Members

Martin W Bauer, London School of Economics and Political Science, UK
John Besley, Michigan State University, USA
Massimiano Bucchi, University of Trento, Italy
Rui Chen, China Association for Science and Technology, China
Michel Claessens, European Commission, Belgium
John Durant, Massachusetts Institute of Technology, USA
Zhe Guo, China Association for Science and Technology, China
Liuxiang Hao, University of Chinese Academy of Sciences, China
Robert Iliffe, University of Oxford, UK
Les Levidow, The Open University, UK
Hui Luo, China Association for Science and Technology, China
Jianjun Mei, University of Cambridge, UK
Gauhar Raza, National Institute of Science Communication and Information Resources, India
Fujun Ren, National Academy of Innovation Strategy, China
Shukun Tang, University of Science and Technology of China, China
Hongwei Wang, Chinese Academy of Social Sciences, China
Xiaoming Wang, Shanghai Science and Technology Museum, China
Masataka Watanabe, Tohoku University, Japan
Jiangyang Yuan, University of Chinese Academy of Sciences, China
Li Zhang, Peking University, China
Yandong Zhao, Renmin University of China, China

Volume 5 Issue 1 March 2022

Culture Of Science

Contents

Commentary

Open science: The science paradigm of the new era 3
Ke Gong

Articles

Co-construction and sharing of a Chinese medical case repository helps medical workers strengthen capacity for clinical practices 10
Junmin Wei, Jing Li, Xibin Shen and Qihang Tian

The political background of a pattern transformation in the Chinese system of science and technology during the 20th century 16
Guangbi Dong

From experience to theory: Science recreation workshops as a practice-led approach in informal environments for science learning 33
Miguel García-Guerrero and Bruce V Lewenstein

Science popularization from the perspective of the theory of communicative action 50
Ana Eliza Ferreira Alvim da Silva, José Roberto Pereira and Luiz Flávio Felizardo

Commentary

Cultures of Science
2022, Vol. 5(1) 3–9
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/20966083221091867
journals.sagepub.com/home/cul

Open science: The science paradigm of the new era

Ke Gong
Nankai University, China

1. Background of the open science movement

Science is characterized by the demand for open communication within a community. In the early days, members of the scientific community exchanged their academic results through correspondence, and they later established academic organizations to organize academic conferences, and to publish academic journals to strengthen communication. It is shown that there is an inherent need of scientific community to seek improvement through exchanges. At present, academic journals have become an important channel for the academic community to conduct academic exchanges internally and externally, and communication and mutual learning are intrinsic needs.

The informatization of global society that started in the 1990s has unlocked the demand for scientific development and created unprecedented conditions for the open exchange of scientific research. Science and technology, as the primary productive force, has penetrated into our lives and production, resulting in an unprecedented public interest in the outcomes and applications of scientific and technological innovation. In the past few decades, such public interest has gained much traction. For example, the discussion of issues such as genetic modification, climate change and 'carbon peaking and neutralization' target is no longer confined to the scientific community and a small circle of scientific sponsors but has become a topic of extensive public interest. Against such a background, a new concept — 'post-normal science' — appeared in the 1990s.

Normal science refers to science in which scientific issues are discussed by scientists within the scientific community. Post-normal science gives the concept a wider scope. After entering the public domain, scientific issues have become public science or open science, and the earlier concept of the 'science of science' has also evolved into the concept of public science policy. As part of public policies, public science policy represents the aspirations of the general public. The most distinctive feature of the ongoing open science movement is open data, because, with the development of the internet and the creation of big data, people have increasingly realized that data plays a very important role in our lives and production, and is in a sense a new economic factor. Based on that fact, open data has served as the starting point of the current round of open science promotion.

Internationally, developed countries, especially European countries, have acknowledged the trend of open science since the beginning of this century. They have attached great importance to its development model and the composition of a country's discourse in this development process. Governments have taken the lead in promoting its development and played a dominant role in this round of open

This article was revised based on the author's report delivered at the Open Science and Open Source Innovation Development Forum held on 7 November 2021 in Beijing.

Corresponding author:
Ke Gong, Nankai University, 94 Weijin Road, Nankai District, Tianjin 300071, China.
Email: gongk@nankai.edu.cn

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

data and the open science movement. Table 1 shows some of the documents issued by different countries or regions to promote open science since the beginning of the 21st century, dealing with not only the promotion of open data, but also rule-making and governance in the opening process. Unfortunately, China has not yet published dedicated document on this subject.

2. UNESCO's effort to promote open science

UNESCO has gone through the following stages in promoting open science. In November 2019, a proposal was made at the 40th session of UNESCO's General Conference to draft a UNESCO recommendation on open science, which was adopted by the conference. After the adoption of the proposal, UNESCO launched an online campaign to call for proposals on open science from all member states and collected the policies of international governmental and non-governmental organizations. The wide-ranging consultation gathered more than 3000 proposals from 133 member states. After the completion of the first draft in March 2020, UNESCO organized a series of committees of technical experts, legal experts and policy experts, with the participation of both governmental and non-governmental organizations such as the World Federation of Engineering Organizations and the International Science Council. From March 2020, UNESCO started an extensive consultation process and produced a new draft, which was sent to 139 member states for comments. At the end of 2020, on the basis of the consultation, UNESCO held a series of meetings in the world's six regions, including the Asia–Pacific, the Arab states, America and Western Europe, to discuss the draft. On the basis of the discussion, the draft was put to rounds of consultation and revision. It was finally adopted by the 41st session of UNESCO's General Conference. The whole process reflected the principle of open science, as this document on open science was formulated in a thoroughly open way. Inclusiveness, consultation, responsibility and transparency are the most prominent features of the policy-making process.

The recommendation consists of six main parts: Preamble, Aim and objectives of the recommendation, Definition of open science, Open science core values and guiding principles, Areas of action, and Monitoring.

Preamble

There are several important points in the preamble of the recommendation that deserve particular attention. First, it argues that open science is an urgent policy to address the complex global problems facing humanity. Second, science, technology and innovation (STI) have contributed to human progress, and the imperative now is to close the STI gap between countries. Third, access to and enjoyment of the fruits of science is a universal human right, and open science plays a crucial role in realizing that human right. Fourth, open science has the potential to promote the democratization of knowledge and reduce the imbalance in STI development within and between countries. Finally, we need to respect cultural diversity and the plurality of knowledge holders and sources, which in this case includes indigenous knowledge and citizen science. Open science respects the cultures and legal policies of all countries and makes policy recommendations within the international framework.

Aim and objectives

The purpose and goal of the recommendation is to provide an international framework for the policy and practice of open science. First, to recognize disciplinary and regional differences in perceptions of open science; second, to consider the factors of academic freedom, the specific ways to promote reform in gender equality, and the practical challenges faced by scientists and other open science actors in different countries, especially developing countries; and finally, open science can bridge the digital, technological and knowledge divides that exist between and within countries.

Definition of open science

Open science is defined as an inclusive construct that combines various movements and practices aiming to:

Table 1. Documents on open science published since 2000.

Year	Document
2001	Europe: Budapest open access initiative
2003	Europe: Berlin declaration on open access to knowledge in the sciences and humanities
2007	The seventh framework programme for research and technological development
2008	WorldWideScience alliance agreement
2008	European Commission: Open access pilot in FP7
2011	Brazil, Indonesia, Mexico, Norway, Philippines, South Africa, UK, US: Open data statement
2012	Europe: Towards better access to scientific information
2012	Europe: Open science for the 21st century
2013	Global Research Council: Action plan towards open access to publications
2013	Policy recommendations for open access to research data in Europe
2013	Europe: Guidelines to the rules on open access to scientific publications and open access to research data in Horizon 2020
2013	France, US, UK, Germany, Japan, Italy, Canada, Russia: G8 open data charter
2013	UK: Open government partnership: UK national action plan 2013 to 2015
2014	European Commission: Horizon 2020
2014	Europe: Towards European open science commons
2014	Finland: Open science and research leads to surprising discoveries and creative insights: Open science and research roadmap 2014–2017
2014	Europe: Open research data pilot
2015	OECD: Making open science a reality
2015	US: Today's data, tomorrow's discoveries
2015	Europe: Policy guidelines for open access and data dissemination and preservation
2015	Open science 2030
2016	Europe: OA2020 initiative
2016	Japan: The fifth science and technology basic plan
2016	Europe: General guidelines for research and innovation
2016	Europe: Open innovation, open science, open to the world
2017	European Open Science Cloud (EOSC) declaration and action list
2017	Netherlands: National plan open science
2018	Implementation roadmap for the European Open Science Cloud
2018	Europe: Plan S for open access
2018	US: Open science by design: Realising a vision for 21st century research
2018	US: Open science by design
2018	Europe: Open science and its role in universities: A roadmap for cultural change
2018	Europe: LIBER open science roadmap
2018	Canada: 2018–2020 national action plan on open government
2019	Serbia: Open science law
2019	France: CNRS roadmap for open science
2019	European Commission: White paper on open science cloud
2020	Canada: Roadmap for open science
2020	UNESCO: Draft recommendation on open science
2021	SPARC Europe: New strategy 2021–2024

1. make scientific knowledge openly available, accessible and reusable for everyone
2. increase scientific collaborations and sharing of information for the benefits of science and society
3. open the processes of scientific knowledge creation, evaluation and communication to societal actors beyond the traditional scientific community (UNESCO, 2021).

It is important to emphasize here that access to scientific knowledge should be as open as possible and that any restrictions on access should be proportionate and reasonable. By reasonable, restrictions should be imposed only for reasons of protecting human rights, national security, confidentiality, privacy and respect for the people who are the subject of the research, legal process and public order, protection of intellectual property and personal information, protection of sacred and secret indigenous knowledge, and protection of rare, threatened or endangered species.

The concept of open science has evolved during the course of drafting the recommendation. It was suggested to consist of nine aspects: open access,

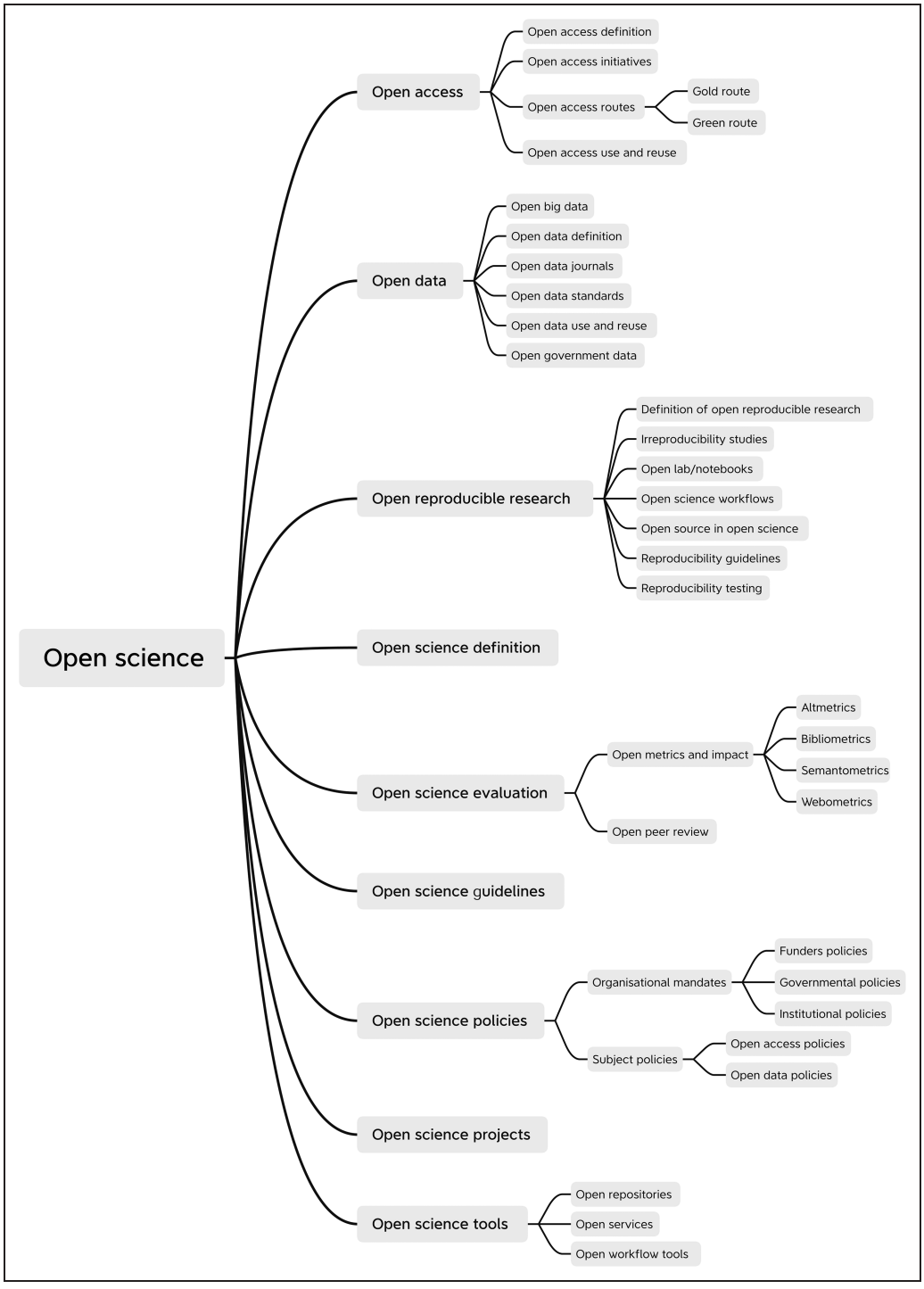


Figure 1. Open science taxonomy (revised based on Bezjak et al., 2018).

open data, open reproducible research, open science definition, open science evaluation, open science guidelines, open science policies, open science projects and open science tools (Figure 1).

Finally, it is agreed to comprise five elements of open science: first, open scientific knowledge, including open scientific publications, open research data, open educational resources, open source software and source code, and open hardware; second, open scientific infrastructure; third, open participation of social actors; fourth, open research programmes in which the public sector plays a leading role and the private sector provides funding; and fifth, open dialogue with other knowledge systems.

Core values and guiding principles

The core values of open science include quality and integrity, equity and fairness, collective benefit, and diversity and inclusiveness. The guiding principles are: 1) transparency, scrutiny, critique and reproducibility; 2) equality of opportunities; 3) responsibility, respect and accountability; 4) collaboration, participation and inclusion; 5) flexibility; 6) sustainability (UNESCO, 2021). These principles serve as important guidelines for the further promotion of open science in the future, such as the establishment of international rules and standards for open source.

Areas of action

The recommendation proposes seven specific areas of action:

1. Promoting a common understanding of open science, associated benefits and challenges, as well as diverse paths to open science
2. Developing an enabling policy environment for open science
3. Investing in open science infrastructures and services
4. Investing in human resources, education, digital literacy and capacity building for open science
5. Fostering a culture of open science and aligning incentives for open science
6. Promoting innovative approaches for open science at different stages of the scientific process
7. Promoting international and multi-stakeholder cooperation in the context of open science and with a view to reducing digital, technological and knowledge gaps (UNESCO, 2021).

Monitoring

The recommendation proposes deploying appropriate monitoring and evaluation mechanisms to measure the effectiveness and efficiency of open science policies and incentives against defined objectives; collecting and disseminating progress, good practice, innovation and research reports on open science and its implications with a multi-stakeholder approach; and developing a monitoring framework with qualitative and quantitative indicators, within national strategic plans and shared at the international level, with objectives and actions in the short, medium and long term for the implementation of the recommendation. In the meantime, the recommendation calls for the adoption of strategies to monitor the effectiveness and long-term efficiency of open science, which include a multi-stakeholder participatory approach. Such strategies could focus on strengthening the connections between science, policy and society and increasing transparency and accountability for research (UNESCO, 2021).

3. Observations and suggestions

Some people trace the spirit of open science back to the Renaissance in the 17th century, when science gradually spread from aristocratic circles into the people and knowledge became a public good through open science. At present, open science is the call of the times and an inevitable policy choice. My understanding of the motivation of open science includes the following four points.

First, inevitability. Open science is an intrinsic need of science, not imposed from the outside. Second, relevance to the present times. Open science is the need of the society. While science needs to enter society, the public also needs to understand science. Third, morality. Open science is a basic human need and a basic human right. From the perspective of international human rights as well as values and beliefs, access to scientific

research and its applications is a basic human right, and openness is a fundamental value of the scientific and technological community. The 'Joint appeal for open science' issued by UNESCO, the World Health Organization and the United Nations Human Rights Council calls on 'every Member State to ensure the fundamental right to access scientific research and its applications, with a view to creating a global knowledge commons and closing existing gaps in science, technology and innovation, especially in developing countries and with respect to women' (UNESCO, 2020). Fourth, urgency. Open science is needed for promoting sustainable development and addressing pressing issues. Viewed in the context of global sustainable development, open science can help unite the world's efforts to tackle global challenges, such as climate change, public health, the environment restoration and water resources, through international, interdisciplinary and cross-sector cooperation.

As an important actor, China needs to be more proactive. The best way to avoid following in others' footsteps is to keep the initiative in hand. The founding mission of the Communist Party of China was to secure human rights and democracy for its people. Human rights today are no longer just about having enough food, clothing and shelter. As the primary productive force, science and technology has propelled human society to a point where universal human rights have evolved to include the ability to understand knowledge and use technologies. In becoming an innovation power, China must be able to develop a stronger awareness about this.

Having learned about the motivation of open science, the second question we must think about is how to understand the open science movement. In my view, open science can be understood as a new paradigm for scientific innovation. From the perspective of the academic community, it is a paradigm shift from normal science to post-normal science. Whereas in the past we emphasized that issues must be discussed within their discipline, now we not only have to cross disciplinary boundaries, but even go beyond the conventional scope of the academic community and communicate with the public as equals. In the past, the work of science popularization was to tell the public and let people accept the results of science. Now the public wants to participate in the verification of scientific results, which raises the requirement for scientific literacy and rational scepticism on the part of the public. For the government, it used to deal mainly with the scientific community and scientific research institutions in conducting science and technology management. However, in the context of open science, the government needs to face all stakeholders involved in the scientific process.

Based on such changes, the Chinese Government has proposed to deepen the reform of the scientific research system. Open science provides a very important opportunity for China to integrate into the global scientific and technological innovation system from a new starting point. Then, in addition to deepening the reform of the scientific research system, what else can we do to strengthen and improve open science? First, foster a culture of honesty and rigour, freedom and relaxation, openness and cooperation, self-discipline and responsibility; second, build an incentive mechanism that respects pioneering and bold experimentation; third, deepen reforms and establish a reasonable evaluation system and trust mechanism; fourth, make use of diversified and well-designed standards and tools; fifth, encourage the media and science and technology workers to participate in science popularization, focusing on areas of public interest; and finally, take an active part in the international open science process to increase China's influence through greater participation.

First, China should take pragmatic initiatives to promote open science. In this endeavour, non-governmental organizations such as the China Association for Science and Technology can play an active role. To achieve this goal, we should adopt a problem-oriented approach. We need to know the things we lack in terms of scientific atmosphere and culture, evaluation of and public trust in science, scientific standards and tools, science popularization in the media, and participation and influence in the international community. Based on that knowledge, we must do something to improve the situation. We need to put the open science concept into action, with specific initiatives on the ground.

Second, in the international arena, China needs to look at the big picture but start with small things. Looking at the big picture means always bearing in

mind the sustainable development goals, and properly managing international conflicts in the current geopolitical context. Starting with small things means to begin our work with open data. On open data, people always say that a big pool of data is China's strength, but to use it well is easier said than done. To put big data resources to good use and break the barriers is not an easy task. Considering China's plan and ambition for science, we must be determined to do our work well.

I suggest an idea called 'FAIR + PS'. FAIR is the open data principle championed by the International Council for Science. F stands for *findable*, A for *available*, I for *interoperable* and R for *reasonable*. Together, they make the word FAIR, and that is why the council is promoting this principle. And then two more letters, P and S, are suggested to add. P stands for *privacy*, and S for *security*. I think the Chinese scientific community could start working on scientific data and make it an important tool for promoting sustainable development in the country's rapid progress.

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.

References

Bezjak S, Clyburne-Sherin A, Conzett P, et al. (2018) Open Science Training Handbook. Available at: https://www.fosteropenscience.eu/content/open-science-training-handbook (accessed 18 February 2022).

UNESCO (2020) Joint appeal for open science. Available at: https://en.unesco.org/news/joint-appeal-open-science (accessed 10 January 2022).

UNESCO (2021) UNESCO recommendation on open science. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000379949.locale=en (accessed 10 January 2022).

Author biography

Ke Gong is the President of the World Federation of Engineering Organisations (WFEO), the Chairman of the Academic Committee of Nankai University, and the Executive Director of the Chinese Institute for New Generation Artificial Intelligence Development Strategies. He is an electronic engineer with expertise in information and communications technology and more than 30 years of experience in engineering education, research and management. Since 2009, he has dedicated himself to WFEO activities and has made great contributions to the development of WFEO with his efforts and experience. He has stressed the essential role of engineering and engineers in the United Nations' sustainable development agenda and endeavours to unite the world engineering profession. He has established strong bonds with the United Nations, international organizations and industrial communities.

Article

Cultures of Science
2022, Vol. 5(1) 10–15
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2096608322109210
journals.sagepub.com/home/cul
SAGE

Co-construction and sharing of a Chinese medical case repository helps medical workers strengthen capacity for clinical practices

Junmin Wei, Jing Li, Xibin Shen and Qihang Tian
Chinese Medical Association Publishing House, China

Abstract
The advent of the era of big data is bound to promote the development of databases. How to bring clinicians' focus back to clinical practice and enhance the clinical capabilities of general physicians at the primary level is a question that every member of the academic publishing profession needs to consider. If data and knowledge can be shared openly, research and medical management will develop at an accelerated pace. Given the global consensus on open science, the co-construction and sharing of a Chinese medical case repository will surely improve the practical capability of clinicians.

Keywords
Chinese medical case repository, co-construction, open sharing, application and evaluation

1. Background on open science

The 41st session of the General Conference of the United Nations Educational, Scientific and Cultural Organization was held from 9 to 24 November 2021. Following an inclusive, transparent and multi-stakeholder consultation, the meeting adopted the Recommendation on Open Science, marking a new phase of global consensus on this topic. Open science includes open access (OA), open data, open reproducible research, open science evaluation and open science policies (Paton and Kobayashi, 2019).

OA was proposed by the Open Society Institute in the Budapest Open Access Initiative published in 2001 with the aim of providing the public unrestricted and free access to academic research resources. There are two main OA forms: gold OA and green OA (Wang, 2021). Both gold OA (journal-based, free and immediate access to the full content) and green OA (subject-based, self-archiving repository) should develop side by side. With the advancement of technology and data-driven research, open research data as well as data and text mining have attracted a great deal of interest.

Green OA allows authors to deposit their articles (pre- or post-publication) into the publisher's archive and other repositories, such as a pre-publishing platform. The copyright of a green OA article usually belongs to the publisher or a social organization, and there are specific terms and conditions that

Corresponding author:
Jing Li, Key Laboratory of Knowledge Mining and Service for Medical Journals, Chinese Medical Association Publishing House, 69 Dongheyan Street, Xicheng District, Beijing 100052, China.
Email: lijing@cmaph.org

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

specify how and when public access to the article can be granted in the repository. The advantage of this approach is that the author does not have to pay any fees.

In the case of gold OA, authors retain the copyright of their articles and can reuse a published article (or a revised version of the article) in a new publication without seeking prior permission; however, they are required to cite the published article. Scholars may use the articles of other authors for non-commercial purposes with the consent of the editorial office or the publisher provided that they use proper citation. This is the licence for republishing a published article in an OA publication.

2. Implications of open science

At the end of 2019, the novel coronavirus (COVID-19) emerged, and the World Health Organization declared that the outbreak was a public health emergency of international concern. COVID-19 continues to affect people's health, the economy and our society, and the global impact of the disease has generated a great deal of interest in the development of new drugs and vaccines. Open science has been considered to be an accelerator of biomedical research and is important in the face of the pandemic. The spread of the disease forced people to work aggressively on the development of new therapeutics, and open science has the advantages of sharing data, reducing duplication of work and accelerating the dissemination of important research results. As of August 2020, more than 7000 articles on COVID-19 had been submitted to the bioRxiv15 and medRxiv16 platforms for pre-publication (Tse et al., 2020); more than 2000 papers related to COVID-19 have been made available for free and rapid public exchange on the academic exchange platform for COVID-19 research results created by the Chinese Medical Association Publishing House. The purpose of pre-publication is to give researchers an opportunity to quickly disseminate their research results prior to formal publication. In the field of rare disease (RD), the value of open science is even more significant. RD research has been constrained by a lack of patients and resources as well as the need for experienced expert teams and therapeutics. These problems have caused delays in diagnosis and treatment and may be ameliorated when open science principles are followed (Rubinstein et al., 2020).

Open data sharing and access are an inevitable result of increased requirements for research transparency and reproducibility and can help facilitate secondary research on health management, education and training, and innovation. However, researchers may be reluctant to share their data for many reasons, including time and resource constraints, privacy issues linked to patients' data, lack of access to appropriate funding, inadequate recognition of the contributions of data sponsors, and concerns that commercial or academic competitors may benefit from the shared data. Despite all these factors, researchers and users have a strong interest in creating data resources for sharing. From this perspective, we will make a tentative analysis of the scope of 'openness' and 'data access' and the strengths and weaknesses of existing data-sharing platforms based on a Chinese example of a medical case repository.

3. Background on the construction of the Chinese medical case repository

Artificial intelligence (AI) is a general term that encompasses a range of technologies developed for solving problems by using human-like intelligence. Machine learning (ML) is one type of AI approach. In the medical care industry, some people suggest using ML-supported clinical decision support systems to conduct image analysis and interpretation in radiology, dermatology and pathology (Hosny et al., 2018; Fogel and Kvedar, 2018; Zakhem et al., 2018; Salto-Tellez et al., 2019) and to improve the scope and accuracy of biological signal interpretation (Orphanidou et al., 2015; Triantafyllidis et al., 2015). The database-enabled deep-learning approach provides a foundation for the creation of a Chinese medical case repository.

Against the backdrop of rapid advances in technology, AI is starting to be applied in medical care, and a number of issues have emerged that deserve people's attention. Medical care is a critical industry involving human lives. Compared to systems that are currently using low-risk AI technologies, such as

Alpha Go (Silver et al., 2016), the medical care industry needs a higher level of openness and validation before adopting AI-based tools. By examining how open science can guide the use of AI in the medical care industry, we can recognize that new ML systems need big data sets to improve their accuracy and predictive ability. Currently, biomedical databases developed by governments, medical societies and international research collaborations are relatively mature open databases in foreign countries (Table 1).

The open databases shown in Table 1 are used to keep abreast of bioinformatics developments. For example, they can be used to improve the prediction of drug responses in cancer cell lines, and to reveal the relationship between rare variants and diseases through phenotypic association analysis of genomic data. Open ML databases that are based on clinical information, such as the CheX-pert database for chest X-rays (Irvin et al., 2019), are now being widely used. In China, the relatively mature databases, such as CNKI, Wanfang Data and Cqvip, still primarily consist of papers published in scientific journals, and there are not yet databases that are based on clinical cases and serve clinical purposes.

Table 1. Open databases for biomedical research in foreign countries.

Organization	Open database
National Center for Biotechnology Information, National Cancer Institute	Gene Expression Omnibus (GEO), Genbank, Pubmed, Omics Datasets
European Bioinformatics Institute (EBI)	Gene-Wide Association Study, Uniprot, EBI-Pfam
Research Collaboratory for Structural Bioinformatics (RCSB)	The Protein Data Bank (RCSB PDB)
Gene Ontology Consortium	Gene Ontology
SIB Swiss Institute of Bioinformatics, Novo Nordisk Foundation Center for Protein Research, European Molecular Biology Laboratory, Centre for Genomics and Personalized Medicine	String Database (a database of protein interactions and outputs)
Stanford University	RegulomeDB (a comprehensive database linked to GEO)
National Cancer Institute	LIDC-LDI (a database with lung images from 1018 cases)

Propelled by the trend of open science in the academic circle, scientific journals are placing new requirements on open access to articles, open data, open practice, open collaboration and open awards, aiming to promote faster and more effective science development and improve the transparency and reproducibility of research results. Case report articles are an innovative type of medical research paper.

China's 2021 document on reform guidelines for the professional title system for health professionals published by the Ministry of Human Resources and Social Security, the National Health Commission and the National Administration of Traditional Chinese Medicine clearly states that a system of representative works should be implemented. Clinical cases, surgical videos and nursing cases, among others, can all be used as representative works when applying for a professional title. To overcome institutional barriers, structural problems and policy obstacles in scientific and technological innovation, the China Association for Science and Technology (CAST) has proposed a 'clinical case representative works system', encouraging clinical practitioners to write case reports based on their clinical practices, thus gathering practical experience and improving treatment performance. This approach will also help to improve the evaluation system for health professionals and accelerate the reform of the system.

In the context of open science, following the principle of green OA and the guidance of China's policy on professional title evaluation and CAST's initiative of a 'clinical case representative works system', the Chinese Medical Association Publishing House has constructed a Chinese medical case repository with the funding support of CAST. The purpose of the database is to encourage clinical practitioners to produce standardized case reports based on their clinical practices, thus improving treatment services through case sharing, expanding the diversified evaluation of physicians and accelerating the reform of the talent evaluation system.

4. Methods for building the Chinese medical case repository

4.1 Use case resources available in the journals published by the Chinese medical association (CMA)

The construction of the Chinese medical case database would not be possible without data, so the main task in this process is collecting clinical case reports from extensive sources and expanding the size of the database. CMA journals, most of which are at the forefront of their respective disciplines, have the reputation of being the 'banner of Chinese scientific and technical journals'. Thus, we used the CMA's valuable resources in building the database. However, case reports have not yet been widely recognized and promoted in China's medical institutions. Therefore, in order to expand the size of the database, we have tried to introduce and promote the database to medical workers and editorial board members of journals at various academic conferences that take place within the medical field. We have also developed a unified template for writing based on the characteristics of medical research and have trained medical workers in how to write case reports. In order to encourage medical workers to publish their clinical research results on China's platforms, we have also introduced an incentive mechanism that involves awards for high-quality case reports.

4.2 Joint construction by medical institutions across the country

The construction of the Chinese medical case repository requires the joint efforts of the CMA, journal editors and clinical medical workers. If an open database were to be built based only on the data of a single institution and if it were to collect only limited clinical cases, the goal of green OA could not be fully realized. An open database must be a regional alliance of institutions if it hopes to demonstrate the value of region-wide open sharing of science and technology information.

Construction based on different groups. Medical workers should be evaluated based on different groups according to the nature of their work. Roughly, they can be divided into three groups: clinical workers who are mainly engaged in treating patients and saving lives; scientific research workers who are engaged in academic innovation and development; and educational workers who are primarily engaged in instructing and answering questions. Clinical workers should be evaluated on the basis of their performance and practical work ability. Practical work ability is reflected through high-quality clinical cases. Case reports may appear in a unitary format but have diverse content. In the era of big data, using text alone is no longer the mainstream form of communication. Recording videos of the treatment process in clinical cases, especially in the context of rare and difficult diseases, is a new model of case reporting.

In the medical case database, we have opened a special section for video resources that focus on rare diseases and established a rare disease expert group. Using the CMA's advantages, we have worked with international academic organizations on rare disease research and with patient organizations at home and abroad to hold seminars on rare disease cases and saved the video recordings of those meetings in the video section of the database. Our aim is to provide clinicians, especially those working in primary-level hospitals, with more vivid learning materials that improve their ability to recognize and treat rare diseases. Case reports, imaging materials, videos and other types of resources have enriched the content of the database.

Construction based on different grades. When case reports are used as an indicator for evaluation, their quality should be valued over their quantity. To further promote the development of the database, we need to engage with medical institutions and front-line clinicians at different levels to understand the real needs in the reform of the evaluation of clinicians and learn about the views of medical workers on the 'clinical case representative works system'. We need to organize experts in the field of clinical medicine to develop a comprehensive, graded evaluation method based on some data, such as quantified review conclusions of case reports (including their clinical value, academic quality and writing quality) and the number of their downloads, reposts and

comments. Only when case reports are graded can they present their full value and better represent the authors' qualifications when used in title promotion.

Construction based on different levels. The level and regional location of medical institutions determine their requirements for capacity building and their requirements for the abilities and responsibilities of doctors. It is thus not scientific to use case reports as the sole criterion for evaluating all hospitals and all doctors; the role and value of case reports need to be differentiated based on the level of hospitals. Case reports provided by top-class Grade A hospitals should focus on the diagnosis and treatment of rare and difficult diseases, and they can be used as instructional materials for medical workers at primary-level medical institutions. Case reports provided by primary-level medical institutions, on the other hand, should focus on the standardized treatment of common diseases. They can reflect the medical skills of primary-level doctors and can be used as a reference in title promotion. The subdivision of case sources and case types satisfies the varied needs of primary-level doctors, general practitioners and specialists and lays the foundation for the evaluation of clinicians based on different levels.

Construction based on different disciplines. The process of disease progression is complex and sometimes requires multidisciplinary consultation between clinical and medical-technical departments. Therefore, cases that originate in medical-technical departments are equally valuable for the database. However, due to their different clinical duties, medical-technical and clinical departments have different focuses, so different case report templates need to be developed according to the focus of specific departments. When the database has collected a certain number of case reports, it will be possible to highlight the characteristics of each hospital's specialties and even analyse the disease spectrum of different geographical regions using discipline-based marks of case reports.

5. Sharing

The Chinese medical case repository publishes the full text of case reports in an OA model (under the CC-BY-NC-ND protocol). All articles published on the platform are available for free on the internet, and any user can read, download, print, retrieve and hyperlink the literature for non-profit purposes. After publishing articles in the database, authors are permitted to republish them on other media platforms. While sharing their own cases, clinicians can also study how others treat rare and difficult diseases. This could help primary-level doctors improve their professional skills and thus could promote the even distribution of medical resources. In this way, patients are able to get primary medical treatment in local hospitals, thus relieving the pressure on top-class Grade A hospitals and addressing the public's concern over the difficulty in accessing medical services. Through the platform of the repository, an institution-based evaluation of clinical capacity could be conducted, which will in turn promote the participation of universities, hospitals and other institutions in the co-construction of the repository, thus adding new content to the sharing model. In addition, a specialty-based evaluation of clinical capacity conducted through the repository could also mobilize the specialist branches of the CMA and further enrich member services (such as case review and interactive Q&A).

With the expansion of ML technology research, the database will inevitably focus on the capability to predict diseases. Through the continuous collection of high-quality cases and the accumulation of authoritative knowledge and using ML technology, machines will be able to recognize high-quality cases and understand and apply medical knowledge. They will function like a medical brain that provides assistance to clinicians in their decision-making during the clinical treatment process. However, what is described here is an ideal situation. Even if new medical technologies can work in the lab, they cannot be readily transferred to clinical practices in real-world contexts. If medical workers stop seeking self-improvement, give up making clinical decisions and rely too heavily on database analysis, that may lead to a deterioration in their clinical decision skills and adversely affect treatment results. Therefore, the Chinese medical case repository should improve its graded evaluation system and play a role in scientific evaluation and continuing education.

6. Conclusion

The co-construction of the database cannot be achieved without the support of the government, doctors and patients and coordination among hospitals. Sharing is not just about doctors improving their clinical practices. It is also about providing better medical services for patients and creating a greater latitude for the country in dealing with public health issues. The creators of and contributors to the database resources are also the owners and users of those resources, while journal editors act as intermediaries. By providing and maintaining the Chinese medical case repository, journal editors are making their contribution to the improvement of doctors' clinical skills and the development of the open science process.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

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

References

Fogel AL and Kvedar JC (2018) Artificial intelligence powers digital medicine. *NPJ Digital Medicine* 1: 5.

Hosny A, Parmar C, Quackenbush J, et al. (2018) Artificial intelligence in radiology. *Nature Reviews Cancer* 18(8): 500–510.

Irvin J, Rajpurkar P, Ko M, et al. (2019) CheXpert: A large chest radiograph dataset with uncertainty labels and expert comparison. *Proceedings of the AAAI Conference on Artificial Intelligence* 33: 590–597.

Orphanidou C, Bonnici T, Charlton P, et al. (2015) Signal-quality indices for the electrocardiogram and photoplethysmogram: Derivation and applications to wireless monitoring. *IEEE Journal of Biomedical and Health Informatics* 19(3): 832–838.

Paton C and Kobayashi S (2019) An open science approach to artificial intelligence in healthcare. *Yearbook of Medical Informatics* 28(1): 47–51.

Rubinstein YR, Robinson PN, Gahl WA, et al. (2020) The case for open science: Rare diseases. *JAMIA Open* 3(3): 472–486.

Salto-Tellez M, Maxwell P and Hamilton P (2019) Artificial intelligence: The third revolution in pathology. *Histopathology* 74(3): 372–376.

Silver D, Huang A, Maddison CJ, et al. (2016) Mastering the game of go with deep neural networks and tree search. *Nature* 529(7587): 484–489.

Triantafyllidis A, Velardo C, Chantler T, et al. (2015) A personalised mobile-based home monitoring system for heart failure: The support-HF study. *International Journal of Medical Informatics* 84(10): 743–753.

Tse EG, Klug DM and Todd MH (2020) Open science approaches to COVID-19. *F1000Research* 9: 1043.

Wang SS (2021) Open-access journals and the ethical issues of open-access articles. *Chinese Journal of Tissue Engineering Research* 25(21): 3278 (in Chinese).

Zakhem GA, Motosko CC and Ho RS (2018) How should artificial intelligence screen for skin cancer and deliver diagnostic predictions to patients? *JAMA Dermatology* 154(12): 1383–1384.

Author biographies

Junmin Wei is general manager and editor-in-chief of the Chinese Medical Association Publishing House (CMA Publishing House). His research focuses on journal management and integrated development.

Jing Li is a journal publisher and vice director of the department of Chinese medical case repository of the CMA Publishing House. Her research focuses on digital publishing and its combination with traditional publishing. She has published 10 academic articles.

Xibin Shen is director of the department of digital publishing of the CMA Publishing House and assistant director of the Key Laboratory of Knowledge Mining and Service of Medical Journals. His research focuses on digital publishing and OA publishing. He has conducted several provincial and ministerial research projects and published more than 30 academic articles.

Qihang Tian is an assistant journal publisher of the department of Chinese medical case repository of the CMA Publishing House. His research focuses on digital publishing and its combination with traditional publishing.

Article

Cultures of Science

Cultures of Science
2022, Vol. 5(1) 16–32
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2096608322109415O
journals.sagepub.com/home/cul
SAGE

The political background of a pattern transformation in the Chinese system of science and technology during the 20th century

Guangbi Dong
Chinese Academy of Sciences, China

Abstract
The development of modern science and technology in China involved three transformations: from a traditional mindset to a modern one through the enlightenment of scientific thought, from the Anglo-Saxon pattern to the Soviet pattern in the process of instituting the Chinese system of science and technology, and from national defence to economics due to an awakening of technical economics after the 'Cultural Revolution'. This paper surveys the political background of the second transformation. The idea of 'doing science for science's sake' never had a footing in China because the Chinese began to learn about modern science and technology only under the threat of colonists' gunboats. Developing science and technology has always been one of the means for China to cast off national humiliation and regain its status as a major country in the world. Compared with science and technology in other countries, Chinese science and technology were more susceptible to the international political environment and domestic political situation. It took about two decades, between the establishment of the Academia Sinica in 1928 and the inauguration of the Chinese Academy of Sciences in 1949, for China to form its system of science and technology. The system had three successive configurations because of the international competition among Japan, the US and the Soviet Union over China, and the domestic political contest between the Chinese Nationalist Party or Kuomintang (founded by Sun Yat-sen in 1912) and the Communist Party of China. China's science and technology system started by modelling itself on its counterparts in Europe and America. After undergoing a series of unconventional developments during the War of Resistance against Japanese Aggression (1931–1945) and the War of Liberation (1946–1949), the system transformed to the Soviet pattern after the establishment of the People's Republic of China.

Keywords
Chinese system, pattern transformation, political background, science and technology

1. Introduction

The struggle between colonialism and anti-colonialism constituted the history of China's international relations between the mid-19th century and the mid-20th

Corresponding author:
Guangbi Dong, Institute for the History of Natural Sciences, Chinese Academy of Sciences, Beijing 100190, China.
Email: donggb@ihns.ac.cn

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

century. The Treaty of Nanjing in 1842, as a result of China's defeat in the First Opium War, represented the beginning of the country's semi-colonization. The status that China acquired in 1945 as one of five permanent members of the Security Council of the United Nations, after its victory in the War of Resistance against Japanese Aggression, symbolized the end of that semi-colonization.

The Self-Strengthening Movement (1861–1894) was the first effort on the part of the Qing government to resist colonization and was of great historical significance. However, the movement was considered a failure because of the government's defeat in the first Sino-Japanese War (1894–1895). The Hundred-Day Reforms in 1898 and the failed Boxer Uprising in 1900 followed. Both demonstrated the determination and power of the Chinese people against colonization, which changed China's situation. On the one hand, international imperialists had to relinquish their desire to conquer China with force and adopted a colonial policy that ceremonially preserved China's administrative integrity; on the other hand, the Qing government was forced to follow a policy that encouraged and promoted industry and commerce. The establishment of the republican political system, the victory in the War against Japanese Aggression and the establishment of the socialist system were three significant and historic events that set China free from colonialist shackles. Modern science and technology in China were always important parts of the Chinese struggle against colonialism.

Although Xu Guangqi (1562–1633) had led calendric reforms as early as the 17th century (using Western astronomy and mathematics), modern science and technology purposely promoted by the government began only with the development of industries in the Self-Strengthening Movement in the late 19th century. During that period, with the support of the officials who promoted the movement, more than 50 modern industrial and mining enterprises were set up. They were either administered directly by the government or privately managed under the government's supervision. The total capital amounted to about 28,000,000 taels of silver, which was roughly equal to the investment of more than 100 foreign factories in China at that time. These self-strengthening industries gave priority to military production and were monopolized by bureaucratic capitalists. Some industrial and mining enterprises funded solely by private entities and Chinese capital also emerged. These two kinds of enterprises were different, but both represented China's effort to resist colonization.

The self-strengthening industries were significant in China's history because they set an example for the development of modern science and technology. Because of the establishment of those modern industries, the Chinese were able to reproduce the first steam engine in China in 1862, the first steam-powered boat in 1865 and the first steam locomotive in 1881. Along with the development of the modern industries, there was also education in modern science and technology as well as modern publishing endeavors. During the Self-Strengthening Movement, the Qing government founded more than 10 industrial schools specializing in machinery, electricity, railways and surveys, in addition to the foreign-language schools needed for handling foreign affairs and modern military schools for strengthening the military forces. Furthermore, the government sent nearly 200 students and interns abroad to learn from the West. The publishing efforts based on *Tongwen Guan* (a newly established governmental school specializing in foreign languages) and the translation bureau of Jiangnan Arsenal replaced the missionaries' work in this field. Native Chinese experts in science and technology also began to emerge.

After the beginning of the first Sino-Japanese War in 1894, capital exports became a means to take money from the Chinese. Foreign capitalists successively set up their factories in China. Because of attrition and indemnities caused by the war, the Qing government could no longer monopolize industries. Hence, it promoted and rewarded private investment in industries by promulgating the *Regulations of Rewarding Technology Promotion* in 1898 and the *Regulations to Reward Companies* in 1903. As a result, there were two upsurges (1895–1898 and 1904–1908) in factory development. By 1911, total Chinese capital in modern industries reached about 1.3 billion silver dollars, and more than 90% of Chinese industries used machines, demonstrating a nationwide trend towards changing the country's traditional economic structure. Nearly 10,000 kilometres of railways were constructed in China during this period. Although over 90% of the railways were

controlled by foreigners due to foreign loans and joint management, these 'industrial arteries' laid a foundation for the development of China's industrial economy. It was during this period that the Peking–Kalgan Railway (Beijing to Zhangjiakou) and the Luanhe River Railway Bridge, the first of their type designed and constructed by Chinese engineers, were completed.

Educational reforms through the new school systems promulgated in 1902 and 1903 and the abolition of the civil service examinations in 1905 legitimized Western learning, prompting the rapid development of modern education. By 1911, there were more than 100 institutions of higher learning with more than 40,000 students; tens of thousands of students went overseas. The imperially endorsed *Constitutional Outline* promulgated in 1908 by Emperor Guangxu (1871–1908) gave the Chinese people freedom of assembly and association, promoting the rapid development of associations, which numbered as many as 600 by 1911. Although the majority of the associations were trade unions, secret societies and political parties, there were a few scientific and technological associations, such as an arithmetic society, an agriculture society, a survey society, a medicine society and a geography society. Non-government publishers also emerged. The Commercial Press and Zhonghua Book Company were founded during this period (in 1897 and 1911, respectively).

2. The nationalist government and the establishment of the scientific system based on the patterns of Europe and the US

After 10 failed attempts, the bourgeois-democratic revolution led by Sun Yat-sen (1866–1925) succeeded after the Wuchang Uprising on 10 October 1911, leading to the founding of the Republic of China (ROC). After the 1911 Revolution, the provisional government in Nanjing issued a series of policies and laws to protect industry and commerce, prompting the appearance of industrial and commercial organizations, such as the ROC Industrial Construction Association (1912), the Chinese Organization of Industries and Commerce (1912) and provincial associations of industry and commerce. However, because the Chinese bourgeoisie was powerless, successive warlords seized power. Although the fighting among the warlords was harmful to the development of national industry, governments controlled by the Beiyang warlords still announced the *Regulations on Rewarding Industrial and Technological Products* in 1912, the *Rules on Guaranteed Dividend for Industrial Companies' Stock* in 1914, the *Law of Chamber of Commerce* in 1915 and various other regulations.

During the First World War, European imperialist powers loosened their grip on China and Chinese national industry was able to develop. The imperialist powers returned to China during 1921–1928 and once again put the newly developed Chinese national industries in a difficult situation. It was during this period that the Chinese national bourgeoisie took the place of the comprador bourgeoisie, millions of workers formed a politically conscious class, and intellectuals dissociated from Confucian scholars developed professional groups. In the development of modern science and technology between the 1911 Revolution and the establishment of the nationalist government in Nanjing on 18 April 1927, the most important advances were the establishment of scientific and technological associations and research institutions. The associations included the Chinese Institute of Engineers (1912), the Science Society of China (1915) and the *Bingchen* (later renamed as *Xueyi*) Society (1916). Important research institutions included the Geological Survey of China (1913), the Biological Institute of Science Society of China (1922) and the Yellow Sea Institute of Industrial Chemistry (1922). These developments showed that modern science was being institutionalized in China, although that owed little to the government.

The deep institutionalization of science and technology in China began with the establishment of the Academia Sinica—the highest national academic institution. Its establishment followed the end of the warlords' fighting and the stabilization of the country. When Sun Yat-sen resigned his provisional presidency in 1912, Song Jiaoren (1882–1913) organized a public party—the Chinese Nationalist Party or Kuomintang (KMT)—by merging five different political organizations, including the Chinese

Revolutionary Alliance, the Unified Republican Party and the Nationalist Common Progress Association. In the following year, Song Jiaoren was assassinated by his political rivals, resulting in the disbanding of the KMT, which was not restored until 1919. In 1921, the Communist Party of China (CPC) was founded, and the party joined the Third International (or Comintern) in the following year. The Comintern regarded the revolution led by Sun Yat-sen as an 'auxiliary force' and thought that Sun needed assistance from the Soviet Union. On 26 January 1923, Sun Yat-sen and Adolph Joffe, a representative of the Soviet government, signed the *Joint Manifesto of Sun and Joffe*.

In June 1923, the third congress of the CPC decided to cooperate with the KMT. At the end of that year, Chiang Kai-shek (1887–1975) visited the Soviet Union and stayed there for three months. In January 1924, the first congress of the KMT adopted the three policies of allying with the Soviet Union, cooperating with the CPC, and assisting workers and farmers. The CPC members joined the KMT as individuals, beginning the first period of KMT–CPC cooperation. That cooperation created the political context for the victory of the Northern Expedition against the warlords. In March 1926, the Comintern accepted the KMT as an allied party, and Chiang Kai-shek became an honorary member of the presidium of the Comintern. On 20 March 1926, Chiang fabricated the Zhongshan Warship Incident and began to act against the communists, putting the CPC cadres in the Whampoa Military Academy under surveillance or house arrest. Chen Duxiu (1879–1942) proposed to withdraw from the KMT but was sternly condemned by the Comintern and Joseph Stalin (1878–1953). In April 1927, Chiang established an autocratic KMT government in Nanjing and the CPC was rendered illegal. In June 1928, Chiang captured Beijing and renamed it Beiping. In November of that year, Zhang Xueliang (1901–2001) and his army pledged their allegiance to the Nanjing government, thus accomplishing the nominal unification of the entirety of China.

The nominal unification, the unstable peace and understanding from the governments of the UK and the US improved the environment in which China was striving for national independence. The nationalist government began to revoke extraterritoriality, restore customs autonomy and rescind unequal treaties. By 1930, the extraterritoriality of all foreign countries, except the UK, the US, France and Japan, had been revoked, and customs autonomy had been restored. By 1937, the 33 foreign concessions had been cut to 13, most of them being returned to Chinese sovereignty. In the decade before the full-scale Japanese invasion of China, there were many proposals for developing the Chinese economy and culture.

In 1919, Sun Yat-sen wrote *The Industry Project*, in which he advocated developing industry and introducing foreign capital and technologies. After the establishment of the Nanjing government, the State Committee of Construction, which was founded in 1928, issued the *Provisional Regulations on Rewarding Industrial Products*. In 1929, the Central Committee of Agriculture Promotion was created. The *Provisional Regulations on Rewarding Industrial Technology* was promulgated in 1932. The National Economic Committee was set up in 1933 as a consultative body to coordinate economic development projects. In 1935, the National Defence Design Committee was reorganized as the Resource Committee, which concentrated on planning heavy industry and drafted the Five-Year Plan for Heavy Industry Construction in the following year. There were also various efforts to develop education and culture. Research institutions were founded: for example, the Academia Sinica was founded in 1928, the Peiping Research Institute in 1929, the Central Industrial Test Station in 1930 and the Central Agricultural Experiment Station in 1931. Through measures listed in the *University Organization Law* (1929), the *Regulations for Universities* (1929) and the *Degrees Granting Act* (1935), and especially because of the government's policy of promoting the teaching of science and technology and restraining studies in the humanities and administrative management, education in science and technology progressed.

Because of the return of students who had studied abroad in the early years of the ROC, Chinese colleges did not have to employ unqualified foreign teachers. The earliest universities, such as Peking University, National Central University (which was founded by reorganizing

Southeast University) and Tsinghua University (which was upgraded from a school preparing students for studying in the US), outperformed most mission colleges in their scholarship, infrastructure, student enrolments and many other metrics. Of the 877 most prominent Chinese scientists, one-third of them graduated from those three universities (Li, 1989).

The evolution of Peking University could be considered an exemplary case of the progress in teaching during this period (Xiao *et al*., 1981). As part of the One-Hundred-Day Reforms, *Jingshi Daxuetang* (the Imperial University of Peking), the predecessor of Peking University, was approved by Emperor Guangxu and founded on 4 July 1898. On 21 September, Dowager Empress Cixi suppressed the reform movement and began practising her 'political tutelage'. As a result, almost all reform measures were abolished except for the Imperial University of Peking. In 1902, Zhang Baixi was appointed as the Minister of Education, and he presided over the drafting of the *Imperial Approved Regulations for Schools* in August that year. This was the first Chinese school system from elementary school to university. In this system, the university's mission was to arouse loyalty and love, develop intelligence and promote industries and commerce. Higher education was divided into three stages: pre-college, college and postgraduate. There were seven kinds of colleges: politics and law, literature, *Gezhi* (natural sciences), agriculture, engineering and technology, business, and medicine. In the college of *Gezhi*, there were six disciplines: astronomy, geology, advanced mathematics, chemistry, physics, and zoology and biology. Those classifications of knowledge have remained essentially the same since then.

In June 1903, minor modifications were made in the revised *Authorized Regulations for Schools*. The colleges did not start until March 1910, and the College of *Gezhi* had only two disciplines: geology and chemistry. In February 1912, Yan Fu (1854–1921) was appointed as the superintendent of the Imperial University of Peking, which was renamed in May as Peking University. As for the quality of the university, Yan Fu, now the president of the university, did not think that it could be compared with the universities in Europe and the US. Yet, he stated that 'The quality [of a university] is not fixed. If we keep improving it, it will one day become an advanced one.'

In October 1912, as the *Decree of University* was promulgated, the College of *Gezhi* was renamed the College of Sciences. There were 58 students in science and engineering disciplines before 1911. Threatened by the 1911 Revolution, most of them fled and never returned, leaving only four students in science and 14 in engineering. During the summer vacation of 1913, the College of Sciences admitted one class each in physics and chemistry, while the College of Engineering had one class each in civil engineering, mining and metallurgy.

On 26 December 1916, Cai Yuanpei (1868–1940) was appointed as the president of Peking University. He implemented an all-inclusive policy and reformed and revived the university, making it a foundation of the New Culture Movement and the May Fourth Movement. Founders of the CPC, including Chen Duxiu (1879–1942), Li Dazhao (1889–1927), Liu Renjing (1902–1987), Zhang Guotao (1897–1979) and Luo Zhanglong (1896–1995), studied at Peking University. Under Cai Yuanpei's leadership, Peking University closed down its School of Business, expanded its colleges of Arts and Sciences and added institutes for research. In the College of Sciences, there were five departments—mathematics, physics, chemistry, geology and biology—and one research institute of geology. The faculty members newly appointed by Cai were young and promising. About one-fifth of members in the first council of the Academia Sinica (1935) were professors of Peking University.

When Jiang Menglin (1886–1964) was the president of the university, he reformed its systems of teaching and research according to its US counterparts, reorganizing teaching staff and promoting a policy requiring that professors focus on their scholarly work, students mind their college studies, staff members manage business matters, and the president take care of the university administration. The university's teaching quality and scientific research were improved after it enacted a series of measures, such as hiring scholars who had studied in the US, setting up research professorships together with the China Foundation for the Promotion of Education

and Culture, naming scholars who had previously taught at Peking University as honorary professors, admitting graduate students (1931) and establishing research institutes (1932). Peking University's full-time professors, research professors or honorary professors occupied one-third of the seats in both the first (1935) and the second (1940) councils of the Academia Sinica.

The establishment of the Academia Sinica in June 1928 marked the institutionalization of China's modern science and technology. In 1912, Ma Xiangbo (1840–1939), as a senior adviser to the president of the government, submitted a joint letter with Zhang Taiyan (1869–1936) and Liang Qichao (1873–1929) to President Yuan Shih-kai (1859–1916) (Fan, 1989) proposing to establish a *Han Xia Kao Wen Yuan* (National Academy of Letters) modelled on the Institut de France. Although the proposal was approved and recorded, the government provided no practical support, and the project failed to materialize. In the winter of 1924, Feng Yuxiang (1882–1948) staged a coup in Beijing and sent a telegram to Sun Yat-sen, inviting him to Beijing to discuss matters of vital importance. When Sun left Guangzhou for Beijing, he proposed to convene a national congress and planned to set up a central academy as the highest national academic institution. He appointed Wang Zhaoming (1883–1944), Yang Quan (1893–1933) and Huang Changgu (1889–1959) to draw up an academic plan, but it was not implemented because of Sun's death in March 1925 and the subsequent preparation for the Northern Expedition (Lin, 1988). After more than a decade's preparation, the Chinese government had failed to establish a central academic institution. By contrast, Japan set up the Central Experiment Station (1907), the Institute of Geological Research (1910), the Institute of Railway Technology (1922) and the Institute of Health (1925) within the system of the South Manchuria Railway Company (SMR) in Manchuria (the north-east of China).

Chinese scholars had established more than 40 societies or associations and had instituted departments of various sciences in universities within the first dozen years of the ROC, but they founded only a few research institutes. The Academia Sinica, founded in 1928, and the National Beiping Academy, founded in 1929, set up a total of 20 specialized research institutes. The institutes under the Academia Sinica included the Institute of Physics (1928), the Institute of Chemistry (1928), the Institute of Industry (1928), the Institute of Astronomy (1928), the Institute of Meteorology (1928), the Institute of Geology (1928), the Institute of History and Philology (1928), the Institute of Sociology (1928), the Institute of Psychology (1929), the Institute of Zoology and Botany (1934), the Institute of Mathematics (1941), the Institute of Zoology (1944) and the Institute of Botany (1944). The institutes belonging to the National Beiping Academy included the Institute of Physics (1929), the Institute of Chemistry (1929), the Institute of Zoology (1929), the Institute of Botany (1929), the Institute of History (1929), the Institute of Radium (1932), the Institute of Biology (1932) and the Institute of Pharmacology (1932). Being an institution for scientific research and an organization to guide, communicate and reward academic research, the Academia Sinica greatly advanced Chinese science. Various universities, industries and departments of health also began to set up research institutes. Before the establishment of the Chinese Academy of Sciences (CAS) in 1949, there had been more than 190 research institutions in China, covering every basic discipline in modern sciences. Through their development in the 1930s, modern science had found a foothold in China.

However, that development was uneven across disciplines. China's development in geology, biology and anthropological archaeology took place earlier, so there were more significant achievements in those fields. However, in mathematics, physics and chemistry—the basic disciplines of modern science—China accomplished very little because those endeavors required the support of industry. Chinese industries during the period of the Nanjing nationalist government were mainly textile and light industries, concentrated in Shanghai, Tianjin and a few ports along the Yangtze River. The Five-Year Plan for Heavy Industry Construction established by the Nanjing government in 1935 could not be carried out because of the full-scale Japanese invasion in 1937. The 10-year industry plan proposed in Chiang Kai-shek's *Chinese Economic Theory* in 1943

remained only a utopian ideal because of the lack of social reforms. Although the textile industry had been distributed across about 75% of China in 1936, there was little machine-building industry, and the regionalization process was slow. As late as 1949, there had not been a system of regional industry distribution and a proper redistribution of industries. In that sense, China's industrialization was rather underdeveloped during the 1930s—a period that has been lauded as the first pinnacle of modern Chinese industry (Dong and Wang, 1991). Even John King Fairbank (1907–1991), an American historian, believed that the Chinese economy during this period remained a commercial economy with semi-colonial characteristics (Fairbank, 1958). Xu Teli (1877–1968), a contemporary communist in Yan'an and the director of the Research Institute of Natural Sciences (RINS), pointed out that, because national industries were underdeveloped, China's development in sciences such as mechanics, physics, chemistry and mathematics lagged behind its development in biology, geology and archaeology, which did not directly rely on industrial development (Xu, 1940). The industrial foundation for the development of sciences was constructed only after the establishment of the People's Republic of China (PRC) and through the First Five-Year Plan (1953–1957).

However, that did not mean that China's achievements in geology, biology and archaeology were insignificant. The 'domestic' sciences, which were developed according to real situations, were beneficial not only for China but also for the world. Studying China's geology, resources and types and distributions of animals and plants, as well as its climate, was indispensable for learning about the entire world. The achievements of Chinese scientists, such as Chinese geological maps, the Chinese botanical atlas, the discovery of *Metasequoia* and Peking Man, and records of Chinese scientific heritage, were all of worldwide significance. Moreover, using foreign experimental equipment, Chinese scientists studying abroad completed, independently or in collaboration, several important works. In physics, Ye Qisun (1898–1977) accurately determined Planck's constant in 1921; Wu Youxun (1897–1977) experimentally confirmed Compton's scattering theory in 1924; Zhao Zhongyao (1902–1998) discovered the phenomenon equivalent to the creation and annihilation of electron–positron pairs in 1930; Qian Sanqiang (1913–1992) and He Zehui (1914–2011) discovered ternary nuclear fission in 1946; Zhang Wenyu (1910–1992) discovered the μ atom in 1949. There were also some important achievements in theoretical studies: Wu Dayou (1907–2000) made a quantum mechanics calculation that predicted the transuranic elements in 1933; Wang Ganchang (1907–1998) proposed an experimental plan to detect neutrinos in 1941; Huang Kun (1919–2005) advanced the Huang scattering theory of solids in 1947.

3. Setbacks and distorted developments in the scientific culture

The period of the War of Resistance against the Japanese Aggression was a time when the Chinese people suffered. Japanese militarists attempted to extinguish the Chinese nation. At the beginning of the war, the US publicly claimed to be neutral but, in private, the US government supplied arms and other materials to both China and Japan, undoubtedly attempting to profit from the war. At the beginning of the war, the Soviet Union aided China in fighting against the Japanese invaders. In 1941, however, it signed a non-aggression treaty with Japan. American loans to China after the outbreak of the Pacific War and the Soviet attack on the Japanese Kwantung Army in 1945 helped China to win the war, but both the US and the Soviet Union intended to control China after the war. If the Chinese people had not fought back, China would have been conquered by Japanese imperialists while the US and the Soviet Union were weighing their national interests. The final victory in this decisive battle for the independence of the Chinese nation was won primarily because of the Chinese sacrifice of 21 million lives and a direct economic loss of 60 billion *yuan*.

The impact of the war on the development of science and technology in China was twofold. On the one hand, the Japanese invasion inflicted serious damage. On the other hand, the war produced some outcomes that could not have been accomplished in peacetime. First, during the war, the nationalist government moved to Chongqing (in the

remote south-west of China) along with many industrial facilities and cultural institutions. That quickly transformed the distribution of industries and cultural facilities in China. Second, the anti-Japanese democratic government established by the CPC in the north of Shaanxi Province implemented preliminary Marxist policies on science and technology. Third, to meet the demands of the war and for permanent occupation, the Japanese invaders set up a relatively complete industrial system, as well as scientific and cultural facilities, in Manchuria.

The Japanese had occupied Manchuria since 1931. On 7 July 1937, they instigated the Marco Polo Bridge Incident and launched a full-scale invasion of China. By the end of July, Beiping and Tianjin were occupied, and Shanghai was lost in November. Extending from those cities, the Japanese Army pushed forward along railways. By 27 October 1938, when the city of Wuhan on Yangtze River fell, the Japanese Army occupied more than half of China, including most parts of the northern, eastern and central regions. Before the full-scale invasion, 70% of Chinese industries were located in littoral cities and provinces, including 70% of textile industries, 62% of flour mills, 53% of match factories and 100% of chemical industries. Within the first few months of the war, those coastal cities and provinces were occupied by the Japanese Army. The industries there were either destroyed by shellfire or seized by the Japanese. In Shanghai alone, 2270 industrial enterprises with a value of 800 million *yuan* were destroyed. The factories in the Yangtze delta area lost 50% of their facilities, and those in the three towns of Wuhan (Wuchang, Hankou and Hanyang) lost 12%.

After the full-scale Japanese invasion began, the nationalist government announced on 20 October 1937 that it would temporarily relocate the capital to Chongqing and transfer important factories and scientific and cultural facilities inland. According to records, a total of 447 factories were transferred inland, including one smelting plant, 181 machine factories, 25 electrical appliance factories, 60 chemical engineering factories, 98 textile factories and 12 other factories; 245 of those factories were moved to Sichuan Province, 121 to Hunan, 25 to Guangxi, 42 to Shaanxi and 14 to Guizhou, Yunnan and other provinces. Through the National Resource Committee under the Military Committee and the Industrial and Mining Adjustment Committee of the Ministry of Economy, the nationalist government reorganized and created many industrial and mining enterprises based on the war's demands. The *Regulations of Agriculture, Mining and Business Administration in the Time of Emergency* issued on 6 October 1938 stipulated that mining enterprises, factories producing military products and electric industries, which were all wartime necessities, would be taken over or jointly run by the government. The regulations also stipulated that the Ministry of Economy could decide at any time, if necessary, to take over and directly run factories producing daily necessities. In this way, private industries were rapidly nationalized. By the end of 1945, the National Resource Committee directly administered 125 enterprises, among which more than 30 factories belonging to the Ordnance Department and more than 40 belonging to the Highway Administration of the Ministry of Transportation. Thus, the number of state-owned enterprises was greater than that of private enterprises. Because of the migration of enterprises and the creation of new ones, the south-western region became the contemporary industrial center. Before the war, in the provinces of Sichuan, Hunan, Guangxi, Shaanxi, Guizhou, Yunnan and Gansu, the total number of factories was only 6.3% of those in China, the total capital only 4.4%, and the total number of workers only 7.3%. During the war, however, the proportion of the three categories in the KMT-controlled regions increased to 88.6%, 93.5% and 85.6%, respectively.

Because of the migration of scientific and cultural facilities, Chongqing, Kunming and Chengdu became wartime centers of science and culture. In Chongqing, besides the local Chongqing University, there were the relocated Academia Sinica, Central Industrial Test Station, Central Agricultural Experiment Station, Central Medicine Research Institute, Geological Survey of China, National Central University, Central Vocational School of Industry, Central Hospital, Science Society of China and Shanghai College of Medicine. In Kunming, in addition to the local Yunnan University, others were added, including the National Southwestern Associated University (SAU), which comprised Peking University,

Tsinghua University and Nankai University; some institutes of the Academia Sinica and Beiping Academy; the Drug Research Institute of the Ministry of Education; and the Central Machinery Works. In Chengdu, besides West China Union University and Sichuan University, there were the relocated Yenching University, Cheeloo University, Ginling College, Nanking University, Wuhan University, Tongji University and the Yellow Sea Institute of Industrial Chemistry. In the north-west, there was the National Northwestern Associated University, which consisted of Beiping University, Beiyang College of Engineering and Beiping Normal University. In Guizhou, there was the migrated Zhejiang University.

Chinese scientists and professors developed applied studies, improved power machines such as the steam engine and internal combustion engine, enhanced the precision of machine tools, and prospected and discovered the Yumen oilfield. They also conducted some basic research, submitting more than 100 scientific papers through the Sino-British Scientific Cooperation Office led by Joseph Needham (1900–1995). Despite great financial difficulties, higher education was still expanding and advancing towards a uniform quality. The SAU nurtured high-quality students such as Yang Zhenning (Chen-Ning Yang, 1922–) and Li Zhengdao (Tsung-Dao Lee, 1926–), the co-winners of the 1957 Nobel Prize in Physics. Chinese scientists and engineers also founded several academic societies, among which the most influential one was the Association of Chinese Scientific Workers set up in July 1945.

In the north-west, there was the Government of Shaanxi–Gansu–Ningxia Border Region led by the CPC. The CPC leaders and the Central Red Army broke through the fifth encirclement and suppression by Chiang Kai-shek's forces in 1934, marching north from Jiangxi Province to resist the Japanese aggression. After covering about 12,500 kilometers they arrived in north Shaanxi in October 1935 and founded a government centered in Yan'an. The peaceful settlement of the Xi'an Incident[1] in December 1936 prompted CPC–KMT cooperation against Japanese aggression. In August 1937, the Nanjing Defence Conference divided the country into five combat zones to fight the prolonged war against the Japanese aggressors. The Red Army in the north-west was reorganized as the Eighth Route Army and was placed in the second combat zone. The Red Army in eight southern provinces was incorporated as the New Fourth Army and was placed in the third combat zone. In September 1937, the Eighth Route Army successfully ambushed Seishiro Itagaki's division at Pingxing Pass. In October, the Xinkou Battle lasted 20 days but the Chinese forces failed to stop the Japanese Army. In the spring of 1938, the bloody Tai'erzhuang Battle lasted for 10 days but, eventually, Xuzhou was lost. The main force of the Chinese national army could not stop the Japanese Army and it retreated in defeat, whereas the Eighth Route Army gradually penetrated the enemy's rear and flanks. In 1940, the victories in the Hundred Regiments Offensive organized by the Eighth Route Army strengthened people's confidence to continue the fight against the Japanese aggressors. Yan'an, where the CPC was headquartered, became a base in North China against the aggressors.

During those trying years of war, hundreds of scientists, engineers and doctors moved to Yan'an to serve the war effort with their own scientific and technological knowledge. Also coming to Yan'an were some international allies, such as Ma Haide (Shafick George Hatem, 1910–1988) from America, Hans Müller (1915–1994) from Germany, Richard Frey (1920–2004) from Austria and Aleksandr Aleksandrovich Alov (1923–1983) from the Soviet Union, who worked in the Yan'an Hospital. To support the war effort and assist in the economic construction in the Border Region, the RINS was founded in Yan'an, and Li Fuchun (1900–1975) was appointed as its first director. In February 1940, the Shaanxi–Gansu–Ningxia Border Region's Research Society of Natural Sciences (RSNS) was founded, headed by Wu Yuzhang (1878–1966). In addition, more than 20 other learned organizations were set up, including the National Defence Science Society and the Border Region Research Society of Chinese Medicine, as well as the branches of the RSNS in agriculture, biology, geology and mining, machinery and electric motors, chemistry, civil engineering, medicine, aviation, and mathematics and physics.

The RINS was initially a research organization. In January 1941, the CPC Central Committee decided

to convert it into an institution that would primarily provide education in natural sciences but also carry out research. As an educational organization, the RINS set up four departments (physics, chemistry, biology, and geology and mining), which were transformed in 1943 into three departments (mechanical engineering, chemical engineering and agriculture). The RINS nurtured students and explored natural resources and studied their exploitation. It had a Division of Biology, which compiled a flora index of economic plants in the border region and organized working groups for living organism collection, forest surveys and geological prospecting.

The RSNS and its branches contributed to economic construction in the border region. They started or renovated many industrial and mining enterprises, such as those producing coal, edible salt, petroleum, steel and iron, textiles, paper, medicines, printed works, leather, matches, glass, ceramics, chemicals for daily necessities, and weapons and ammunition. All those enterprises played an important role in supporting the war effort and improving people's lives.

Although the work during the Yan'an period did not provide a basis for the development of science and technology, it had great influence on the guiding ideas and the system of science and technology. On the one hand, Marxist views on science and technology were firmly established in the minds of senior and mid-level CPC cadres, and those Marxist ideas were put into initial practice by the border region's government. After the establishment of the PRC, the cadres who had had some practical experience in Yan'an took over various leadership positions in science and technology. For example, Yun Ziqiang (1899–1963), who was the deputy director of the RINS, served as a deputy director of the general office of CAS, the deputy commissioner of the Compilation and Translation Bureau and the deputy commissioner of the north-eastern branch of CAS. Li Qiang (1905–1996), who was the third director of the RINS, served as a vice minister of the Ministry of Foreign Trade and concurrently as the counsellor for commerce in the PRC Embassy in the Soviet Union, overseeing 156 Soviet-aided construction projects. Wu Heng (1914–1999), one of the initiators of the RSNS, was the deputy director of the State Scientific and Technological Commission. Yu Guangyuan (1915–2013), the secretary of the RSNS, served as the director of the science division under the Publicity Department of the CPC Central Committee,[2] the deputy director of the State Scientific and Technological Commission and the vice president of the Chinese Academy of Social Sciences. Yun, Li and Wu were elected as the first group of academicians of CAS.

The influence of the Yan'an experience on the development of China requires a separate analysis. Here it suffices to quote a paragraph from a speech by Mao Zedong (1893–1976) at the founding ceremony for the RSNS. This paragraph was short but explicitly demonstrated Mao's view concerning the objectives of natural science study, the relationship between natural sciences and social sciences, and the development of natural sciences and the social system:

> Natural science is a kind of weapon for people seeking freedom. In order to acquire freedom in society, people have to learn about the society through social sciences, transforming society and carrying out social revolutions. In order to acquire freedom in the natural world, people have to understand nature using natural sciences, overcoming nature and transforming nature, and obtaining freedom from nature. Natural sciences are going to transform the natural world under the direction of social sciences, but the development of natural sciences is hindered in capitalist societies. Hence, it is necessary to transform this irrational social system. (Mao, 1940)

As mentioned above, the Japanese built many industries and scientific and cultural facilities in Manchuria before 1945. The role of those industries and facilities in China's development is an important topic in the historical study of modern Chinese science and technology. A discourse on this issue requires an analysis of not only the motivations of the Japanese and the outcomes of their activities but also the consequences of US and Soviet actions.

Since the First Sino-Japanese War (1894–1895), Japan had always coveted China. The Japanese were the main force of the Eight-Nation Alliance that attacked Beijing in 1900. Taking advantage of that opportunity, the Japanese began to seek hegemony in East Asia. To their surprise, however, Russia captured Manchuria first. That bothered Japan because of its territorial ambition in the region and also

because of the menace posed by the Russians to Japan itself. Supported by the UK and the US, Japan waged a war against Russia on Chinese territory in February 1904. Having defeated Russia in the war and signed the Treaty of Portsmouth (1905), Japan inherited southern Manchuria. Later, Japan gradually expanded its control in the area and built up myriad colonial organizations. Japan not only attempted to occupy Manchuria indefinitely but also planned to turn it into a base for conquering the whole of China and fighting against Russia. There were five main colonial organizations: the headquarters of the Kwantung Army, the Manchurian Governor's Office, the SMR, the Manchurian Heavy Industry Development Corporation (MHID) and the puppet government of the so-called Imperial State of Manchuria.

The SMR was founded on 7 June 1906. US President Theodore Roosevelt (1858–1919) took an interest in this matter. Edward Henry Harriman (1848–1909), an American railway magnate, travelled to Japan on 31 August 1905, looking for an opportunity to invest in the SMR and realize his ambition to travel around the globe within one week by land and sea transport. Komura Jutarō (1855–1911), the Japanese Foreign Minister, was strongly against this. To compete with Harriman's consortium, President Roosevelt, who was sponsored mainly by a consortium organized by John Pierpont Morgan (1837–1913), was willing to give Japan a loan of US $300,000–400,000 on the condition that Japan would buy products from Morgan's companies in addition to paying the loan's interest. Thus, Japan established the jointly owned state–private SMR based on both the conditional loan from Morgan's consortium and private capital raised in China and Japan. Gotō Shimpei (1857–1929), the former Japanese governor of Taiwan Province, was appointed the first director of the SMR. Modelling the entity on the East India Company, Gotō built the SMR as a colonial organization with the functions of a state. In the beginning, there were 4000 employees in the SMR. Through years of administration under 17 terms of directorship, the SMR expanded into a corporation that had as many as 400,000 employees by the time Japan surrendered in 1945, making it the largest Japanese company.

In name, the Kwantung Army, the Manchurian Governor's Office and the SMR seemed like the three legs of a tripod, but they were one unified unit. In 1932, to legitimize their colonial rule in Manchuria, the Japanese set up the puppet Imperial State of Manchuria, which was headed by Aisin Gioro Puyi (1906–1967), the dethroned last emperor of the Qing dynasty. The Japanese directly manipulated the puppet regime to serve their expanded invasion of China. To meet the demands of the war, the Japanese government reorganized the industries in Manchuria, following the recommendation of Yoshisuke Aikawa (1880–1967), the president of the Nissan business group. Nissan moved its headquarters to Manchuria in November 1937 and in December was reorganized under the new name of 'Manchurian Heavy Industry Development Corporation', which was jointly sponsored by the puppet Manchurian government and private investors, but primarily by the former. Headed by Yoshisuke Aikawa, the MHID controlled nearly all heavy industries in Manchuria, including coal, steel, iron, petroleum refining, light metals, heavy-duty machines, automobiles and aeroplanes.

Through the SMR and the MHID, the Japanese industrialized Manchuria. By the time Japan surrendered, the gross product of industry had surpassed that of agriculture; the total amount of heavy industry products in Manchuria had exceeded the combined total of those in the remaining areas of China; the annual output of coal was 26.5 million tons; the annual output of pig iron was 1.18 million tons; the annual output of steel was 470,000 tons (the highest annual output once reached 2.9 million tons); and the annual output of cement was 1.14 million tons. Manchuria contained 10,000 kilometers of railways, which was one-third of the total railway length in China. The installed capacity of electric power was about 1.8 million kilowatts, which was two-thirds of that in the whole country.

Furthermore, the SMR built advanced research institutes, such as the Central Experiment Station and the Institute of Railway Technology, as well as colleges with good facilities, such as the Railway Institute, the Medical University and the Institute of Industry. The puppet Manchurian government also founded the Continental Academy of Sciences, which included one branch academy and four research institutes or offices and factories, as well as more than 20 research laboratories. Some vocational schools were also upgraded to universities,

such as Lushun Industrial University, Harbin Industrial University, Fengtian Agricultural University, Manchuria Medical University and Xinjing Medical University.

The Japanese made some advanced technological achievements while they were occupying Manchuria. For instance, the test refining of shale oil was successful and shale oil was in production; soda was successfully manufactured out of salt; the test of coal liquefaction succeeded; there was an aerodynamically shaped train with air-conditioning running on the Changchun–Dalian line at 120 kilometers per hour; and the Fengman Dam, though unable to match the Hoover Dam and the Grand Coulee Dam in the US, surpassed the Dnieper Dam in the Soviet Union in capacity.

Japan boasted of its enormous investment in Manchuria, but most of it was not exported capital from Japan but rather resources taken in Manchuria. For example, more than 70% of the total capital in the MHID system came from the puppet Manchurian government. The Japanese also claimed that they moved 300,000 Japanese into Manchuria to develop the region. However, those Japanese came to rule the local Chinese people, while the main labor force for developing Manchuria comprised millions of Chinese captured from other regions. Using Chinese resources and wealth, and Chinese labor, the Japanese constructed more than 100 large industrial and mining enterprises. More than one-third of those enterprises' products were shipped to Japan; Japan relied on Manchuria to provide 24 of 38 kinds of ordnance. The products not being shipped back to Japan did not benefit the Chinese people, as they were used to expand the aggressive war in the other parts of China. The Japanese even experimented on captured Chinese to develop biological weapons.

One could say that the industrial facilities left by the Japanese would have provided a foundation for China to develop its industries after the war. However, the reality was not so. Little remained after: 1) American B-29 bombers based in Chengdu bombed Anshan and Benxi; 2) the Soviet Red Army's artillery fire targeting the Japanese Kwantung Army obliterated many of those facilities; 3) the Japanese Army in retreat brought about more destruction; and 4) the Soviet Army dismantled whatever was left in those industries and shipped it back to the Soviet Union. In the end, 40% of the industries in Manchuria were destroyed in the war, and another 40% of them were dismantled and taken away by the Soviet Army.

Kojima Noboru (1927–2001), a Japanese historian, exposed some details about the Soviet dismantlement (Kojima, 1976). According to Kojima, in Fengtian, more than 50 factories were dismantled, and machine tools, generators, chemical machinery, transformers and the like were taken away. In Anshan, the facilities of 25 factories were taken apart, and 2890 railway cars and more than 600,000 people were employed to ship equipment, such as mining and mineral dressing equipment and smelters. In Fushun, coalmining and petroleum-refining facilities were disassembled, and only the walls and electric furnaces of a light metal plant were left; 90% of equipment in the Dalian Machine Building Shop was taken away. Industrial facilities for petroleum, chemical engineering, electrical work and woodwork were completely removed. According to the estimate of an American committee dispatched to Manchuria in June 1946, the facilities dismantled and taken by the Soviet troops were worth US$900 million, and it would cost US$2 billion to rebuild them. The committee also provided estimated percentage losses of various industrial facilities: 71% in electric power, 90% in coalmining, 50–100% in steel and iron making, 80% in the railway industry, 75% in machinery, 50% in liquid fuels, 100% in chemical engineering, 50% in cement production, 75% in nonferrous metals, 75% in fiber making, 30% in paper mills, and 20–100% in telecommunications.

4. The formation of China's science and technology system modelled on the Soviet Union's

The constitution of China's scientific and technological system depended on the people's government. Chiang Kai-shek had always attempted to restrict the development of the CPC. When the Northern Expedition was approaching its triumph and the country was nearly reunified, he tried to annihilate the CPC. Through the Nanchang Uprising

(1 August 1927), the Autumn Harvest Uprising (9 September 1927) and the Guangzhou Uprising (11 December 1927), the CPC founded its armed force and established some revolutionary bases in mountainous areas of Jiangxi, Hubei, Hunan, Fujian and Anhui. Chiang Kai-shek mobilized 2.1 million soldiers to encircle and annihilate the CPC but failed. The CPC's policy of forming a national united front against Japanese aggression helped the communist forces expand quickly, forcing Chiang to grant the CPC a legitimate status. However, in Chiang's opinion, the Japanese invasion was like a skin ailment, whereas the CPC was a disease of heart.

The US supported Chiang's government. When the Pacific War broke out, the Americans attempted to make China a base for the fight against Japan and schemed to use China as the main force to stabilize Asia and counterbalance the Soviet Union after World War II. Therefore, they provided US$1.6 billion in aid to the nationalist government during the War against Japanese Aggression. Out of their political and strategic concern to counterbalance the Soviet Union, the Americans began to prepare for Chiang's unification of China in October 1944, when victory in the war against fascism was in sight. At the Yalta Conference in 1945, the US and the Soviet Union made a deal at the cost of Chinese rights and interests in Manchuria. The Soviet Union agreed to attack the Kwantung Army and promised to support the KMT on the condition of regaining the privileges Russia used to have in Manchuria. As a result of that deal, the US no longer needed to rely on the CPC's forces to fight the Japanese, and thus could restrain the CPC and force it to yield to the KMT. After Japan declared its surrender, the US airlifted 500,000 of Chiang's troops to seize North and East China and sent 50,000 American marines to help Chiang fight for the CPC-controlled areas in North China. After World War II, the US helped the KMT government control China by providing military aid worth more than US$5 billion and by mediating between the CPC and the KMT to avoid a civil war, but neither endeavor was successful.

Once KMT troops had lost the three major military campaigns of Liaoshen, Pingjin and Huaihai, and the KMT government was collapsing, the US State Department attempted to start a relationship with the CPC. However, unable to trust America because of its pro-Chiang Kai-shek and anti-communist history, the CPC decided to lean towards the Soviet Union. Since the CPC had defeated the KMT, the Soviet Union naturally wanted to accept socialist China as one of its allies. On 14 February 1950, the two governments signed the Sino-Soviet Treaty of Friendship, Alliance and Mutual Assistance. The Korean War exposed the true colors of the US government. By sending the Seventh Fleet into the Taiwan Strait, the US interfered with Chinese internal affairs.

The historical conditions determined that the PRC founded under the leadership of the CPC joined the socialist camp. Socialist China, which could receive aid only from the socialist camp, was bound to model itself on the Soviet Union in areas such as politics, economics, science, culture and so on. That began the transformation in China's system of science and technology from the Anglo-Saxon model to the Soviet model. Because of the postwar antagonism between the socialist world and the capitalist world, the international environment faced by the PRC was more hostile than that faced by the early Nanjing KMT government. Domestically, however, Chiang Kai-shek's government had never truly reunified China, not only because the CPC had 15 revolutionary bases and 19 liberated areas, but also because the Japanese controlled Manchuria—approximately one-quarter of the Chinese territory—through the puppet Manchurian government.

By contrast, the CPC reunified the Chinese mainland, which was unprecedented in the previous century of Chinese history. The domestic unification, the socialist planned economy and the determination of the Chinese communists to consolidate their power enabled China to recover rapidly from the aftermath of the wars and to develop its economy and scientific culture in a planned manner. The successful completion of the First Five-Year Plan allowed China to acquire a foundation for modern industries. It was because of that industrial base that Chinese scientific education and research developed. Although most scientists in China's science and technology field received their education in European or American schools, the socialist political system in China determined that the Chinese system of science and technology would follow the Soviet model.

Such a transformation of the Chinese system of science and technology was realized through three primary measures: the constitution of CAS according to the blueprint of the Soviet Academy of Sciences, the reorganization of Chinese colleges and universities by modelling their Soviet counterparts, and the construction of 156 leading projects assisted by the Soviet Union. Soviet assistance played an important role. According to the loan agreement, the Soviet government gave China a loan of US $300 million. In comparison to the US$3 billion needed by China, that loan was rather small: it was worth only one-third of the total value of the facilities that the Soviets took away from Manchuria in 1945 and was about the same size as the loan they granted to Poland. Although the Soviet loan was far from enough to meet Chinese needs, it was still quite valuable because the Soviet Union was almost the sole benefactor of China at that time. While providing loans and economic aid, the Soviet government also furnished China with technological assistance. It not only sent more than 10,000 experts to China but also accepted about 1000 Chinese scientists and thousands of Chinese technicians and students to study in the Soviet Union. Soviet experts ingrained the Soviet development pattern of science and technology and incorporated it into various Chinese scientific research institutions, higher education institutions and technical divisions of industries.

CAS was founded on 1 November 1949. Guo Moruo (1892–1978), a Chinese archaeologist, historian and writer, was appointed as president of the organization. CAS was both a national scientific research center and an administrative organization to promote science and technology under the leadership of the State Council. By taking over previously existing research organizations, such as the Academia Sinica and the National Beiping Academy, CAS established 20 research departments, including the institutes of modern history, archaeology, languages, sociology, modern physics, applied physics, physical chemistry, organic chemistry, biochemistry, experimental biology, hydrobiology, systematic botany, geophysics, geology, mathematics, psychology, geography and engineering science, as well as the Purple Hills Observatory and the Industrial Experiment Laboratory. Most of those institutes' directors were former academicians or councillors of the Academia Sinica. Most of CAS's more than 200 researchers had studied abroad.

Through the Thought Reform Campaign in 1952, Chinese scientists' ideas were turned towards socialism, leading to a cult of learning from the Soviet Union in 1953. A CAS delegation headed by Qian Sanqiang visited the Soviet Union in March 1953. They spent three months visiting 98 research organizations, 11 universities and industrial and mining enterprises, and attending seven comprehensive lectures specially organized by the Presidium of the Soviet Academy of Sciences. The delegation introduced into China the Soviet experience of developing the sciences. Many Soviet approaches to leading and organizing scientific studies were mirrored in China, such as the leading position of the academic divisions in the Academy of Sciences, the procedures for formulating research plans, the division of and cooperation on research works among research organizations, and the methods of communication between research institutes, universities and industrial ministries.

After a Sino-Soviet agreement on scientific and technical cooperation was signed in Beijing on 12 October 1954, Soviet experts came to China. In June 1955, CAS's academic division membership system was formally set up. The congress of four constituent academic divisions (the Division of Mathematics, Physics and Chemistry; the Division of Biology and Geology; the Division of Technological Sciences; and the Division of Philosophy and Social Sciences) took charge of specific academic activities. By the start of 1956, the number of research organizations in CAS had increased to 44, and CAS's academic personnel totalled 2,500, among whom 400 were senior researchers. As the highest academic research center in the country, CAS had far surpassed the Academia Sinica in scale and the scientific disciplines that it encompassed.

The Ministry of Education convened a national conference concerning education in Beijing in December 1949, which determined the policies for educational reforms and development. Between June and September 1952, to speed up the training of professional personnel for the PRC's industrial

construction, the ministry reorganized schools and departments in universities according to the Soviet model of specialized education. Hitherto, following the patterns of European countries and the US, Chinese universities were constituted only by schools and departments but not by specialities. Practising the policy of training students in specialities, the reorganization merged similar departments and schools in some universities to constitute specialized colleges. The two great regional cultural centers, North and East China, were the main foci of the reorganization.

Forty-one universities and institutes emerged from the reorganization in North China, concentrated in Beijing and Tianjin. Among them, Peking University and Nankai University were comprehensive universities; Tsinghua University and Tianjin University were converted into advanced multidisciplinary industrial institutes. Fu Jen University and Yenching University (the two former Christian mission colleges in Beijing) were abolished; the former was merged into Beijing Normal University; the latter's schools of liberal arts and sciences were combined into Peking University, and its engineering school was absorbed by Tsinghua University. In addition, many specialized institutes were built, such as the Beijing Institute of Geology, the Beijing Industrial Institute of Steel and Iron, the Beijing Institute of Aeronautics, the Beijing Institute of Forestry, the Beijing Institute of Agricultural Mechanization, the Central Institute of Taxation and the Beijing College of Political Science and Law.

In East China, there were 54 post-reorganization universities and institutes, concentrated in Nanjing and Shanghai. Among them, Nanjing University, Fudan University and Shandong University were designed as comprehensive universities. Zhejiang University and Nanjing Institute of Technology were transformed into advanced multidisciplinary industrial institutes. Newly created institutes included the Institute of Military Engineering of the PLA (restructured as the Artillery Engineering College of the PLA in 1960 and renamed as the East China Institute of Engineering in 1966), the East China Technical University of Water Resources, the Eastern China Aeronautics Institute, the East China University of Sports, and Nanjing Forestry College. The University of Nanking, St. John's University, the University of Shanghai and Aurora University (all previously foreign mission colleges) were abolished, and their departments and programs were merged into other universities or institutes.

After the 1952 reorganization, a total of 215 specialities were established in universities and institutes nationwide, mainly according to the demands of national construction. In 1955, in order to correct the unbalanced distribution of higher learning institutes, some institutes in coastal areas were relocated inland and new colleges were founded, increasing the number of institutes of higher learning to 229 on the Chinese mainland. Among Soviet experts coming to China, nearly 1000 taught at Chinese universities and institutes, where they helped China establish 150 specialities, offered over 900 courses and built more than 500 laboratories. After the 1952 and 1955 reorganizations and under the influence of the Soviet experts' instructions, the Anglo-Saxon-style liberal education in the period of the nationalist government was completely transformed into the Soviet-style specialized education. Although the reorganizations imitated the Soviet system mechanically, designed the disciplinary specialities narrowly and improperly cancelled some academic disciplines and programs, the changes generally met the demand of industrial construction for a large group of specialists.

Scientific research institutes are the sources of new knowledge, and universities are the cradles of scientists. However, if there had been no industrial foundation, there would have been no creative motivation born from industrial demand, and the development of technology would have been undermined. The industrial requirements of the First Five-Year Plan (1953–1957) greatly advanced the development of modern technology in China. The total investment of the First Five-Year Plan was 42.7 billion *yuan*, of which 7.6% was invested in the primary industry, including agriculture, forestry, stock raising and fisheries, 58.2% in the secondary industry, including manufacturing and processing industries, and 34.2% in the tertiary industry or the service industry, including transportation, commerce, finance, culture, education and health. Of the secondary industry investment, the heavy

industries accounted for 85%. In the First Five-Year Plan, 211 of more than 600 principal projects were constructed with Soviet aid. The 156 core projects under Soviet aid included the Anshan Steel and Iron Mill, the Baotou Steel Mill, the Changchun First Automotive Works, the Jilin Chemical Factory and the Lanzhou Petroleum Refining Plant. This unbalanced investment demonstrated both Chinese determination to speed up industrialization and China's imitation of the Soviet pattern of industrialization.

Historically, the first group of countries to achieve industrialization mostly followed the UK pattern by prioritizing the production of consumer goods, which was dominated by the free capitalist economy. Another kind of industrialization was first experienced by Germany and Japan. In contrast to the economy-dominated industrialization in the UK, the US and France, industrialization in Germany and Japan was power-dominated and directed by the government, and developing the production of productive goods took priority. Soviet industrialization was also power-dominated but was preconditioned by the public ownership of productive goods and the planned economy, which became the model for developing countries, especially socialist countries after World War II.

The PRC's First Five-Year Plan was successful, and its main targets were accomplished in 1956, one year ahead of schedule. The fulfilment of the plan changed the structure of the Chinese national economy. The gross value of industrial output in 1956 was 54.7% of the total value of industrial and agricultural output; the value of productive goods produced was 45.5% of the gross value of industrial output; and the value of modern industry output was 71.6% of the gross value of industrial output. Since the Chinese government included science and technology development in the First Five-Year Plan, scientific studies, science and technology education and industry developed as planned, providing unprecedented advantages for China.

By 1955, there were more than 380 research organizations and 9000 researchers in China, and the number of high-level intellectuals in the three systems of scientific research, engineering technology, and culture, education and health care amounted to 100,000. The 34 achievements that won the CAS Natural Science Awards reflected Chinese scientists' capability to conduct independent research. In technological fields, the industrial divisions of material, energy and manufacturing could coordinate with each other, and the ability of Chinese engineers to design, manufacture and construct products greatly improved. China was able to manufacture more than 3500 kinds of mechanical products and to smelt more than 240 types of superior and alloy steel. All of those factors demonstrate that the modern system of science and technology had begun to take form in China.

5. Conclusion

The establishment of the Chinese system of science and technology was largely determined by external factors. The pattern transformation of the system in the mid-20th century also resulted from changes in the international political environment and domestic political situation.

The Chinese system of science and technology did not continue to be based on the Soviet model. In 1956, China began to explore how to end the Soviet pattern because of the incongruity of the Soviet socialist model. Furthermore, some adverse effects of blindly following the Soviet Union had emerged in China. Mao Zedong, as the Chairman of the CPC Central Committee and the President of the PRC, contemplated a socialist pattern that would suit China. His thoughts were presented in his essay 'On the ten essential relationships' (1956) and were established as the political line at the Eighth National Congress of the CPC. The resolution concerning the political report of the congress confirmed that the contradiction between the proletariat and the bourgeoisie had been resolved in China, and that the primary contradiction had shifted to that between people's increasing demand for the rapid development of the economy and culture and lagging social productivity. In the areas of science and culture, the breaking away from the Soviet pattern was exhibited in advancing the policy of 'letting a hundred kinds of flowers blossom and a hundred schools of thought contend', in making a 12-year plan for the development of science and technology, and in establishing a strategy of

'keeping the initiative in our own hands and doing our utmost to catch up'.

In 1978, having experienced the setbacks and failures in the Anti-Rightist Campaign, the Great Leap Forward and the 'Cultural Revolution', the CPC, now at a new starting point, returned to the political line of the Party's Eighth National Congress and generated a new state of affairs through 'reform and opening up'. Having transformed its mindset through the enlightenment of scientific thought and transformed the development pattern of science and technology, China shifted the driving force of developing science and technology from national defence to economics.

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.

Notes

1. In the Xi'an Incident, Chiang Kai-shek was detained by his generals but was eventually released after the CPC's mediation.
2. The science division under the Publicity Department of the CPC Central Committee was an office that turned CPC scientific policies into concrete practice.

References

Dong MX and Wang R (1991) A discussion on the course of modernization of regional economy in China after the Opium War. In: Zhang HF (ed) *The Opium War and the Modernization of China*. Beijing: Chinese Society Publishing House, pp.139–152 (in Chinese).

Fairbank JK (1958) *The United States and China*. Cambridge, Massachusetts: Harvard University Press.

Fan HY (1989) Ma Xiangbo and Hanxia Academy. *Chinese Historical Materials of Science and Technology* 10(4): 39–42 (in Chinese).

Kojima N (1976) *The Imperial State of Manchuria*, vol. 3. Tokyo: Bungei Shunju.

Li PS (1989) The status and functions of homecoming students from abroad in the development of science and technology in China after 1949. *Journal of Dialectics of Nature* 11(4): 26–34. (in Chinese).

Lin WZ (1988) The process of preparing the Academia Sinica. *Chinese Historical Materials of Science and Technology* 9(2): 70–73 (in Chinese).

Mao ZD (1940) Speech at the conference of the foundation of the Research Society of Natural Sciences. *New China News*, 15 March (in Chinese).

Xiao CR, Sha JS, Zhou CE, et al. (1981) *The History of Peking University*. Shanghai: Shanghai Education Publishing House (in Chinese).

Xu TL (1940) How to research natural sciences. *Zhongguo Wenhua (Chinese Culture)* 2(4): 5–7 (in Chinese).

Author biography

Guangbi Dong is a researcher at the Institute for the History of Natural Sciences, Chinese Academy of Sciences. His research focuses on the history of science, the philosophy of science and scientific culture. In addition to academic research, he also has a great interest in science popularization and is committed to promoting the scientific spirit and disseminating scientific ideas. He has published many theoretical books on science popularization and articles about the scientific spirit and scientific progress. He has also been involved in many science popularization activities.

Article

Cultures of Science
2022, Vol. 5(1) 33–49
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/20966083221086097
journals.sagepub.com/home/cul
SAGE

From experience to theory: Science recreation workshops as a practice-led approach in informal environments for science learning

Miguel García-Guerrero
Autonomous University of Zacatecas, México

Bruce V Lewenstein
Cornell University, USA

Abstract

Science recreation workshops (SRWs) create dynamic experiences in which participants discover, explore and understand natural phenomena. This serves as a unique and valuable means of the public communication of science and technology and informal science education activities, with the public at the centre of the process. To achieve this, SRWs integrate action and reflection not as a dichotomy, but as a complementary relation in which sensorial interaction is not a thoughtless process and mental activity is not disembodied. In this way, SRWs create virtuous cycles of meaningful learning.

However, SRW practitioners thus far have not paid enough attention to the development of a theoretical foundation to support their strategies; they remain highly dependent on empirical experience and tacit knowledge. The little attention paid to the creation of a conceptual framework represents a critical barrier for reflection, discussion and, with them, the maturation of the SRW community.

This work links a characterization of the SRW, built upon empirical experiences, to a variety of learning theories to identify an essential basis for discussion on the subject. Our objective is to complement the rich empirical tradition of the SRW with analytic elements intended to encourage discussion and promote—as tends to happen in activities with the public—virtuous cycles of theory and practice.

Keywords

Science recreation workshops, public communication of science and technology, informal science education, experience-based science activities

1. Introduction

Science recreation workshops (SRWs) are collective activities in which participants build science-related experiences based on three levels of interaction:

Corresponding author:
Miguel García-Guerrero, Science Museum, Autonomous University of Zacatecas, Jardin Juarez 147 Col. Centro, Zacatecas 98000, México.
Email: miguel@grupoquark.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

physical, intellectual and emotional (García-Guerrero and Lewenstein, 2020). The public becomes a protagonist in a dynamic that shows science as both a process (method) and a result (accumulation of knowledge), which relates to the ideas of Dewey (1910) and Merton (1973). One of the main features of this approach is the possibility to adjust, in real time, to the participants' needs and interests while allowing them to explore, discover and reach conclusions on their own—without having to trust the authority of experts (García-Guerrero, 2008).

SRW practitioners often ask why they do not receive more support for their endeavours. It is a valid question, but a better one would be: What have SRW practitioners done to deserve more support? They are convinced that their activities are interesting, amazing and even laudable, but we have to ask whether the quality of reflection and formal discussion of their job is on par with their practice.

SRWs, as a means for the public communication of science and technology (PCST), emerged in the late 1970s and early 80s as a result of initiatives by science enthusiasts who wanted to engage in outreach activities using scarce resources. Unlike other means of PCST (such as magazines and museums), which started with amateur initiatives but evolved into well-established institutions, SRWs are mostly developed by informal organizations. Most work is performed by volunteer groups (integrated by students), although several museums, schools and research centres incorporate them as a complement to their main activities.

In the past, this perceived lack of formality in the work of SRW groups—compared with other institutions—resulted in some degree of misinformed contempt from parents of volunteers who wanted their offspring to spend time in something 'more productive', teachers demanding that their students stop wasting time in SRWs and concentrate in class, schools not being open to letting groups develop activities with their students, and funding agencies not willing to provide support for SRW projects. Even if the past decade has brought a new sense of value for this kind of activity, the work done to support and legitimize SRW organizations remains inadequate.

Even if groups interact on an informal basis to share experiences and discuss their practice, that discussion has resulted in a scarcity of explicit materials that serve both as a reference for practice and as a framework for discussion. The community of SRW practitioners lacks what Wenger (1999) calls *complementarity* between participation and reification, which is effective feedback between practice and reflection. Practitioners need to engage in discussion to build coordinated meanings that reflect their enterprise—reifications of their work, or paradigms, in the language of Kuhn (1971)—and then promote more participation to interpret, produce and use that reification.

In this article, we provide a review of science communication and learning approaches that are useful to establish a foundation for the analysis of SRWs. Our discussion starts with informal environments for science learning as the broad category to which SRWs belong. We then use contributions that address them from an empirical perspective to recognize the essential features of the SRW. Once we have that initial structure in hand, our focus turns towards learning theories that can provide a conceptual basis for making sense of the way these activities work. Our goal is to build a framework that serves as an initial basis for the analysis and discussion of SRWs.

2. Informal environments for science learning

SRWs are situated at an interesting intersection: They develop informal science education (ISE) activities and are a means of PCST. This is not an uncommon circumstance. Ellenbogen (2013) claimed that there is an important affinity between the two fields. Even if several PCST practitioners reject the idea of learning as one of their goals, it is indisputable that the public learns in the process, and a number of practitioners do pursue the objective of learning (Lewenstein, 2011). Hence, following Bell et al. (2009), we use the term 'informal environments for science learning' (IESLs) to designate the convergence of the two concepts.

IESLs incorporate all activities independent of the school curriculum (Hofstein and Rosenfeld, 1996), which means that they account for most of what people learn about science in their lives (Falk et al.,

2012; Falk and Dierking, 2000). They involve participants of all ages and cultural and socioeconomic backgrounds and are typically characterized as participant-motivated, guided by their interests, voluntary, emotionally satisfying, personally rewarding, ongoing, contextually relevant, collaborative, nonlinear and open-ended (Bell et al., 2009; Bonnette et al., 2019; Falk and Dierking, 2000).

A review of the literature on IESLs (Bell et al., 2009; McCallie et al., 2009; Fenichel and Schweingruber, 2010; Lewenstein, 2013; Kim and Dopico, 2016) reveals references to a wide variety of activities—mentorship, scientific texts, expert talks and lectures, science cafes, museum exhibits, zoo and aquarium visits, educational videos, science clubs, citizen science programmes—but there is no specific mention of anything resembling SRWs. However, the literature still refers to several features that fit SRWs well, such as increasing participant interest, involvement and knowledge, as well as promoting inquiry, enjoyment and a sense of science learning being personally relevant and rewarding (McCallie et al., 2009; Fenichel and Schweingruber, 2010).

In addition to these goals, shared by all IESLs, we can add a process-driven objective:

> For my own part, I have a stock formulation: I deeply believe that the world would be a better place if more people had access to the kind of reliable knowledge about the natural world that people we call 'scientists' produce. I would like to contribute to improving that access. My own research, and that of many of my colleagues in the general area of science and technology studies, suggests that improvement will come when 'we' stop focusing exclusively on delivering information about particular scientific findings, and instead help more people understand the complex social process through which information and observations becomes 'reliable knowledge'. (Lewenstein, 2011)

This puts even more emphasis on the practice–experience relation inherent in SRWs to address the nature of science: the values and beliefs necessary for the development of scientific knowledge, or science as a way of knowing (Quigley et al., 2011). To achieve the aforementioned goals, for IESLs (in general) or SRWs (in particular), it is important to understand that there is no generic formula that is effective for all kinds of participants. Moreover, there is no such thing as the general public; in reality, 'the public' is a very heterogeneous group, as multifaceted and unpredictable as the individuals who compose it (Burns et al., 2003).

If we define communication as 'the practice of producing and negotiating meanings, a practice which always takes place under specific social, cultural and political conditions' (Schirato and Yell, 2000: 1), we have to consider that the same practice may have a different meaning for each person depending on their context. In practice, engagement may have patterns, but it is in the interaction of such patterns and participants that the experience of meaning arises (Wenger, 1999). To work as a community, and not just as a collection of isolated individuals, negotiation is important. That does not mean that arriving at an agreement is obligatory, but participants have to try to understand one another.

This is why IESLs are highly dependent on context and require the ability to adjust depending on the participants' situation. It also shows the source of critiques for events or programmes that fit into what is called the 'deficit model' of science communication: initiatives directed at filling 'holes' in the public's scientific knowledge in the hope that it receives the message in the same way that the message was sent/intended (Durant, 1999; Lewenstein, 2003; Bubela et al., 2009; Stocklmayer and Rennie, 2017). This makes the implicit assumption that access to the same information is identical to drawing the same meaning and opinion from it, regardless of the subject.

On the opposite end of the spectrum, the 'public engagement model' builds on an essential fact: different audiences, with diverse backgrounds and experiences, derive different meanings from the same process (Stocklmayer and Rennie, 2017). It also recognizes the need for a diversity of voices, other than science experts, for successful communication processes. This results in a multidirectional dialogue with mutual learning, which allows people with varied backgrounds and scientific expertise to articulate and contribute their perspectives, ideas, knowledge and values in response to scientific questions or science-related controversies (McCallie et al., 2009).

However, as Einsiedel (2008) and Lewenstein (2011) have shown, there is no need to understand

things as such a 'black or white' dichotomy—one of either deficit or dialogue. There are situations, such as public health campaigns, in which deficit-like strategies work best, and other cases, when looking to solve local problems, that require public engagement. In most cases, a mixture of the two models is used within a continuum of participation. Even for participant-centred activities like the SRW, we have to bear in mind that some processes demand that the mediator provide information directly, even if we aim for the activities to be as engaging as possible for participants. With reference to this kind of process, we move on from the broad perspective of IESLs to a specific outline of the SRW in the next section.

3. Characterization of the SRW

The concept of the SRW emerged from the convergence of educational workshops and science recreation activities. For this purpose, workshops are considered places where several people work cooperatively to create something, or solve a task, while learning together in a practice-driven approach that requires observation, assimilation and emulation (Maya, 1996; Guile and Young, 1998; Falk and Dierking, 2000; Gajić and Milutinović, 2011). Science recreation has a dual meaning: enjoying the process of engaging with science while building new science-related experiences and knowledge; that is, recreating them (García-Molina, 2011; Lewenstein, 2013).

The SRW responds to Dewey's (1910; 1986) call for a science education approach centred on active participant experience, linking the exploring and handling of materials to emotional excitement and mental activity (Gajić and Milutinović, 2011). This provides the added virtue of understanding science as both a process and a product, relating to the ideas of Merton (1973). This emphasizes something that is not usually highlighted in other forms of IESL: learning about scientific procedures and methods (Caamaño, 2003) by stimulating participants to explore, perform experiments and discuss their previous ideas in the light of their findings to provide meaning to the scientific issues at hand (García-Guerrero, 2008; Cabral and Rivera, 2010; García-Guerrero, 2014).

All the above features help break with traditional learning processes that focus on teachers or expositors and relegate learners to a secondary role (Freire, 1972; Dewey, 1986). Participants become protagonists in a process of inquiry (Gabrielson, 2015) in which they play the role of scientists. SRWs are a relevant case of facilitative learning activities, with a mediator who establishes an atmosphere in which participants feel comfortable to explore and test new ideas (Falk and Dierking, 2000; Sahin, 2013). The role of the mediator in the workshops is to encourage members of the group to share knowledge, commit to their enjoyment of the process, and help promote learning by others in the group (Robinson, 2019).

The SRW builds on the importance of creating appealing settings for participants to engage with science through three levels of interaction: physical, intellectual and emotional (Hofstein and Rosenfeld, 1996; Fenichel and Schweingruber, 2010; CSOSSL, 2015). Experiences in the SRW combine sensory, cognitive and social stimuli that enable a meaning-making process, assigning personal significance to the activity and the scientific elements associated with it (Bell et al., 2009). The key is to involve participants in a purposeful activity—a combination of acting and knowing, manipulating and thinking—that involves other people, leading to the creation of an inquiry community (Wenger, 1999; García-Guerrero, 2008; Moura et al., 2011; Pandya and Dibner, 2018).

One of the most powerful features of SRWs is that practitioners have the opportunity to adjust in real time to participants' conditions, needs and interests (García-Guerrero, 2014), thus making the activities more appealing. This factor is critical, as established by Bonnette et al. (2019), in fostering participants' interest to re-engage with science over time, which leads to repeated and deepening participation.

Despite several decades of work with the public and the development of successful methodologies, most SRW groups have not been able to turn their rich experience into meaningful conceptual tools. Such elements are essential for different situations: reflecting on their strategies and evaluating their performance, easing the creation and development of new groups, as well as achieving the reification of SRW practice into paradigms that can serve as the foundation for the community of SRW groups. To

establish an effective link between the reality of SRW activities and learning theories that can support their strategies, and build a deeper comprehension of how they operate, we address the essential stages in the development of SRW activities with the public. We support empirical references with the relevant elements of PCST and ISE, which, in turn, provide essential connections with the subsequent review of pedagogical elements.

3.1 Developing the SRW

For an activity to achieve the characteristics we have established for the SRW, with participants engaging with science as protagonists of a practice–reflection process, it cannot have a rigid structure, especially considering the wide variety of contexts and participants that we have to account for. Moreover, each practitioner should be able to put a personal touch on their workshops to enable better development, and try to enable participants to enjoy the process as much as possible.

Some general key points need to be considered for the SRW dynamic because the success of these activities is highly dependent on the structure and quality of the scheme (Gajić and Milutinović, 2011). In this section, we address the essential stages of the SRW with a combination of empirical experience (García-Guerrero, 2008; Gajić and Milutinović, 2011; García-Guerrero, 2014; Bonnette et al., 2019) and the support of a model of five broad personal responses to science that sets the purpose of PCST activities. Burns et al. (2003), in their widely recognized work, grouped these personal responses under the label AEIOU (the vowel analogy): **A**wareness of science; **E**njoyment or other affective responses to science; **I**nterest in science; the forming, reforming or confirming of science-related **O**pinions (or attitudes); and **U**nderstanding of science. With such a foundation, we identify six stages in the development of an SRW activity: introduction, exploration, active experience, questioning–reflection, discussion and conclusion.

a) Introduction. SRWs require trust for successful development. Participants must feel that they can rely on the mediator and can be comfortable with the community as a whole. That is why mediators have to introduce themselves to the community and emphasize that participants use their first name (or a catchy nickname), which helps establish the role of a partner instead of a teacher. It is important, if time allows, to invite participants to introduce themselves to help them establish an identity within the group.

> Thus, when the moderator gives instructions, it is of crucial importance that he/she puts himself/herself in the children's position and is aware of what has to be said, in what way and order, to make the instruction clear. Besides, the language of instruction has to suit children's age as well, so it is a good practice to have a pair of moderators. (Gajić and Milutinović, 2011: 295)

b) Exploration. It is impossible to develop an SRW without a clear idea of the participants' context regarding the topic at hand. We introduce a dual sense of the 'Awareness' in the AEIOU model: informing participants about what they are going to work with and exploring what they know about it. The mediator asks relevant questions to help determine the proper approach for the specific group—where to start, what kind of narratives could be useful, how deep to go, and so on—as well as to find previous knowledge that will lead to meaningful learning.

This diagnosis lets the mediator know whether the group is composed of what Burns et al. (2003) call the 'lay public' (uninformed or uninterested), the 'interested public' (informed on the subject) or the 'attentive public' (specialists). While the 'lay public' outnumbers the other two groups in most cases, it is rare to have a homogeneous group. Identifying informed or specialist participants plays a major role in getting them involved in the process as allies—by sharing their knowledge and experience and serving as experts that help others.

c) Active experience. Once the starting point has been established, it is action time. An effective way to get started is through sensory perception, leading to an intense personal experience influenced by emotions (Gajić and Milutinović, 2011). Usually, this is associated with 'hands-on' activities but can go considerably further to include seeing, hearing, smelling and even tasting things.

A fundamental part of the SRW is that, as long as it is safe for the participants, the action should be performed by them; otherwise, they are mere spectators watching some other person having fun. When handling large groups, it is best to break them into small teams (with enough material) to make interaction easier for everybody. This also helps to establish a competitive environment that encourages stronger engagement.

According to Burns et al. (2003), the essential idea here is to engage participants in an 'Enjoyable' practice; that is, to allow them to have fun while they face new aspects of the phenomenon they are encountering. That is why it is so important for the mediator to avoid performing demonstrations and explanations as much as possible, and instead let the participants explore, discover and sort things out for themselves.

d) Questioning–reflection. From the outset, we have repeated that SRWs promote the interaction between action and reflection, or practice and theory, and that the active experience would be empty without a stimulus to think about. For that, we use triggering questions that connect the experience of participants with the scientific issues we intend to address, and this leads to the 'Interest' part of the AEIOU model.

For Burns et al. (2003), if we manage to inspire people, they will choose to become involved in activities to seek more information. This is very important, as most IESL activities imply voluntary participation (they are not mandatory, as with school). This is why it is important to find the proper questions that can help us dispose people to engage with the workshop dynamic (Bonnette et al., 2019). Such interest will lead to a process of reflection in which participants make sense of their experience and prepare to share their ideas. It is worth noting that this part of the process is fluid: It can develop at any moment but reaches its highest point after the sensory interaction has led to pleasant and meaningful experiences.

e) Discussion. As a result of the previous step, the stage is set for participants to share and explain their perspectives on the phenomenon at hand. At first, the goal is for people to predict what will happen and explain their reasoning, analyse and discuss the ideas of their partners and try to negotiate meanings between them. Afterwards, they can make suggestions that lead to adjustments to the activity in creative ways, explain what happened and relate their experience to what is considered reliable knowledge of nature (Lewenstein, 2011). This is an important part of the process because the exchange among peers helps articulate, shape and enrich their experiences (Gajić and Milutinović, 2011). If the discussion does not flow, which happens often, the mediator must turn to trigger questions or provocative examples; and, if the group has a hard time achieving reliable knowledge, the mediator will have to help with that as well.

This step involves the 'Opinion' component of the AEIOU model. During discussions, participants share more than explanations, especially when addressing social issues or personal experiences related to science: They present their opinions. It is necessary to find the right balance between the participants' discussion of their respective perspectives and respecting somebody else's opinion. Sometimes, people (such as specialists and even mediators) try to impose their opinion on others—a line that should not be crossed.

f) Conclusion. Once the above stages have been completed, the community tries to reach some conclusions about the subject and discusses practical uses of what it has just worked with. This implies reaching the 'Understanding' component of the AEIOU model. The goal here is to connect the scientific issues at hand to the participants' reality, helping them link their SRW experience (and the implicit knowledge) with their previous ideas to promote meaningful learning (Ausubel, 1968).

It is useful to let participants recapitulate what they have just experienced and learned by using narratives that serve to reaffirm knowledge (Cohen and Haden, 2015). Finally, the community should air some final questions and, instead of drowning them with direct answers, rephrase them to stimulate participants to find answers on their own. The idea is to send people with more doubts than certainties and let them know that this is what science is all about: the next question.

With the conclusion of the workshop, if it is successful, we might have planted a seed of curiosity in the participants to find out about more things: a need to know or desire to resolve any remaining uncertainties, which works as a basic human motive. To satisfy that curiosity, the participants might feel the need to

transition from early exposure to science to a sustained and well-developed interest (Bonnette et al., 2019). This provides the opportunity for more ambitious programmes involving SRWs.

3.2 Taking a further step

The main goals of ISE and PCST are to create interest in science through excitement, wonder and surprise, as well as for participants to develop knowledge and values that make their experiences relevant and meaningful (Fenichel and Schweingruber, 2010). All of this is associated with the concept of fascination, as described by Bonnette et al. (2019): a motivational construct that integrates interest, curiosity and mastery as goals. Fascination helps us capture an emotional and cognitive attachment/obsession with topics and tasks in science. Hence, successful SRW events have the potential to get participants more involved in science-related events. There is a need for follow-up programmes to avoid leaving participants on their own after positive initial experiences (García-Guerrero et al., 2019). As is the case with other ISE activities (Durant et al., 2016), SRWs provide an opportunity to connect interested participants with established learning communities or programmes, provided such spaces exist in a specific area.

Interestingly, SRWs can also provide the foundation for this kind of periodic approach that take things a step further: fostering closer relationships between science and the participants' interests. Regular science programmes provide permanent free-choice learning opportunities for people (García-Guerrero et al., 2019). This involves participants taking up science as a hobby, learning about it, having a bigger choice in what and how they learn, and developing projects on their own (Lewenstein, 2013; Liu and Falk, 2014).

These kinds of programmes, or clubs, provide opportunities for participants to pursue deeper goals, to 'seek more opportunities related to science, become aware of gaps in their knowledge, persist through closing challenging gaps, and gain pleasure from building competence, knowledge, and skills in science' (Bonnette et al., 2019). There is evidence linking participation in periodic extracurricular programmes to positive attitudes towards science, improved science learning and a greater sense of appreciation for scientific endeavours (Hartley, 2014). Although it is important to promote such endeavours, they have been addressed in detail elsewhere (Sahin, 2013; Vartianen and Aksela, 2013; Hartley, 2014; García-Guerrero et al., 2019). We must turn our attention to the learning theories that can provide a foundation for the discussion of SRWs.

4. Literature review of learning theories (learning arsenal)

In the original conception, workshops are spaces where artisans manufacture or repair specific goods. To achieve their purposes, those people require a certain skill at their craft, which can only be attained with practice but also requires a deep understanding of what they do. Here, we find the traditional model of apprenticeship, developed long before modern learning theories, implicit in workshops. It involves four elements: the apprentice as a learner, a fixed set of craft knowledge, the master as teacher, and the idea that the desired expertise is context bound and not conductive to transfer (Pratt, 1992; Guile and Young, 1998; Harrison and Grant, 2015).

Although the essence of the SRW breaks with the idea of a traditional teacher, and we have to recognize that scientific knowledge is not fixed, SRWs show classic elements of workshops, such as practice-led and context-bound learning. It is also noteworthy that SRWs have been developed independently of learning theories: They did not come to life as a result of pedagogic reflections. Nevertheless, SRW strategies seem to apply the ideas of several learning theories that can help us better understand how to promote experience-building processes around science and provide resources to face different challenges. As an analogy, García-Guerrero (2014) claimed that pedagogic theories could be viewed as some sort of 'Batman's belt': Just like the utility belt that the fictional hero wears, they provide diverse tools that will never be used together in the same activity, but, at the same time, there is no single tool that (itself) will help face all possible situations. Hence, these theories give us resources to develop the SRW in a wide variety of contexts.

Rather than thinking of the possibility of a 'best way' to learn, we need to be aware of the great diversity in how people think and learn (Harel and Papert, 1991). To maximize participation, it is best to have the ability to adapt to the different ways of learning that we can find. With this in mind, we performed a literature review to look for pedagogic elements that can help build a foundation for SRW practice. In this section, we present the relevant elements of various approaches that contribute to our goal: behaviourism, cognitive development, social components, constructivism and constructionism, and discussion. We close with a broad scope of the 'communities of practice' theory that will help us shed a different light on the analysis of SRWs.

4.1 Behaviourism

Behaviourism, as a learning perspective, has taken as much criticism as the deficit model in PCST. It is easy to find descriptions of behaviourist practice that sound a lot like deficit theory: the educator as the indisputable agent whose task is to 'fill' learners with the contents of their narrations, which are just pieces of reality, disconnected from the totality that breeds them and the context in which they acquire sense (Freire, 1972).

Behaviourism takes learning as a process of forming connections between stimuli and responses (Bransford et al., 2000). Hence, the main concern is how an association between stimuli and responses is made, reinforced and maintained (Ertmer and Newby, 1993). In this perspective, there is someone (the teacher) who presents information in its final form for participants to memorize and be able to recite in the future (Ausubel, 1968; Freire, 1972).

This perspective prevailed in schools for a long time, with an imposition—from above and outside—of subject matter, methods of learning and behaving on learners (Dewey, 1986). However, we have to acknowledge that some things are almost impossible to learn without it. Such is the case with multiplication tables, the symbols for chemical elements and the names of subatomic particles. However, for the most part, it is important to discard the conception of learners as empty vessels that must be filled by transmitting information to them (Rodriguez, 2012); there is a need to understand the importance of logic and reasoning in learning. We thus turn to cognitive development.

4.2 Cognitive development

Jean Piaget was the pioneer of the cognitive analysis of learning, based on the inner structures of the minds of the learners, especially children. For Piaget (1967), mental development starts at birth and is comparable to organic growth—a march towards the final equilibrium of the adult spirit. Through the process of cognitive development, individuals go through stages that define the kinds of tasks a person can perform and solve (Piaget, 1964).

In this context, logic and reasoning are not innate attributes of human beings but features that must be created and fostered (SECT, 2001). Cognitive growth is not a given process, but depends on the stimulus the individual is subjected to. Every new experience triggers changes in the mental structures, adapting them to reality (Piaget, 1964; 1967).

With Piaget's framework, a new possibility emerged: to discard the idea of learning as knowledge transmission and to work towards guiding children in acquiring their own knowledge through action and through trial and error as they attempt to assimilate new information into their existing understanding of the world (SECT, 2001). This shows an intrinsic relation between new experiences and practices and the mental structures of each individual. As Ausubel (1968: 18) puts it: 'If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.'

According to Ausubel's meaningful learning approach, people cannot learn something alien to their existing ideas and experiences. To achieve true understanding, the new information must have meaning for learners—it must link with their existing knowledge (Ausubel, 1968; Pozo and Gómez, 1998). It is important to start from the learners' internal logic, considering their prior experiences and beliefs, to engage them in the learning process and get them to understand some of the meanings in scientific knowledge (Pozo and Gómez, 1998; CSOSSL, 2015).

We also have to account for the fact that not all existing knowledge is complete or scientifically sound. Educators have to pay attention to the incomplete understanding, false beliefs and naive renditions of concepts that learners bring with them in order to bridge the differences and try to achieve a more mature understanding (Bransford et al., 2000; Pandya and Dibner, 2018). Otherwise, the outcomes will be very different from what was intended.

From our discussion so far, it might appear that learning is an essentially individual process, but that is not the case. There is another important component—the influence of interaction with other people—which leads us to address the social side of learning.

4.3 Social components

The mind of the individual is not, as such, an individual mind. People participate in learning processes with a prior system of beliefs, knowledge, ideas, experiences and meanings that has been socially instituted (Dewey, 1958; Falk et al., 2012; Wehrmann and Henze-Rietveld, 2016) and affects their abilities to remember, reason, solve problems and acquire new knowledge (Bransford et al., 2000). Even when people learn 'alone', reading from a book or having an independent experience, the meanings they construct are heavily context dependent. Most of the time, in either formal or informal settings, individuals get to understand something new while interacting with others. Therefore, learning is widely accepted as a fundamentally social process in which individuals learn from the collective, and the collective learns from individuals (Dalkir, 2005). Jerome Bruner stressed the importance of action and discovery in the process of learning, treating every cognition as a form of (social) construction (Gajić and Milutinović, 2011).

In contrast to Piaget's individualistic approach, Lev Vygotsky worked on the social nature of learning. For him, any process of verbal interaction (talking) with others represents a stimulus for cognitive development (García-Guerrero, 2014). This situates talk as a powerful social tool to build communities and help minds grow, as learners benefit from opportunities to reflect and share their ideas as part of the process of internalizing them (Resnick et al., 2010; King and Tran, 2017). The use of talk, reasoning and questioning relates to the concept of non-foundational knowledge that shifts responsibility away from the teacher as an expert and towards the participants as learners (Braund and Lelliot, 2017).

Perhaps the most important contribution Vygotsky made to our understanding of learning is the concept of the proximal development zone: the distance between the actual development of an individual, determined by their capacity for independent problem solving, and the level of potential development, determined through problem-solving under adult guidance or in collaboration with more capable peers (Vygotsky, 1980). This collaborative process helps learners perform certain tasks and serves as a means of developing new experiences, knowledge and abilities, which, when sustained, set off a virtuous cycle of cognitive development.

The goal of helping learners has given importance to the notion of 'scaffolding', in which a teacher or mediator provides temporary support that can be gradually removed as the learner grows (Guile and Young, 1998; Braund and Lelliot, 2017). While not explicitly calling it a scaffolding, for the specific case of science learning, Fenichel and Schweingruber (2010) proposed juxtaposing the participants' understanding of a natural phenomenon with the formal disciplinary ideas that explain it, to help learners revise their ideas and see whether it is possible to approach current scientific understanding. However, we have to be careful. It is valid to seek to render the participants' perspectives on a phenomenon coherent with reality, but we cannot impose our vision on them (Freire, 1972) or we risk turning them away. Mediators should attempt a dialogue to find common ground between different participants' perspectives while using empirical results to validate their hypotheses. In addition to providing a comfortable learning environment, this will help show how science works in creating and validating theories that can explain natural phenomena.

4.4 Constructivism and constructionism

As stated above, participants get involved in learning experiences with specific sets of knowledge and experiences that shape their ideas, interests and motivations (Pandya and Dibner, 2018). This is the

reason why an event, such as an SRW, might have different meanings for each of the individuals involved. Even in deficit-like science communication processes, each person has a different interpretation of what was said because they internally build meaning according to their conditions.

Constructivism, in pedagogy, assumes that all knowledge is built upon a person's prior ideas (Bransford et al., 2000; King and Tran, 2017) and seeks a balance between the influence of the social environment and internal cognitive features. From this perspective, knowledge is neither a copy nor a reflection of reality but is actively constructed by learners using physical and social interactions in an attempt to understand the world (Dalkir, 2005; Minner et al., 2010; García-Guerrero, 2014; Pandya and Dibner, 2018). The constructivist approach has an important imprint of the work of Dewey (1910; 1958; 1986) in highlighting the importance of play, experience and practice in the learning process (Halverson and Sheridan, 2014). It is possible to see this reflected in IESL activities that use inquiry-based and hands-on strategies to help participants with active thinking to build their own knowledge (Minner et al., 2010; Voussoghi and Bevan, 2013).

Taking a step forward, constructionism shares the aforementioned principles and proposes that the individual construction of knowledge goes deeper when the learner is consciously engaged in constructing a public entity or externalized product (Harel and Papert, 1991; Pandya and Dibner, 2018). In addition to Dewey's contributions, contemporary research in neuroscience confirms the importance of tactical engagement and using our hands in the learning process (Dougherty, 2012; Pandya and Dibner, 2018). This has become a staple for several IESL movements, such as hands-on exhibits in museums, tinkering workshops (Gabrielson, 2015), the 'maker movement' (Dougherty, 2012), and, of course, the SRW. This approach allows the public to take matters into its own hands for a much higher degree of control over its knowledge, instead of being a passive recipient (Papavlasopoulou et al., 2017). Finally, participants make something shareable (Halverson and Sheridan, 2014; Gabrielson, 2015) in two senses: to let others handle the object, as well as to use it to discuss and debate topics in science, or even inspire others to participate.

4.5 Discussion

Most theories we have addressed, especially constructivism and constructionism, place a high value on practice as a motor for learning. Usually, it is easier to get participants involved in the physical part of practice (experimenting, tinkering and making) compared with the intellectual and emotional components (to complete the three levels of interaction). For this, as we saw in Vygotsky's idea and other ideas on social learning, we have to appeal to oral communication: discussion.

Talk, as a direct exchange between humans who attribute intentionality and understanding to each other, is an essential tool for building communities (Resnick et al., 2010). SRW mediators have to be able to prompt talk in all kinds of contexts, for which they can utilize a variety of techniques useful to get participants involved:

1. Ask questions that link participants' contexts to the issue at hand, to help them realize that they have valuable contributions to make to the community.
2. Repeat and rephrase learners' contributions and emphasize particular comments (King and Tran, 2017) to help everybody get into the same line and encourage others to talk.
3. Even when answers have no apparent relation to the discussion, try to understand the logic behind the participant's idea or a 'spin' that can get it along the conversation line. If participants feel that they have been shown as being wrong, it will be difficult to get them to talk again.
4. Let participants lead the route of discussion. The more they feel they have a choice in the process, the more they will get involved in it (Falk and Dierking, 2000).

In discussion within SRWs, we attach great importance to the idea of accountability in talk for the full development of learners' abilities and dispositions for reasoned civic participation (Resnick et al., 2010). There are three essential aspects of accountable talk.

a) Accountability to the learning community. The mediator should make sure that the participants

listen to each other, ask each other questions and try to build arguments based on each other's ideas.

b) Accountability to standards of reasoning. This involves participants making logical connections and drawing reasonable conclusions in arguments, and implies explanation, analysis and self-correction.

c) Accountability to knowledge. Perhaps the trickiest of the three, this involves ensuring that talk responds to proven facts and reliable sources. The importance of this aspect goes well beyond the SRW to lifelong learning, especially in an era when people need to identify what kinds of sources to trust.

4.6 Communities of practice

We have thus far addressed general aspects deriving from learning theories and have started identifying important relations among cognition, context and practice. As Guile and Young (1998) note, the process of learning involves changes in knowledge and action that are central to learning and developing new forms of practice. This leads us naturally to understand the SRW as a collective, practice-centred IESL, but one that lacks a fundamental theoretical foundation.

After establishing a general learning landscape, we can introduce an approach that fits the SRW almost perfectly: communities of practice (CoPs). Lave and Wenger (1991) started using the concept, in an intuitive form, in their studies on the learning processes of practitioners of different crafts—midwives, tailors, sailors, butchers, and even recovering alcoholics. Their conclusions led to a broader learning theory that contemplates all settings, even academic ones, where novices, or apprentices, need to get involved in the community's social practices to develop a full domain of knowledge and skills (expertise).

Wenger (1999) used four premises to present the above approach: we are social beings, knowledge is a matter of competence (expertise) concerning valued enterprises, knowing is a matter of active engagement in the world, and meaning (our ability to experience the world and our engagement with it) is the ultimate product of learning. This shows a focus on learning as social participation, not just in the sense of local events but with the wider meaning of being active participants in the practice of social communities and constructing identities in those communities.

Wenger's work uses the concept of identity to provide a major insight into integrating individualistic and collective learning in the CoP framework (and in the practice of SRWs). Building identity consists of negotiating the meanings of our experience while participating in social communities, serving as a link between the social and the individual, in which each can be talked about in terms of the other (Wenger, 1999). This avoids what he calls the 'simplistic individual–social dichotomy' without having to negate such a distinction. In this way, our perspective incorporates both the lived experience of the individual and the cultural–historical aspects of the social. By bringing together our experience and its social interpretation, we construct who we are in our negotiation of meaning (Wenger, 1999). This leads to the development of practice-linked (or domain-specific) identities and a sense of belonging, which happens in science clubs (as CoPs) that shape commitments to science learning (CSOSSL, 2015).

This is a major insight because SRWs perform collective processes in which we want to allow all participants to be protagonists, which seems like a contradiction. The concept of identity, and the construction of such an identity through practice in the SRW, gives a theoretical basis for the idea of collective protagonism in the community. Each participant plays a different and important role that makes him or her relevant within the group.

According to Wenger (2011), CoPs are formed by people who share a passion for something they do and regularly engage in a process of collective learning about it. They have three crucial characteristics, which we illustrate using the case of the SRW.

a) Domain. A CoP has an identity that arises from a common interest (the domain), being a member implies a commitment to developing a certain distinctive competence. The implicit stance here is that participants will share knowledge through their activities, discuss it and negotiate meanings to achieve the intended competence. The domain of the SRW is science, not only referring to knowledge but also to its history, practice, values, and even unresolved issues.

b) Community. Members' collaboration (or mutual engagement) is key to the successful pursuit of their interests: They discuss, help one another and share information. This is the essential social dimension of CoPs and calls for the use of social learning as well as the constructivist and constructionist ideas addressed earlier. In an SRW, the participants' input is more than welcomed: It is needed, and members encourage each other as they advance. That is how newcomers learn and become experts: by engaging with other members, being active in community events and taking on increasing responsibilities within their communities (Liu and Falk, 2014).

c) Practice. Sharing an interest is not enough for a CoP to exist; participants have to actually do something and socially interact while doing it. Herein lies a rupture with traditional dichotomies, which divide acting from knowing, manual from mental, and concrete from abstract, because engaging in practice always involves the whole person, acting and knowing at once (Wenger, 1999). To accomplish this, members of a community have a shared repertoire of resources: experiences, stories, materials, tools and ways to solve problems. The very essence of the SRW comes from participants playing with materials, doing experiments and solving problems in interactive processes of action and reflection.

Finally, we need to discuss reification: the process of 'making into a thing'. Wenger (1999) refers to this concept as giving form to our experience by producing objects (or concepts) that shape it into something concrete. In this sense, reification is central to every practice: Any CoP creates abstractions, tools, symbols, stories, terms and concepts that can reify something of that practice in a congealed form. Reification, then, invites the participation of community members as they use, discuss and refute the meaning and worth of those reifications (Nolen and Ward, 2008).

In this article, we have worked towards the reification of the SRW, by using empirical experiences and ideas deriving from the community's debates, to build a framework for further discussion and development of practice. However, debates stemming only from empirical notions, which have been around since the late 1990s (García-Guerrero, 2010; García-Guerrero and Lewenstein, 2020), are not enough to consolidate a professional community for this specialty of IESL. That is why we have had to review learning theories (due to their link to practice) and find an approach to serve as the bedrock for discussion on SRWs. CoP theory provides the theoretical support that we have been looking for.

5. Science recreation workshops as communities of practice

Practice as a means of experience is the very reason for the existence of the SRW, and the set of resources to carry out SRW activities includes interaction, questioning, inquiry, narratives and problem solving. SRWs are closely linked with the characteristics of CoPs presented by Wenger (1999): They are essentially communities looking to build pleasant experiences through active practice while constructing knowledge about a specific scientific domain. However, the degree to which SRWs adopt a full CoP identity depends on their temporal duration and degree of participation, allowing us to distinguish among four situations: single events, periodical programmes, SRW groups and SRW analysis.

Before addressing the above situations in detail, we must emphasize that they are dynamic: People can move from one to another. Practitioners usually encourage participants from single events to join periodical programmes, and expert members of periodical programmes can rise to become apprentices in the SRW community. Finally, SRW groups have recently started encouraging their practitioners to be part of the professional discussion, whether in face-to-face events or web-based forums. This route to identity, with the possibility of achieving different levels of expertise to access the CoP in different situations, provides a set of possibilities to which novices are exposed as they build their own trajectories (Wenger, 1999).

a) Single events (isolated practice). This is the most basic form of engaging the public. It happens when SRW groups have a single-day event with first-time participants. In their initial experience with this kind of activity, the participants make up a small community mostly of novices, but with at least one expert (the mediator). It might be a bit shallow, as

most first-time science activities are, but it has the potential to be interesting and to arouse enthusiasm among the people involved (García and Meza, 2007; García-Molina, 2011; Cabral and Rivera, 2010).

The people involved constitute a miniature version of a CoP by interacting with materials, collaborating in different ways, negotiating meanings with each other and sharing information. While it has most of the features attributed to a CoP (Lave and Wenger, 1991; Wenger, 1999), it lacks the necessary regularity to allow for the development of certain expertise in the domain of science recreation. Thus, this can be seen only as a quasi-CoP.

Even if a single event does not achieve all the benefits of regularly engaging in practice, it presents the opportunity for initial learning experiences that have proven essential for supporting children's interest in and motivation for science (Bonnette et al., 2019), and it becomes even more important because it is the gateway to the following situations.

b) Periodical programmes (basic practice). Isolated experiences provide essential sparks of interest but cannot 'keep the flame lit'. To foster a closer relation to science, they need subsequent follow-ups to flourish (García-Guerrero et al., 2019). To achieve deeper connections, there is a need for participants to replicate what they have done, reflect on it and discuss it with their peers (Robinson, 2019). There is a need for systematic activities—for people to go back regularly and grow their interests, knowledge and abilities.

Periodic participation in free-choice science programmes, such as science clubs, astronomy programmes, tinkering workshops and maker spaces, allows new members to enter the CoP as novices and gives them the opportunity for regular participation and engagement with other members of the community. Through practice, they can work their way to basic expertise in different aspects related to the domain of science recreation: handling materials, developing inquiry processes, understanding essential scientific principles, building devices, as well as clearly communicating ideas and results to others. This case is what we addressed as 'taking a step further' with the SRW to fully achieve the conditions to be considered a CoP.

c) SRW groups (committed practice). This is the case of the community within SRW groups, and it has the peculiarity of working towards making the first two situations possible. Its domain is the creation and development of SRW models and translating them into action in single events and periodical programmes. It means having a CoP that enables members to develop the abilities, knowledge and experience to create more CoPs, which demands that members work on two domains of expertise: on scientific knowledge and as SRW mediators. SRW practitioners have to achieve a minimum degree of knowledge on the topics they will address with the public. However, being adept at something is not just about knowing facts but about organizing knowledge into coherent frameworks and recognizing the relevance and potential application of knowledge in varying contexts (Pandya and Dibner, 2018). This kind of structured understanding allows for greater flexibility in learning and facilitates application across multiple contexts (Fenichel and Schweingruber, 2010). Only with a deep understanding will it be possible to relate to the broad spectrum of situations that different learners will pose.

Serving as a mediator in SRWs demands a basic knowledge of the fundamentals of the relevant activities (which we have addressed above) and a set of practical skills to develop them properly. Thus, people interested in becoming practitioners become apprentices in a workshop devoted to the development of SRWs and in a process in which they also contribute to the growth of their peers and the group as a whole. This is how the goal of developing SRWs contributes to a rich CoP—one that often feeds off former participants in isolated events and periodical programmes (Cabral and Rivera, 2010; García-Guerrero et al., 2019) to create new generations of practitioners.

Once people enter this kind of CoP, they participate in a safe environment of collaboration and cooperative learning. They are empowered to build knowledge, contributing their strengths to the group (and benefiting from those of others) while helping plan for how to better develop and explain specific activities (Robinson, 2019). Here, we find an excellent route for empirical growth in groups; the problem is that most of them spend too much time and effort to achieve what others have done before them, and very

few take the time to formally share the results of their experiences (García-Guerrero and Lewenstein, 2020). This poses a challenge to build and communicate the fundamentals of SRWs in order to help the advancement of the community of organizations dedicated to these activities.

d) SRW analysis (professional discussion). Mimicking the ideas of Nolen and Ward (2008), we can say that the emerging community of specialists (practitioners and theorists) that discusses the SRW, as an object of study, is a CoP. In general, SRW practitioners already share experiences and argue about methodologies, mediators' training and the design of activities, but for the most part they do it informally and lack explicit documents resulting from such discussions. Some groups in Mexico have taken the initiative to publish books and academic articles to share their contributions and spark discussion (García-Guerrero and Lewenstein, 2020), but that remains an isolated effort. The professionalization of the SRW demands a broader participation in this process: Just as the success of an activity depends on the variety of voices and experiences involved, the analysis of SRWs needs broad participation to build, validate and use relevant ideas for their philosophy, methods, challenges and evaluation.

While the identity component of the CoP plays a fundamental role in all four situations described above, we want to highlight its impact on the creation and evolution of the professional SRW community. In this way, we have a perspective that allows for each group's experience to be considered, as well as the cultural–historical aspects of the whole community. Each group can thus construct a stronger identity by bringing together its specific trajectories and social interpretation in the process of the negotiation of meaning. The groups recognize themselves as SRW professionals as they take part in the larger discussion that links their organizations and defines the paradigms for the community of groups. For example, in Mexico, the National Colloquium of Science Recreation (NCSR) has served as an essential forum to stimulate reflection and discussion on the SRW. The event started in 2016 and led to the creation of 'Recreación en Cadena', the Mexican Network for Recreative Science, which has kept the NCSR going yearly with an average of 40 papers and 100 participants (García-Guerrero and Lewenstein, 2020). Although this case is an important step forward, most presentations rely heavily on empirical knowledge and lack a theoretical foundation. The emergence of the NCSR, and the network behind it, demonstrates an opportunity to strengthen the work of this community of groups through a richer discussion that leads to a proper theoretical foundation for the SRW.

6. Conclusions

Our analysis of theories of learning allows us to highlight the importance of a contextualized approach to science learning. Maybe the most important feature of the SRW, one that sets it apart from most means of PCST and ISE, is its ability to integrate theory and practice. For the most part, this virtue has not been analysed properly, mainly owing to a lack of theoretical tools. The CoP model helps us understand how SRWs build CoPs around science, as a domain, that sets them off into virtuous cycles that allow for future growth, especially when it comes to the route of practice that evolves from isolated, to basic, committed and even professional approaches. There is an interesting path for the development of SRW experts, assuming that SRW groups build their internal communities and external networks just as they build the CoP with the public.

However, the low levels of analytical discussion on SRWs represent a latent contradiction, as García-Guerrero and Lewenstein (2020) have shown in the case of Mexico: Most practitioners and groups have neglected theory to focus almost entirely on practice. Discussions and collaborations are heavily based on empirical experience and tacit knowledge. It is still a challenge for the SRW community to reify its practice into a widely accepted set of concepts, with shared meanings, about what it does, how it does it, and why it does it in a certain way.

This lack of a fundamental shared conceptual framework is a critical barrier for reflection, discussion and, along with them, the maturation of the SRW community. Only by mutually engaging on essential principles for practice can SRW groups establish a much-needed process of reification. By publishing this article, we intend to work towards an initial reification, through reflective practice, that stimulates others to participate with us in further conversation (Nolen and Ward, 2008). We hope that

more practitioners will soon engage in the joint enterprise of discussing SRWs, helping them grow and earning well-deserved support for their activities.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

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

ORCID iD

Miguel García-Guerrero https://orcid.org/0000-0002-0291-3968

References

Ausubel DP (1968) *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.

Bell P, Lewenstein B, Shouse A, et al. (eds) (2009) *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington DC: National Academies Press.

Bonnette RN, Crowley K and Schunn CD (2019) Falling in love and staying in love with science: Ongoing informal science experiences support fascination for all children. *International Journal of Science Education* 41(12): 1626–1643.

Bransford J, Brown A and Cocking R (2000) *How People Learn*. Washington DC: National Academies Press.

Braund M and Lelliott A (2017) Opening up the dialogic space. Using questions to facilitate deeper informal learning. In: Patrick PG (ed) *Preparing Informal Science Educators: Perspectives from Science Communication and Education*. Cham: Springer, pp. 561–574.

Bubela T, Nisbet MC, Borchelt R, et al. (2009) Science communication reconsidered. *Nature Biotechnology* 27(6): 514–518.

Burns TW, O'Connor DJ and Stocklmayer SM (2003) Science communication: A contemporary definition. *Public Understanding of Science* 12(2): 183–202.

Caamaño A (2003) Los trabajos prácticos en ciencias. In: Jiménez Aleixandre MP (ed) *Enseñar Ciencias*. Barcelona: Graó, pp. 95–118.

Cabral RC and Rivera JLM (2010) Enseñanza de las ciencias físicas a estudiantes de primaria y secundaria por medio de sencillos talleres científicos. *Latin-American Journal of Physics Education* 4(2): 23.

Cohen T and Haden C (2015) Learning about learning: The story behind the story. *Hand to Hand* 29(4): 3–4.

CSOSSL (Committee on Successful Out-of-School STEM Learning) (ed) (2015) *Identifying and Supporting Productive STEM Programs in Out-of-School Settings*. Washington DC: National Academies Press, pp. 1–68.

Dalkir K (2005) *Knowledge Management in Theory and Practice*. Amsterdam, Boston: Elsevier/Butterworth Heinemann.

Dewey J (1910) Science as subject-matter and as method. *Science* 31(787): 121–127.

Dewey J (1958) *Experience and Nature*. New York: Courier Corporation.

Dewey J (1986) Experience and education. *The Educational Forum* 50(3): 241–252.

Dougherty D (2012) The maker movement. *Innovations: Technology, Governance*, *Globalization* 7(3): 11–14.

Durant J (1999) Participatory technology assessment and the democratic model of the public understanding of science. *Science and Public Policy* 26(5): 313–319.

Durant J, Buckley N, Comerford D, et al. (2016) Science live: Surveying the landscape of live public science events. Available at: https://www.informalscience.org/science-live-surveying-landscape-live-public-science-events (accessed 12 July 2019).

Einsiedel E (2008) Public participation and dialogue. In: Bucchi M and Trench B (eds) *Handbook of Public Communication of Science and Technology*. London, New York: Routledge, pp. 172–184.

Ellenbogen K (2013) The convergence of informal science education and science communication. *Curator: The Museum Journal* 56(1): 11–14.

Ertmer PA and Newby TJ (1993) Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly* 6(4): 50–72.

Falk JH and Dierking LD (2000) *Learning from Museums*. Walnut Creek, California: AltaMira Press.

Falk JH, Ballantyne R, Packer J, et al. (2012) Travel and learning: A neglected tourism research area. *Annals of Tourism Research* 39(2): 908–927.

Fenichel M and Schweingruber H (2010) *Surrounded by Science: Learning Science in Informal Environments*. Washington DC: National Academies Press.

Freire P (1972) *Pedagogía del Oprimido*. Buenos Aires: Siglo XXI.

Gabrielson C (2015) *Tinkering: Kids Learn by Making Stuff*. San Francisco, CA: Maker Media, Inc.

Gajić O and Milutinović J (2011) Museums as learning centers: Pluralism of theoretical-methodological paradigm. *The New Educational Review* 25(3): 288–300.

García H and Meza L (2007) Los talleres de ciencia en el museo Universum: Análisis de su impacto en el usuario. *XReunión de la Red de Popularización de la Ciencia y la Técnica en América Latina y el Caribe*. San José: Red Pop, pp. 1–10.

García-Guerrero M (2008) *Ciencia en Todos los Rincones: Manual de Divulgación en Talleres*. Zacatecas: Universidad Autónoma de Zacatecas, Coordinación de Investigación y Posgrado.

García-Guerrero M (2010) *Los Talleres de Divulgación Científica Como Agentes Para el Desarrollo de un Cultura Científica (Maestría)*. Bernal: Universidad Nacional de Quilmes.

García-Guerrero M (2014) Caracterización de los talleres de ciencia recreativa. In: Michel B and García M (eds) *La Ciencia en Nuestras Manos*. Zacatecas: Texere, pp. 95–158.

García-Guerrero M and Lewenstein B (2020) Science recreation workshops groups in Mexico: A study on an emergent community. *International Journal of Science Education, Part B* 10(2): 133–148.

García-Guerrero M, Michel-Sandoval B, Esparza-Manrique V, et al. (2019) Keeping the flame lit: The value of the long-term permanence of a science club. *Science Communication* 41(1): 132–143.

García-Molina RG (2011) Ciencia recreativa: Un recurso didáctico para enseñar deleitando. *Revista Eureka Sobre Enseñanza y Divulgación de Las Ciencias* 8(1): 370–392.

Guile D and Young M (1998) Apprenticeship as a conceptual basis for a social theory of learning. *Journal of Vocational Education & Training* 50(2): 173–193.

Halverson ER and Sheridan K (2014) The maker movement in education. *Harvard Educational Review* 84(4): 495–504.

Harel I and Papert S (1991) Constructionism: Research reports and essays, 1985–1990. Available at: https://hal.archives-ouvertes.fr/hal-00692031 (accessed 7 March 2022).

Harrison S and Grant C (2015) Exploring of new models of research pedagogy: Time to let go of master–apprentice style supervision? *Teaching in Higher Education* 20(5): 556–566.

Hartley MS (2014) Science clubs: An underutilised tool for promoting science communication activities in school. In: Tan Wee Hin L and Subramaniam R (eds) *Communicating Science to the Public*. Dordrecht: Springer, pp. 21–31.

Hofstein A and Rosenfeld S (1996) Bridging the gap between formal and informal science learning. *Studies in Science Education* 28(1): 87–112.

Kim M and Dopico E (2016) Science education through informal education. *Cultural Studies of Science Education* 11(2): 439–445.

King H and Tran L (2017) Facilitating deep conceptual learning: The role of reflection and learning communities. In: Patrick PG (ed) *Preparing Informal Science Educators: Perspectives from Science Communication and Education*. Cham: Springer, pp. 67–85.

Kuhn TS (1971) *La Estructura de Las Revoluciones Científicas*. México: Fondo de Cultura Económica.

Lave J and Wenger E (1991) *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.

Lewenstein BV (2003) Models of public communication of science and technology. Available at: https://ecommons.cornell.edu/handle/1813/58743 (accessed 7 March 2022).

Lewenstein BV (2011) Changing our ideas. *International Journal of Science Education, Part B* 1(1): 17–21.

Lewenstein BV (2013) Recreation in the public communication of science and technology. In: Reynoso M and García (eds) *La Recreación Para La Re-Creación Del Conocimiento*. Zacatecas: SOMEDICYT, pp. 89–101.

Liu C-C and Falk JH (2014) Serious fun: Viewing hobbyist activities through a learning lens. *International Journal of Science Education, Part B* 4(4): 343–355.

McCallie E, Bell L, Lohwater T et al. (2009) Many experts, many audiences: Public engagement with science. Available at: https://www.informalscience.org/many-experts-many-audiences-public-engagement-science (accessed 7 March 2022).

Maya A (1996) *El Taller Educativo*. Bogotá: Coop. Editorial Magisterio.

Merton RK (1973) *The Sociology of Science: Theoretical and Empirical Investigations*. Chicago: University of Chicago Press.

Minner DD, Levy AJ and Century J (2010) Inquiry-based science instruction: What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching* 47(4): 474–496.

Moura H, Cardador D, Vega K, et al. (2011) Co-designing collaborative museums using ethnography and co-creation workshops. *VII Simpósio Brasileiro de Sistemas Colaborativos* 1: 152–159.

Nolen S and Ward C (2008) Sociocultural and situative approaches to studying motivation. In: Maehr ML, Karabenick SA and Urdan TC (eds) *Social Psychological Perspectives*. Bingley: Emerald Group Publishing, pp. 425–460.

Pandya R and Dibner KA (2018) *Learning Through Citizen Science: Enhancing Opportunities by Design*. Washington DC: National Academies Press.

Papavlasopoulou S, Giannakos MN and Jaccheri L (2017) Empirical studies on the maker movement, a promising approach to learning: A literature review. *Entertainment Computing* 18: 57–78.

Piaget J (1964) Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching* 2(3): 176–186.

Piaget J (1967) *Six Psychological Studies*. New York: Random House.

Pozo JI and Gómez MÁ (1998) *Aprender y Enseñar Ciencia: Del Conocimiento Cotidiano al Conocimiento Científico*. Madrid: Ediciones Morata.

Pratt D (1992) Concepts of teaching. *Adult Education Quarterly* 42(4): 207–220.

Quigley C, Pongsanon K and Akerson VL (2011) If we teach them, they can learn: Young students views of nature of science during an informal science education program. *Journal of Science Teacher Education* 22(2): 129–149.

Resnick L, Michaels S and O'Connor MC (2010) How (well-structured) talk builds the mind. In: Preiss DD and Sternberg RJ (eds) *Innovations in Educational Psychology: Perspectives on Learning, Teaching, and Human Development*. New York: Springer, pp. 163–193.

Robinson C (2019) Thoughts on the history of professional development programs in museums. *Journal of Museum Education* 44(2): 123–130.

Rodriguez V (2012) The teaching brain and the end of the empty vessel. *Mind, Brain, and Education* 6(4): 177–185.

Sahin A (2013) STEM Clubs and science fair competitions: Effects on post-secondary matriculation. *Journal of STEM Education* 14(1): 7–13.

Schirato T and Yell S (2000) *Communication and Culture: An Introduction*. London, Thousand Oaks, California: Sage Publications.

SECT (Scholastic Early Childhood Today) (2001) Jean Piaget: Champion of children's ideas. *Scholastic Early Childhood Today* 15(5): 43.

Stocklmayer SM and Rennie LJ (2017) The attributes of informal science education: A science communication perspective. In: Patrick PG (ed) *Preparing Informal Science Educators: Perspectives from Science Communication and Education*. Cham: Springer, 527–544.

Vartiainen J and Aksela M (2013) Science clubs for 3 to 6-year-olds: Science with joy of learning and achievement. *LUMAT* 1(3): 315–321.

Vossoughi S and Bevan B (2013) *Making and Tinkering: A Review of the Literature*. San Francisco: National Research Council Committee on Out-of-School Time STEM.

Vygotsky LS (1980) *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, Massachusetts: Harvard University Press.

Wehrmann C and Henze-Rietveld I (2016) A pedagogy to educate novices to professionalize: On the crossroad of science and technology education and communication. In: Van der Sanden M and De Vries M (eds) *Science and Technology Education and Communication*. Rotterdam: Sense Publishers, 107–128.

Wenger E (1999) *Communities of Practice: Learning, Meaning, and Identity*. New York: Cambridge University Press.

Wenger E (2011) Communities of practice: A brief introduction. Available at: https://scholarsbank.uoregon.edu/xmlui/handle/1794/11736 (accessed 7 March 2022).

Author biographies

Miguel García-Guerrero, PhD, is a scientific popularizer who, since 1995, has held workshops and conferences attended by more than 50,000 people. He is responsible for outreach activities of the Science Museum of the Autonomous University of Zacatecas, is the coordinator of the Quark Group, a former president of Recreación en Cadena, the Mexican Network of Recreational Science and the outreach director of the Mexican Society of Physics. He has been a speaker at 40 national and international events, as well as an instructor in more than 50 courses. He belongs to Level 1 of the National System of Researchers in Mexico, and is the author of five books and the coordinator of another 10, all related to the public communication of science.

Bruce V Lewenstein, PhD, is a widely known authority on the public communication of science and technology—how science and technology are reported to the public and how the public understands controversial scientific issues and 'emerging technologies' such as biotechnology and nanotechnology. Trained as a historian of science, he often uses historical case studies in his research. He has also done extensive work evaluating 'citizen science' outreach projects, in which citizens fully participate in the scientific process by gathering, entering and sometimes analysing scientific data. In recent years, he has helped connect the 'public communication' field with the 'learning sciences' field, especially on issues of public engagement in science. He is the chair of the Department of Science and Technology Studies at Cornell University.

Article

Cultures of Science
2022, Vol. 5(1) 50–66
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2096608322108804 1
journals.sagepub.com/home/cul
SAGE

Science popularization from the perspective of the theory of communicative action

Ana Eliza Ferreira Alvim da Silva, José Roberto Pereira and Luiz Flávio Felizardo
Federal University of Lavras, Câmpus Universitário, Brazil

Abstract
This theoretical article proposes using Jürgen Habermas's theory of communicative action (TCA) as a normative instruction for texts intended for science popularization (SP). We used TCA approaches, such as the validity claims that should characterize argumentative debate and the interactive processes with 'lifeworld' components (culture, person and society), to create a theoretical relationship between Habermas's theory and SP practices. We propose that the TCA aligns with the objectives of a dialogic communication about science with the non-specialist public and can contribute to perspectives that emphasize dialogue about science in society. We conclude that the premises of communicative action can guide SP policies.

Keywords
Science popularization, theory of communicative action, Jürgen Habermas, public participation

1. Introduction

At different times in history, different theoretical approaches have been applied to deal with science popularization (SP) (Cooter and Pumfrey, 1994). Whether for evaluating new technologies, transforming cultural values related to health or habits, or encouraging citizens to participate actively in decisions of collective interest, scientific arguments are perceived to be relevant. Even in the 21st century, scientific knowledge still needs to be better introduced to different social classes around the world. A recent survey of large research institutions in eight countries showed that communication with the non-specialist public is growing (Entradas et al., 2020): 61% of the surveyed institutes reported that this practice had increased in the past five years, while 50% had adopted communication policies of some kind, with an average of around 3% of annual research budgets being spent on public communication. Despite this evolving scenario, the dialogic perspectives of the public communication of science are still considered by some authors to be vague, misunderstood, experimental and dependent on external actors (consultants), and there are cultural barriers to an effective collaboration in policy

Corresponding author:
Ana Eliza Ferreira Alvim da Silva, Federal University of Lavras, Câmpus Universitário, Lavras, CEP 37.203-024, Minas Gerais, Brazil.
Email: anaeliza.alvim@gmail.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

formulation (Bauer and Gregory, 2007; Pieczka and Escobar, 2012).

We argue that Jürgen Habermas's theory of communicative action (TCA) has elements that can potentially guide SP in contemporary democratic societies, particularly by providing important reflections for consideration in the dialogical and intersubjective processes of producing and interpreting scientific information circulated in the public sphere. We do not contend that including the TCA as a guideline for SP actions will solve every difficulty inherent in communication between scientists and citizens. Nevertheless, we believe that adopting the TCA's principles can advance the dialogues about science that must take place in the public sphere.

Lidskog (1996) has already warned that the supposed social authority of science is not always present: for example, people seem to ignore certain environmental risks despite the existence of scientific evidence of those risks. Culture, values, social belonging, economic factors, local knowledge, practical knowledge and other factors actively shape citizens' evaluation of situations, influencing their confidence in science or perception of the risks that it highlights. Therefore, citizens often do not follow scientific recommendations on health, the environment and other matters. We argue that it is not enough for scientists to merely convey scientific knowledge. Intersubjectivity must be the result of daily dialogical practice on themes and problems of a scientific nature within the heart of society. Accordingly, it is necessary for scientists to engage in dialogue with citizens by using different communication resources, such as the internet, printed newspapers, television networks and events, in order to scientifically improve the public debate, while always being attentive to what citizens say and share.

We also recommend that scientists and science communicators assume the task of talking about science with society in a dialogical and continuous way. In this regard, it is important to consider some aspects mentioned by Lidskog (1996). First, there are legitimate controversies in science, and it is necessary to discuss them. Second, there is a need for permanent self-reflection in the sciences, as the production of scientific knowledge is a process developed in several centres, permeated by different values. Last, it is essential to consider that the public is reflective and capable of taking a stand for or against the scientific information presented to it. Thus, when we talk about SP, we are advocating communication practices based on dialogue with the non-specialist public. Germano and Kulesza (2007) favour the use of the term 'science popularization' instead of others, such as 'scientific dissemination', 'popularization of knowledge' and 'scientific literacy'. SP is understood as communication involving interaction and sharing. It goes beyond the diffusion model and the dissemination of ready-made information by proposing co-participation in knowledge construction (Freire, 1983). It is important to emphasize that our conception of SP involves not only discussions of major controversies in science but the communication of all scientific information, including basic sciences, which are often the starting point for a broader understanding of major issues of public interest.

In this paper, to consider dialogism in SP, we propose the use of Habermas's TCA. The goal is for the TCA to guide and provide a normative, evaluative orientation for scientists and science communicators in their interactions with citizens, especially the non-specialist public, as suggested by Burkart (2007) in the case of public relations. Furthermore, it is necessary to consider that scientific information enters the public sphere as arguments against many other factors that influence people's decisions. Therefore, such information must be expressed as rational arguments that seek to present the validity claims pointed out by Habermas (2012). Considering the interaction of components of the 'lifeworld' (*Lebenswelt*) discussed by Habermas (2012), one route to achieve SP could be through culture, personality and society.

We consider that the popularization of scientific knowledge must be conducted within the ethical principles of the TCA approach proposed by Habermas. This will give legitimacy to scientific arguments among the non-specialist public. Furthermore, the knowledge shared with the public may integrate deliberative political discussions and contribute to transforming social and cultural relations, thus achieving more balanced social, environmental, political, cultural and economic development, despite strategic rationality and the various obstacles to communicative rationality. In the strategic rationality discussed by Habermas,

social action is a strategic action oriented only to success, to the pursuit of utilitarian ends; that is, an actor tries to achieve his or her own ends, and not mutual understanding. Hence, we contend that Habermas's theory should serve as a normative instruction for SP practices and as a parameter in public policies, aiming to ensure that the population participates in matters related to science and technology, or as a parameter for analysing scientific texts already in circulation. We regard this proposal as an important institutional mechanism to reduce the impacts of strategic rationality and counter power flows that may threaten the communicative approach to science.

In 1968, Habermas observed that the 19th-century idea that science could penetrate daily life by only two means—the technical use of scientific information and the upbringing of students—had been overcome. He further affirmed that scientific information should not only be disclosed within private educational systems, but instead require a process of 'translation' to other social contexts through language. This affirmation motivates us to use Habermas as a reference for studies related to SP, especially as he has always been motivated by the ideal of a critical theory of society that seeks to emancipate individuals through a peaceful, language-based process. This differentiates Habermas's view from that of other theoreticians of the Frankfurt School, to which he is connected (Andrews, 2011). Most importantly, Habermas's approach is not limited to criticism but proposes a possible solution for society through the TCA. Bachur (2017: 1) calls the TCA 'one of the most significant theoretical initiatives of the 20th century'; it is a sociological theory based on the European crisis of social democracy and the social welfare state, as long as effectively includes the study of language on the agenda of social theory. We want science to be discussed with citizens in an emancipatory manner, so they can benefit from what is liberating and promising in scientific knowledge. In addition, we want them to be critical of science in situations where it deviates from the public interest and the commitment to the common good. One way to achieve this is through language and argumentation.

Habermas's critical and propositional thinking provides an important set of guidelines for researchers to share and discuss science with citizens in a dialogical perspective with the aim of diversifying world views. Therefore, this theoretical article draws a connection between the challenges of SP and specific considerations of the TCA. In the next section, we initially analyse the linguistic perspective in the TCA, which aims to seek mutual understanding and is based on validity claims. We suggest that this language perspective serves as a guide in constructing communication texts between scientists and citizens to enhance the legitimacy of those texts with the public. The third section then analyses the thematization processes in the lifeworld and the structural components of the lifeworld cited by Habermas, which allow us to understand SP within the dynamics of the lifeworld and communicative action. The fourth section then ponders and discusses questionings of Habermas's propositions.

These reflections allow us to claim that SP texts should be produced and publicly circulated as arguments on a given topic, susceptible to evaluation of their validity claims, submitted to an intersubjective understanding, and interacting with the subjects' culture, society and personalities. Where the communication of science is limited to the unidirectional transmission of information, considering non-specialist citizens as an 'empty box', the outcomes tend to be limited. This approach does not consider the factors raised by Lidskog (1996) showing that science has weaker social authority than is assumed by many researchers. We agree with Lewenstein's (2013) assessment that initiatives based on the deficit model should not be rejected, as they allow people to access information. For him, no model fits perfectly on its own. However, while discussions about a dialogical model of interaction between science and society are already very frequent, they still need to be enriched. Habermas's perspective of communicative action can help us to consider the interaction between scientists and the public as an intersubjective exchange capable of structuring social consensus over time.

We consider that the process of making reflections on communicative rationality, developed by Habermas and aimed at societal emancipation, is related to the theme of science in society at different points. In the 1960s, Habermas addressed the importance of public opinion in mediating the relationship between scientific knowledge and political decisions.

As a result of the pragmatism that he adopted, the prevailing idea is that communication between politicians and scientists cannot be detached from social interests and existing guideline values. In the pragmatic model, communication provides scientism to political practice but does not leave out a permanent exchange of information that occurs in the pre-scientific phase. It is a communication rooted in the community or a group of citizens in such a way that policy is transformed by the relationship between science and public opinion (Habermas, 1968). In other words, by rational means, a politically effective discussion must be able to relate the social potential of technical knowledge and the power of practical knowledge and desire. Following this approach, Habermas (1968) even speaks of a necessary translation process (a rational discussion network extended from praxis and science), which implies flows of scientific content between the lifeworld and instances of science production.

We know that communicating about science in society faces numerous challenges. One is the need to overcome the facts–values dichotomy and consider the various factors influencing citizens' perception of scientific information (Dietz, 2013; Nisbet and Scheufele, 2009; Myers, 2003). Moreover, there are problems in the relationships between SP actors, such as journalists, scientists and the public (Bauer and Gregory, 2007; Fjaestad, 2007; Mueller, 2002; Gregory et al., 2007; Oliveira, 2010). This article focuses specifically on the dialogic and intersubjective processes of SP.

2. Language in the search for understanding and validity claims: The theory of communicative action in science popularization

In formulating the TCA, Habermas (2012) promotes the privileged use of language in the search for understanding and provisional consensus among individuals through free debate, drawing on the best arguments and assessing the validity claims presented by speakers, always towards the common good. This communicative approach is a path available to society and meets its need for liberation in a way that would not have been developed by Habermas's predecessors in the Frankfurt School.

The concept of communicative action presupposes that all the actors are speakers and listeners, forming a 'community of interpreters' that presents validity claims that can be accepted or questioned. Arguments are always provisional and open to critique and new interpretations; they are exclusively used to seek understanding and intersubjective agreement. Habermas (2012) contrasts communicative rationality with strategic rationality, which serves private interests and predetermined purposes that benefit an individual or group. Whereas communicative rationality aims for a better argument that serves the common good, strategic rationality pursues a previously determined end for private interests.

Habermas (1985) clarifies that communicative action is teleological in that it has objectives, aims and purposes. However, such aims differ from those guiding strategic action. Telos is a component of understanding-oriented and success-oriented action, which both result in interventions in the objective world. To act teleologically means selecting means that have a chance of achieving a certain aim, which is intersubjective agreement in the case of communicative action. However, the teleological model is transformed into strategic action when each actor involved is committed to his or her own success and relations are regulated by exchange and power. In this respect, strategic action is instrumental and utilitarian.

Communicative action entails the use of language in daily interactions such that dialogic participants accept or reject what Habermas (1998) calls universal validity claims, on which every argumentative proposition is based:

> The aim of reaching understanding [*Verstandigung*] is to bring about an agreement [*Einverstandnis*] that terminates in the intersubjective mutuality of reciprocal comprehension, shared knowledge, mutual trust, and accord with one another. Agreement is based on recognition of the four corresponding validity claims: comprehensibility, truth, truthfulness, and rightness. (Habermas, 1998: 23)

The three universal validity claims are, therefore, the claim to truth (the statement is factually true), the claim to truthfulness (the statement expresses the

speaker's true intention) and the claim to normative justice (the statement is appropriate for the existing normative context). Habermas (1998) also requires that a statement be comprehensible to be considered part of a communicative act (the claim to comprehensibility). Each of the first three validity claims is associated with one of Karl Popper's three worlds (the objective, subjective and social worlds) and with the basic functions of language. Specifically, the claim to truth is related to the objective world and cognitive use of language; the claim to truthfulness is related to the subjective world and expressive use of language; and the claim to normative justice is related to the social world and interactive use of language. The uttered sentence is thus compared to the external reality (what can be understood), internal reality (what the speaker intends and desires) and normative reality (what is socially and culturally appropriate). 'Whereas a grammatical phrase fulfils the claim to comprehensibility, a successful utterance must satisfy three additional validity claims' inherent in all speech acts (Habermas 1998: 49). In summary:

> It belongs to the communicative intent of the speaker (a) that he performs an act that is right in respect to the given normative context so that between him and the hearer an intersubjective relation will come about which is recognized as legitimate; (b) that he makes a true statement (or correct existential presuppositions) so that the hearer will accept and share the knowledge of the speaker; and (c) that he expresses truthfully his beliefs, intentions, feelings, desires and the like, so that the hearer will give credence to what is said. (Habermas, 1985: 171)

As a means of achieving shared understanding, communication presupposes rationality; that is, the ability to present good reasons and arguments to support the validity claims of uttered statements, which are always open to questioning. Argumentation is the reflective form of the communicative act. Meeting validity claims makes the argument valid for understanding but does not mean it will be elected as the best argument during intersubjective communication. Habermas (2012) immerses himself in a theory of argumentation as a means of reconstructing the formal-practical conditions of rational behaviour. Furthermore, Habermas admits that complete agreement is not the normal state of linguistic communication. A lack of understanding, misinterpretation, intentional or unintentional lack of sincerity, and disagreement are common. Hence, intersubjective agreement is not achievable in situations in which strategic rationality predominates. Accordingly, Habermas believes that linguistic interactions aimed at understanding have validity claims that might or might not be accepted. We propose that SP texts must also be produced based on these validity claims, which will enable their discussion as arguments in social conversation. When producing those texts, scientists and science communicators should be aware of the need to present elements in their discourses that demonstrate the search for understandability, truth, normative rightness and truthfulness.

Silva's (2019) study in Brazil shows that scientific journalism texts do not always take the necessary precautions to present all information capable of supporting the validity claims and strong arguments, leaving several absences that raise possible questions. Another problem identified by Silva is the lack of responses to citizens' comments on texts available online. Thus, it is necessary to invest more in dialogic communication and in communicative action within science to provide the public with complete and varied information.

As an example, among the scientific journalism texts analysed by Silva (2019), one group concerned a study on the impact of deforestation on the operation of hydroelectric plants and, therefore, on the generation of electricity in Brazil. The study argues that deforestation around the Xingu River basin will reduce evapotranspiration, generating a climatic effect that could reduce the volume of rainfall and, consequently, the amount of water available in the flooded areas that supply the Belo Monte hydropower plant. The analysed texts do not explain the climate simulation methodology used to make the predictions. In the comments below one text available online, one reader questioned the efficiency of this type of prediction, thus raising doubt about the study's claims. Had the text been written to defend the truth claim by better explaining the methodology, such questioning might not have arisen; even if it did, other readers could have identified in the text the counterpoints to the questioning, and thus better positioned themselves about the study's 'truth'.

Consequently, it is essential that scientists and science communicators verify that public reports of research contain enough information to make sense and support the validity claims. It is also important to respond to readers' comments on the reports and consider such comments as feedback for new publications, thereby improving scientific argument through interactions with the non-specialist audience.

Based on the above, we can add a fifth column to Habermas's framework (1998): a set of questions to pose in evaluating a text's potential for effectively promoting SP (Table 1). These questions should guide the scientist or science communicator when they are talking about scientific research to citizens. Previously published SP texts can also be more effectively analysed by using questions linked to validity claims to assess the texts' potential to achieve understanding in conversations with citizens.

For example, if an SP text aims to share the knowledge that a new drug can cure COVID-19, readers can question that statement based on its validity claims. First, the text must be accessible, meaningful, comprehensible and capable of being objectively interpreted (the claim to intelligibility or comprehensibility). Among other requirements, it is necessary to check whether the meanings of technical terms and scientific jargon are explained, whether there are coherence and cohesion, and whether information is organized throughout the text to facilitate understanding by the reader. Consequently, many studies of SP are essentially concerned with language and speech, although none has considered Habermas's TCA approach. These studies are dedicated to reflecting on topics such as the conflicts between standards of journalistic writing and scientific language (Motta-Roth and Sherer, 2016; Muurlink and McAllister, 2015; Scharrer et al., 2016). Many academic discussions of SP centre on the basic but still unresolved issue of making SP texts intelligible and comprehensible. This challenge refers to what Habermas (1968) calls translating scientific language to be easily understood by the general population. Only after this requirement is satisfied can assertions be evaluated on their truth, normative rightness and truthfulness.

Next, the text must present information and arguments that allow readers to accept them as representing the truth. The predominant mode of communication for this purpose is cognitive. Public reports of scientific studies should contextualize the research, specify sources and procedures, use numbers, give practical examples, provide links, and include other types of information that allow the public to check and evaluate whether or not the text meets this claim of truth.

Returning to the example of a new drug for combating COVID-19, the following questions may be posed to test whether the SP text is committed to demonstrating the truth claim: On how many people and where has the drug been tested? How long did the study last? Is there a link to the original scientific article reporting the study? Has the drug been evaluated by regulatory agencies? Are any side effects or limitations of the results considered? Are there testimonials from people who used the drug in clinical trials? How many researchers are involved and from which institutions? Are any of the researchers directly quoted? Silva (2019) showed that such important issues are often not covered in public reports of scientific research, leaving gaps that inhibit public understanding of scientific topics.

From a normative perspective, one can ask whether the research presented in an SP text followed required ethical protocols (such as sufficient testing, use of control groups and ethics committee approval). It can also be determined whether the researchers' primary mode of communication is interactive, based on a concern for justifying choices, explaining procedures and considering the study's limitations, thus anticipating the audience's legitimate scepticism. This stance does not regard the citizen as a passive recipient of knowledge. It is also necessary to identify whether the researchers were predominantly motivated by socially shared values, such as the preservation of human life.

Regarding the claim to truthfulness, one can assess whether the researchers or certain interest groups derive a private benefit from the results, which can undermine the truth of what is said. Questions that may be posed include: Do the researchers promote the new drug because it is effective and safe, or because a company driven by economic interests finances them? Are the researchers who promote the drug committed to some

Table 1. Reflections on the interface between validity claims and science popularization.

Domain of reality	Mode of communication: basic attitudes	Validity claim	General function of speech	Interface of SP: required characteristics to promote SP
'The' world of external nature	Cognitive: objectivating attitude	Truth	Representation of facts	Does the SP text contain elements that allow the citizen to verify or perceive the truth of the information presented? Such elements include verifiable factual information; testimonials from people; source citations; numbers and statistics; narrative excerpts describing the process of knowledge construction; diversity of actors involved; use of modalizers that emphasize the limitations of statements; links to other content (from other sources); links to facts already known by the public; consideration of the research limits; detailed and coherent description of the technology or study; and presentation of the methodology.
'Our' world of society	Interactive: conformative attitude	Normative rightness	Establishing legitimate interpersonal relations	Are the values that supported the research and the researcher clear in the text? What socially accepted and shared values are involved in the research and its results? What formal rules and regulations are involved? Do the results conflict with current norms and values? Does the study follow the necessary ethical protocols?
'My' world of internal nature	Expressive: expressive attitude	Truthfulness	Disclosure of speaker's subjectivity	Is the research organization or scientist pursuing interests other than the public interest? Does the scientist behave consistently in line with the values involved in the research?
Language	——	Comprehensibility	——	Even for complex topics, is the text completely comprehensible to non-specialist audiences? Is there any effort to adapt the language to facilitate communication with non-specialist audiences?

Source: Adapted from Habermas (1998: 92).

political interest? Would the researchers use the drug personally, or recommend it to a family member or close friend? What is the ethical record of the researchers? Thus, popular texts on science need to include information that defends their validity claims, allowing questions to be raised by the public. Accordingly, those texts should not seek to avoid questioning but rather to improve any debates that may arise.

One of Habermas's observations (1998) that applies to SP texts is that a knowledge differential between speaker and listener may make it difficult to analyse validity claims. If the difference in knowledge is highly significant, there is a risk that studies may be accepted as true and valid without being questioned, resulting in the instrumental use of scientific dissemination, rather than a search for intersubjective agreement. Given these considerations, practising SP based on the precepts of the TCA is essential, as it can gradually increase participants' ability to engage in increasingly complex debates. While the public's capacity to debate and question claims and validity may initially be limited by knowledge differences, the consolidation of SP practices will enable speakers and listeners to participate in increasingly engaged dialogue as deeper and more wide-ranging arguments emerge.

As science is increasingly popularized, its contribution to the subjects' heritage of knowledge will become greater, and it will increase the public's ability to judge validity claims and participate critically in the search for understanding. This idea supports Santos's proposal (1988) for the second epistemological rupture of science, in which a dialogue is established between science and common sense to produce enlightened practical knowledge. It also supports his proposal for an 'ecology of knowledge' in which scientific knowledge is considered to be one of several types of knowledge. We do not claim here that the more citizens know scientific information, the more they will accept it; instead, they will develop greater skills to debate science topics, thereby reducing the knowledge gap between speakers and listeners.

Given that speech acts aim to facilitate understanding, there are two subcategories of objectives: to ensure that the listener understands the meaning of the statement and that the listener acknowledges the statement's validity. Thus, a statement's illocutionary success fundamentally depends on the listener's rationally motivated agreement; that is, success can only be achieved cooperatively (Habermas, 2012). There are three key considerations here: a) the illocutionary objectives of communicative rationality are tied to the telos of understanding; b) the speaker must enter the dialogue knowing that the listener is free to agree or disagree; and c) although perlocutionary expressions are not a priority, speech acts may have perlocutionary effects. In communicative action, the consequences of speech acts should follow from their illocutionary effects; any perlocutionary effects occur discretely, not in a programmed manner. Strategic success here is necessarily tied to the success of the illocutionary act.

Drawing a parallel between these reflections, which are related to Austin's speech act theory, addressed by Habermas (2012), and SP texts, we can consider speech acts of science to be 'institutionally dependent' (Habermas, 1998: 63), in that their illocutionary force often relies on the perceived authority of science, which discourages questioning. If science is acknowledged as infallible, the listener need not question its truth, normative rightness or truthfulness. However, if we adopt the view that SP is composed of institutionally independent speech acts, we face the challenge of spurring involvement and motivating the listener to recognize its validity claims. Thus, the action of popularizing science might be considered an illocutionary act, in the sense that scientific information is understood and debated, allowing citizens to form their perception of a given scientific topic based on their analysis of validity claims. In debates on controversial topics such as climate change, some understanding is always achievable, even if only provisional, as Habermas (2012) predicts, as political and collective impact decisions can be taken at specific times that may precede the exhaustion of discussion on the focal topic. The social consensuses achieved do not exclude the existence of different individual positions. Nevertheless, illocutionary success depends on a cooperative attitude between the speaker and the listener. Such cooperation cannot be imposed or manipulated. For instance, science reporting that disguises its commercial aims is not advancing the search for understanding but rather operating at the

strategic level. Speech acts at that level have weaker illocutionary force and undermined validity claims, and thus become perlocutionary.

Although Habermas (1998) considers the illocutionary aspect of communicative action, he recognizes that such action may generate spontaneous perlocutionary effects. This suggests the possibility of SP speech acts resulting in perlocutionary effects. For example, the consensus in scientific debates may be used to formulate and revise public policy and laws. According to Bachur (2017), debating science in the public sphere may serve as preparation for political discussion. Therefore, whoever conducts projects of public communication about science must believe in that possibility with Habermasian optimism. Publicizing scientific content in the public sphere supports the process of deliberative democracy by increasing the flow of arguments that affects the formation of the collective will, with potential implications for formal legislation.

An important point to consider is that most SP initiatives occur through mediation of communication channels that mobilize wide audiences. Yet, even if mediated by mass media or other means, those initiatives are ultimately interactions of scientists with non-specialist lay citizens, and so can still be analysed through the TCA. We agree with Fairclough's (1995) view of media texts as a form of social action, capable of being answered with other forms of social action. Accordingly, we treat those texts as arguments that improve the public debate on a certain subject and can incorporate evaluations into political deliberations, even if the dialogue between subjects does not occur within the text itself.

Habermas's stance on the media evolved to the recognition of the media's important role in public sphere dynamics in absorbing the demands expressed by central actors (such as politicians) and actors of civil society (such as minorities and social movements) and transforming them into 'news, reports, comments, conversations, scenes, images, shows and films with informative, controversial, educational or entertainment content' (Habermas, 2006: 415). These flows of conversation in the media form what Habermas (2003) calls the abstract public sphere, in which readers, listeners and viewers are spread globally. In the period of the establishment of the bourgeoisie, the press was positioned as one of its most important institutions of struggle. Habermas developed a pessimistic view about the press when it entered its commercial (second) phase, as identified in his book *The Structural Transformation of the Public Sphere* (Habermas, 1991). However, his stance changed in later works, as noted by Marques (2008). Although Habermas pointed to the contradictory aspects of the media, in the 1980s and 1990s he recognized the press as a space with specific characteristics essential to strengthening and maintaining the deliberative structures of democratic dynamics in contemporary societies. For Habermas (2008), the unequal distribution of access to the media does not exclude the possibility of the common construction of public opinion. The participatory construction of public opinion is possible by accepting the rules of the 'right game' (Habermas, 2008: 18), requiring the self-regulating media system to maintain independence from surrounding systems. Another rule is to guarantee citizens the power to participate in conversations about science. Maintaining an inclusive civil society means that discourses do not degenerate into a colonizing mode of communication.

3. The lifeworld as the locus *par excellence* of communicative action: The thematization of scientific information

Habermas (2012) structures his social theory around the notions of lifeworld and system. The system comprises the executive, legislative and judicial powers, characterized by bureaucracy and the control of money, administration and the economy. The workings of the system result in legislative decisions, political programmes, opinions, measures and related outcomes. The system is governed by an essentially teleological and strategic rationality, oriented by calculated ends and the pursuit of success. Parallel to the system is the lifeworld, in which daily interactions and informal relations occur among people and the public sphere is formed. The lifeworld is the realm of communicative rationality and the backdrop for communicative

action, in which people seek common agreement, understanding and consensus through dialogical and discursive practices.

Importantly, within the framework of alternatives for thematically open action, Habermas (1985) highlights so-called 'action situations' in the lifeworld. The lifeworld is, therefore, a context that delimits the horizons of the processes of understanding in which situations of action are determined:

> While the actor has the lifeworld 'behind' him as a resource for enabling communicative actions, he encounters the contingent restrictions, imposed on the carrying out of his plan, as elements in the situation. These can be classified, in the system of reference of the three formal world concepts, as facts, norms, and subjective experiences. (Habermas, 1985: 164)

The lifeworld is a universe of pre-understanding in which the subject finds himself. However, the basic knowledge this universe entails is mostly implicit; it is not known in the strict sense, nor questioned or well reasoned. Only those fragments of this context that become relevant to a particular situation are purposefully thematized. Therefore, 'in the everyday practice of communication, there are no totally unknown situations. New situations, too, emerge from a lifeworld constructed from a stock of cultural knowledge taken for granted' (Habermas 1985: 166). It is, therefore, necessary to distinguish pre-reflection knowledge that informs the process of understanding (but is not thematized) from knowledge that is thematized in speech acts. Implicit knowledge is intuitively mastered and requires rational reflection to be transformed into 'know-that'. This knowledge is an aspect of linguistic competence. In producing speech acts, implicit knowledge is useful and 'generates communicative action but does not serve to complement and supplement it' (Habermas, 1998: 240). As Habermas elaborates:

> Most of what is said in everyday communicative practices remains unproblematic, escapes criticism, and avoids the pressure of surprise exerted by critical experiences, because it draws in advance on the validity of antecedently agreed-upon certainties, in other words, the certainties of the lifeworld. (Habermas, 1998: 240)

Nonthematic knowledge can be understood by problematization, requiring only a shift in the horizon of the situation:

> *Homo sapiens* must have had an intuitive knowledge of how levers work ever since they started to use certain tools for survival; yet the law of levers was discovered as law and given the form of explicit knowledge only in the course of methodical questioning by modern science of our pre-theoretical knowledge. (Habermas, 1998: 242)

When information is thematized and problematized in the lifeworld through a dialogical process committed to finding truth and at least provisional consensus, it becomes knowledge. The construction of knowledge enables emancipation, behavioural change, and social and cultural transformation. According to Habermas (1998), knowledge accumulates based on assumptions or judgements (which may be true or false). The facts can be known only when it is known why statements about them are true. Otherwise, this knowledge is implicit or intuitive knowledge that may emerge through a dialogical process. Such knowledge constitutes the discursive justification of a validity claim.

Based on these initial views of the lifeworld as the locus where themes may be problematized through the dialogical–discursive process, we can understand public communication as a movement for science thematization. Science enacts a 'shift' in the horizon of a lifeworld situation, triggering or challenging nonthematic (or background) knowledge. Though pre-reflective, implicit knowledge arguably has a role in society; thematizing knowledge through speech acts confers greater potential to spark social transformation (or legitimize an already established scenario) and promotes systemic changes through legislation, political decisions and citizens' behaviours or attitudes.

Within Habermas's framework (lifeworld and system), we consider that science is generally produced by institutions located in the system or on its periphery. However, according to Habermas (1968), the lifeworld contains the 'context of discovery' in which questions of interest to society arise, which science investigates. Therefore, SP can ensure that scientific research, whether in progress

or completed, is always linked to that context of discovery and is open to the rationalization and the criticality of public debate.

The active role of researchers and research institutions is essential to this movement of thematicization, but it is nonetheless subject to limitations worldwide. For example, Bentley and Kyvik (2011) compared the numbers of popular science publications and academic publications in 13 countries. Their study revealed that a minority of scientists publishes for a popular audience and that the scale of popular scientific publications is much smaller than that of traditional scientific publications. Whereas over 90% of the researchers interviewed had published a scientific article in the previous three years, only one-third had published an article for the general public. On average, eight scientific articles are published for every article published for a popular audience. Entradas et al. (2020) found some evolution in scientific dissemination, as we mentioned in the introduction to this paper, but reported big differences in that advance when comparing different countries and highlighted the influence of prevailing conditions in research institutes.

According to Habermas (1998), the lifeworld comprises three major structural components: culture, society and personality:

> The components of the lifeworld—culture, society, and personality structures—form complex contexts of meaning that communicate with one another, although they are embodied in different substrata. Cultural knowledge is embodied in symbolic forms—in objects of utility and technologies, in words and theories, in books and documents—just as much as in actions. Society is embodied in institutional orders, in legal norms, or webs of normatively regulated practices and customs. Finally, personality structures are embodied—in a literal sense—in the substratum of human organisms. (Habermas, 1998: 249).

Situations are connected with existing conditions of the lifeworld through processes of cultural reproduction, social integration and socialization. It is in the field of action situations, set against the backdrop of the lifeworld, that the actor can be identified as both the initiator of actions and the product of existing cultural traditions, the solidarity groups to which the actor belongs, and the processes of socialization and learning the actor has undergone. By acting based on communicative rationality and practising the TCA's principles, actors ensure the perpetuation of traditions and/or the renewal of cultural capital, the establishment of ties of solidarity with social impact, and the development of personal identities (through socialization).

The three structural components of the lifeworld are intertwined and share a common origin: culture is related to the stock of knowledge and values; society comprises legitimate orders that regulate social groups; and personality entails the skills that make a subject capable of speaking and acting, thus forming his or her identity. The flow of relations among those three components engenders the conditions for reproducing or transforming actors' identities and social and/or cultural components. Symbolic reproduction occurs through the appropriation of traditions, the renovation of solidarity and socialization, which in turn depend on daily communication and the formation of consensus through language.

We can conceive, based on Habermas (2004), that SP establishes flows in this close relationship with the lifeworld components, so that conversations between scientists or science communicators and citizens through different texts take the position of 'ego–alter interaction'. When scientific knowledge is disseminated (interaction between science and society) to promote popular participation in scientific discussions, cultural reproduction, social integration and socialization are stimulated. Scientific knowledge affects the stock of knowledge and values (culture), the skills that make the subject capable of speaking and acting (personality) and the orders that regulate social groups (society). Simultaneously, these components of the lifeworld affect scientific knowledge. Focusing on the flow of scientific knowledge to the components of the lifeworld, we propose the following reflections:

(a) When information is popularized, it becomes public knowledge and can be incorporated into a population's cultural heritage (subsequently supporting new interpretations of the world in new action situations).
(b) The information will add to the subject's competence and arguments to enable him or her to participate in dialogue from the perspective of the TCA (with additional

knowledge improving the ability to justify or question claims to truth).

(c) The information may spur changes in laws and political decisions that regulate or direct social behaviour.

On the other hand, from the flow of components of the lifeworld to scientific knowledge, we reach the following reflections:

(a) There is a projection of existing cultural knowledge onto the interpretation of scientific dissemination texts.

(b) There is a use of legitimate institutional orders and social mechanisms to implement SP (for example, media as channels for dissemination and existing laws that regulate the topic under discussion).

(c) The subject's motivations and ability to understand and discuss the topic contribute to the intersubjective recognition of validity claims, which may alter behaviours and facilitate social transformation or perpetuation of traditions. Knowledge must confer the potential for emancipating the individual.

This flow from lifeworld components to knowledge is consistent with Santos's ideas (1989) concerning the ecology of knowledge, as it occurs when commonsense knowledge interacts with scientific knowledge. Figure 1 summarizes the relationship between SP and lifeworld components.

We can notice based on Figure 1 that, if SP is implemented according to the TCA's principles for dialogic–discursive interaction, it can mobilize the social structure by influencing components of the lifeworld (culture, society and personality) and also be influenced by them. While interaction with the content of SP texts depends on existing circumstances in terms of culture, society and personality, the accumulation of SP actions may cause changes in these components for the mutual benefit of science and society.

As Habermas (1968) remarked, when one considers the formulation of public policy for scientific research, which ensures public interest in this investment, the search for consensus and intersubjective understanding should be made along the lines suggested by the TCA. This path is compatible with democratic principles as it includes the public as not only listeners but also as speakers. Countering possible arguments that the lay public lacks the technical competence to discuss scientific matters, the continuous development of SP over time tends to increasingly diversify personal skills as knowledge accumulates and new ideas are developed; these outcomes refer to the impacts of SP on personality and culture and its possible effects on society.

The proposed configuration in which SP practice follows the TCA's principles faces the challenge of departing from historical patterns of scientific knowledge dissemination, which are more closely related to the interests of the system than to flows of the lifeworld. Focusing specifically on Brazil, Moreira and Massarani (2002) and Massarani and Moreira (2016) sought to retrieve historical aspects that may elucidate how forms of scientific dissemination have varied over time, depending on philosophical assumptions, scientific content, underlying culture, political and economic interests, and available resources at various times and in various places. During the early centuries of colonization, only a few science-related activities developed in response to immediately relevant technical or military requirements. During the second half of the 19th century, the dissemination of science increased but focused largely on applying science to industrial arts. Only later, at the end of the 20th century and beginning of the 21st century, was the topic discussed from the perspective of social engagement.

Moreira and Massarani (2002) state that SP flows consider the general population to be scientifically illiterate and in need of the saving content of knowledge. This demonstrates how much SP flows can have a bad type of connection with the lifeworld components. In summary, 'Cultural aspects that are important to any dissemination process are rarely considered, and the interfaces between science and culture are frequently ignored' (Moreira and Massarani, 2002: 62, our translation).

4. Criticisms that label the TCA unreachable

When proposing a popularization of science based on the TCA, we do not disregard the conflicts of power and situations that permeate the organizations

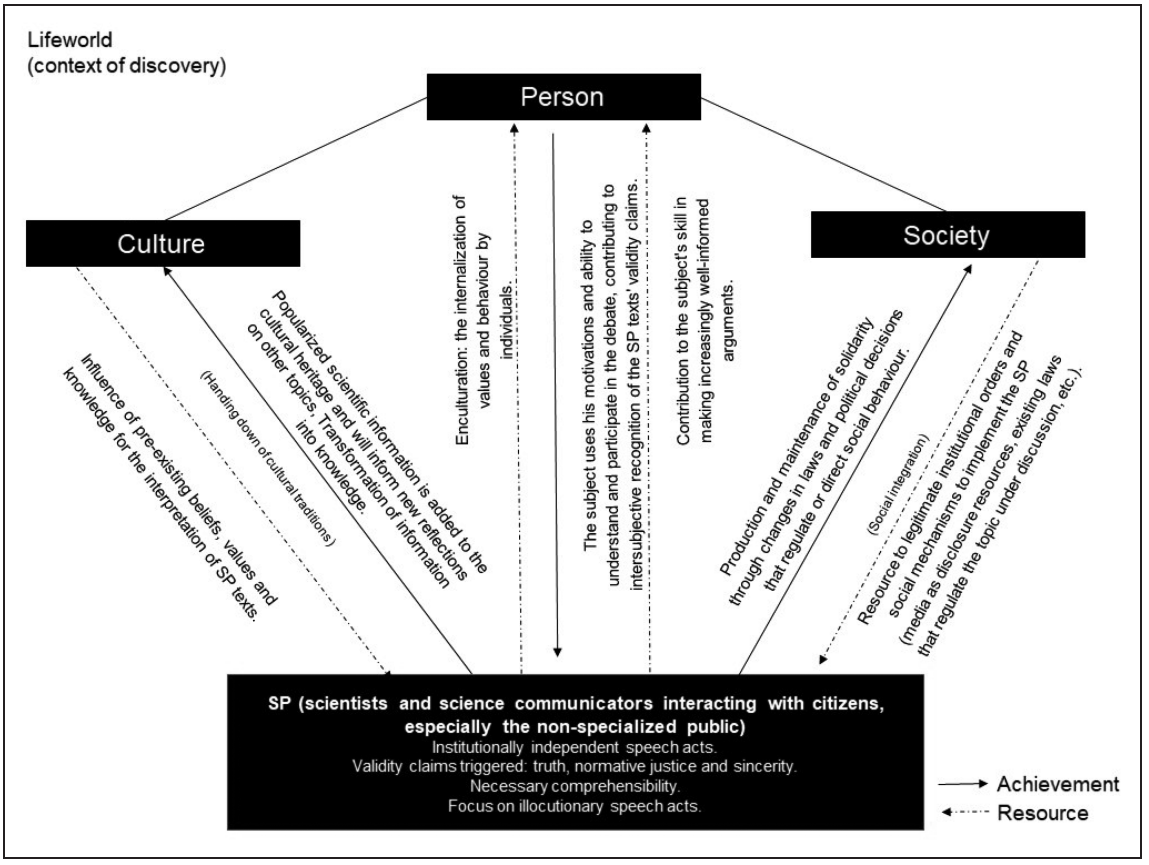


Figure 1. The relationship between science and society through science popularization (SP): Flows among the lifeworld components. Source: Adapted by the authors from Habermas (1998: 253).

responsible for conducting scientific studies and society itself. These issues would impede the full performance of communicative action under ideal speech conditions, which is extensively questioned in Habermas's thinking. There are asymmetries in the public communication process, and argumentative exchange is not guaranteed to be equal. It is necessary to admit, as Mafra (2016) does, that the current scenario is tense and controversial, and to reaffirm the necessity of democratic participatory contexts as a guide and normative horizon.

For Marques et al. (2017), the weak point in Habermas's proposal lies in the ethics of discourse and the search for a moral point of view that requires the interlocutor to abandon self-centred positions and put himself in the other's place, including by adopting that other's perspective. Normative principles are thus needed to reconcile particular interests with social interests. One way to do this, according to Habermas, is via moral feelings, which seek to prevent the subject from applying his own understanding to interpret all situations. Marques et al. (2017) criticize Habermas for not deepening the discussion of how the individual can be transformed into a discursively competent interlocutor for communicative action. In their view, the dialogical harmony resulting from public communication based on Habermas would ultimately lack conflict, politics and dissent. On the other hand, authors such as Matos and Gil (2017) see Habermas's TCA as the premises of public communication, arguing that this perspective favours people's expression and the search for rights and recognition

based on civic conversation. They claim that rational argument, as intrinsic to political processes, becomes central to public communication.

Matos and Gil (2017) also believe that argumentative ethics, based on universal moral values, is the way to legitimize the ideal of justice. They consider that, when joining the argument, people include themselves in the social order as equals. By doing this, people can solve controversies and injustices at the origin of the communicative process. Communicational capital, alongside social capital, is seen as the basis for citizens to engage in the necessary confrontations, being the power of the social agents: 'Practical projects guided by the promotion of communicational capital in an institution or community should try to activate this potential to improve the quality of civic engagement between citizens' (Matos and Gil, 2017: 114).

We are also inspired by Matos and Gil (2017) and Mainieri et al. (2018) to not discount the possibility of communicative action as a normative horizon within the scope of SP. As far as we are from ideal speech conditions, it is a challenge today facing organizations and governments to meet the public demand for ethics, dialogue and participation. The objective here is to create democratic conditions for public communication. Therefore, to reach discursively competent interlocutors for communicative action who are able to face possible asymmetries, it is certainly necessary to form the critical subject; alternatively, referring to Freire (2005), we would say that the formation of critical consciousness is necessary for the subject.

We understand that, where asymmetries and particular interests prevail on the part of communication subjects, the action is not communicative but strategic. The cases in which strategic rationality predominates are those pointed out by Habermas (1997) as manipulation and systematically distorted communication. He contends that it is possible to destroy self-deceptions with argumentative means, for example by methodologically induced self-reflection. Thus, Habermas does not ignore the challenges to communicative action caused by deviations towards strategic action.

Habermas (1997) recalls that the ideal situation of speech is an attempt to clarify the formal pragmatic assumptions of argumentative speech. However, he clearly denies that consensus can occur only in these ideal terms. He says that dissent, when under discursive elaboration, will not have agreement as a horizon if the participants are not open to recognizing the pertinence of the best argument or if any party uses strategic resources. He admits that the discourse in a rationally motivated agreement must satisfy unlikely conditions but reinforces the need to have these conditions on the agenda: Habermas (1989) assesses that it is necessary to be content with approaches to meeting discourse rules in an approximate and sufficient manner. He also uses the comments of Alexy (cited in Habermas, 1989) to defend the institutionalization of devices that assert the pragmatic content of argumentative assumptions under empirical conditions.

Discourses are subject to space and time limitations and depend on social contexts; participants in arguments are moved for reasons other than the only acceptable one (the cooperative search for truth); and it is necessary to order themes and contributions, assure relevance and assess skills. Given all these considerations, institutional arrangements are needed to neutralize the inevitable empirical limitations and avoidable external and internal influences, so that the idealized conditions, always assumed by the participants in the argument, can be fulfilled satisfactorily and in the best possible way (Habermas, 1989).

5. Final considerations

Our case promotes adopting the TCA as a normative standard and parameter for analysing different SP texts (including those from scientific journalism), considering that these texts establish the interaction between scientists and the public. Using this parameter, as detailed in the questions presented in Table 1, it is possible to verify how close or distant is the practice of SP in relation to communicative rationality.

In summary, we propose that the TCA can effectively contribute to an emancipatory SP by promoting the perspective that scientific texts should enter the public sphere as arguments that corroborate dialogue and advance the search for intersubjective understanding with a non-specialist audience. By starting from this legitimate process of building a social consensus on the various themes addressed by science, better conditions are created for influencing deliberative processes and, therefore, transformations in the

attitudes of citizens that boost the common good. This perspective differs from the communication of science as the last word on a matter that needs only to be understood and accepted by citizens.

Therefore, scientific information needs to be accepted as valid by citizens, considering that they are influenced in the lifeworld by factors in the components of culture, society and personality (Habermas, 1998). Thus, scientific texts must excel in presenting validity claims. Scientists and science communicators must be attentive to responses in order to listen to citizens and incorporate new information into a continuing dialogue. Hence, we suggest key questions that the author of the text should consider to assess whether it strongly supports the validity claims, paying attention to and anticipating legitimate questions that may arise from the public. The common good and intersubjective understanding must guide this process towards the formation of a predominant social consensus that can better orient people's decisions in daily life and on major issues of public interest. Although divergent individual positions will remain, it is possible to reach a broader social consensus.

We also believe that SP is a process that affects and is affected by structural components of the lifeworld. SP activities between the public and scientists or science communicators are placed as an ego–alter interaction in the presence of lifeworld components, which can influence those activities but also be changed by them. Investing in SP is much like investing in the problematization of scientific themes within the lifeworld, considering that the flows will be enriched in the long run. Scientific research itself results from a certain problematization in the lifeworld, and the popularization of science democratizes and expands this thematization.

Regarding the obstacles that can hinder communicative action, as repeatedly raised by critics of Habermas and discussed in Section 4, we contend that there are instruments capable of limiting strategic rationality and bringing speech conditions closer to what is necessary for communicative action to materialize. Our recommended solution is to invest in developing SP policies with the TCA as a normative guideline, whether in research institutions, countries, or any other spheres in which scientists and science communicators are inserted. This way of conceiving SP encourages a critical positioning from the citizens in different situations, which might include, for example, those in which science is fully committed to the general public interest and the common good, or those with parallel intentions guided by strategic rationality, such as advancing private interests or defending positions and decisions that harm citizens. Communicative action gives citizens the chance to reach qualified conclusions through legitimate means of intersubjective interaction. It should be noted that so-called fake news, which also affects science from the TCA perspective, cannot meet the requirements for validity claims and so is unsuitable for communicative action. Even if fake news continues to circulate, it will not have the significant impact on the broader social consensus that communicative action is capable of generating.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This work was supported by the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (grant number APQ-04177-15).

ORCID iD

Ana Eliza Ferreira Alvim da Silva https://orcid.org/0000-0001-8602-6946

References

Andrews C (2011) *Emancipação e Legitimidade: Uma Introdução à Obra de Jürgen Habermas*. São Paulo: Unifesp.

Bachur JP (2017) Intersubjetividade ou solipsismo? Aporias da teoria do agir comunicativo de Jürgen Habermas. *Dados* 60(2): 541–575.

Bauer MW and Gregory J (2007) From journalism to corporate communication in post-war Britain. In: Bauer MW and Bucchi M (eds) *Journalism, Science and Society: Science Communication between News and Public Relations*. New York: Routledge, pp. 33–51.

Bentley P and Kyvik S (2011) Academic staff and public communication: A survey of popular science

publishing across 13 countries. *Public Understanding of Science* 20(1): 48–63.

Burkart R (2007) On Jürgen Habermas and public relations. *Public Relations Review* 33: 249–254.

Cooter R and Pumfrey S (1994) Separate spheres and public places: Reflections on the history of science popularization and science in popular culture. *History of Science* 32(3): 237–267.

Dietz T (2013) Bringing values and deliberation to science communication. *PNAS* 110(3): 14081–14087.

Entradas M, Bauer MW, O'Muircheartaigh C, et al. (2020) Public communication by research institutes compared across countries and sciences: Building capacity for engagement or competing for visibility? *PloS One* 15(7): 1–17.

Fairclough N (1995) *Media Discourse*. London: Bloomsbury Publishing.

Fjaestad B (2007) Why journalists report science as they do. In: Bauer MW and Bucchi M (eds) *Journalism, Science and Society: Science Communication between News and Public Relations*. New York: Routledge, pp. 123–131.

Freire P (1983) *Extensão ou Comunicação?* 7th ed. Rio de Janeiro: Paz e Terra.

Freire P (2005) *Pedagogia do Oprimido*. Rio de Janeiro: Paz e Terra.

Germano MG and Kulesza WA (2007) Popularização da ciência: Uma revisão conceitual. *Caderno Brasileiro de Ensino de Física* 24(1): 7–25.

Gregory J, Agar J, Lock S, et al. (2007) Public engagement of science in the private sector: A new form of PR? In: Bauer MW and Bucchi M (eds) *Journalism, Science and Society: Science Communication between News and Public Relations*. New York: Routledge, pp. 203–213.

Habermas J (1968) *Técnica e Ciência Como Ideologia* (Morão A, trans.). Lisboa: Edições 70.

Habermas J (1985) Remarks on the concept of communicative action. In: Seebass G and Tuomela R (eds) *Social Action*, vol. 43. Dordrecht: Springer, pp. 151–178.

Habermas J (1989) *Consciência Moral e Agir Comunicativo* (Guido AA, trans.). Rio de Janeiro: Tempo Brasileiro.

Habermas J (1991) *The Structural Transformation of the Public Sphere: An Inquiry into a Category of Bourgeois Society* (Burger T, trans.). Cambridge: The MIT Press.

Habermas J (1997) *Teoria de la Acción Comunicativa: Complementos y Estudos Previos*, 3rd ed. (Redondo MJ, trans.). Espanha: Cátedra Teorema.

Habermas J (1998) *On the Pragmatics of Communication* (Cooke M, ed.). Cambridge: The MIT Press.

Habermas J (2003) *Direito e Democracia: Entre Facticidade e Validade*, vol. 2, 2nd ed. (Siebeneichler FB, trans.). Rio de Janeiro: Tempo Brasileiro.

Habermas J (2004) *Pensamento pós-Metafísico: Ensaios Filosóficos* (Nahodil L, trans.). Coimbra: Livraria Almeidina.

Habermas J (2006) Political communication in media society: Does democracy still enjoy an epistemic dimension? The impact of normative theory on empirical research. *Communication Theory* 16: 411–426.

Habermas J (2008) Comunicação política na sociedade midiática: O impacto da teoria normativa na pesquisa empírica (Marques ÂCS, trans.) *Líbero* 11(21): 9–20.

Habermas J (2012) *Teoria do Agir Comunicativo*, (Siebeneichler FB, trans.). São Paulo: Martins Fontes.

Lewenstein B (2013) Comunicar la Ciencia Hoy. Universidad Veracruzana / XBalamUV, Mexico. Available at: https://www.youtube.com/watch?v = qY0xjCCtOAo (accessed 14 September 2019).

Lidskog R (1996) In science we trust? On the relation between scientific knowledge, risk consciousness and public trust. *Acta Sociologia* 39(1): 31–56.

Mafra R (2016) Diálogo público, instituições científicas e democracia: Reflexos sobre a constituição de uma política de comunicação organizacional. *Intercom–RBCC* 39(2): 161–174.

Mainieri T, Marques ÂCS, Lima FP, et al. (2018) Comunicação e poder organizacional. In: Mainieri T and Marques Â (eds) *Comunicação e Poder Organizacional: Enfrentamentos Discursivos, Políticos e Estratégicos*. Goiânia: UFG, pp. 12–21.

Marques ÂCS (2008) Os meios de comunicação na esfera pública: Novas perspectivas para as articulações entre diferentes arenas e atores. *Líbero* 11(21): 23–38.

Marques Â, Mafra R and Martino LMS (2017) Um outro olhar sobre a comunicação pública: Uma constituição discur siva de políticos no âmbito das associações. *Dispositiva* 6(9): 76–92.

Massarani L and Moreira IC (2016) Science communication in Brazil: A historical review and considerations about the current situation. *Academia Brasil eira de Ciências* 88(3): 1577–1595.

Matos HH and Gil PG (2017) Uma rota para teoria e prática em comunicação pública: Uma argumentação como luta cívica pelo reconhecimento, respeito e justiça. In: Marques Â, Oliveira IL and Lima F (eds) *Comunicação Organizacional: Vertentes Conceituais e Metodológicas*. Belo Horizonte: PPGCOM UFMG, pp. 101–118.

Moreira IC and Massarani L (2002) Aspectos históricos da divulgação científica no brasil. In: Massarani L,

Moreira I and Brito F (eds) *Ciência e Público: Caminhos da Divulgação Científica no Brasil*. Rio de Janeiro: Casa da Ciência / UFRJ, pp. 43–64.

Motta-Roth D and Sherer AS (2016) Popularização da ciência: A interdiscursividade entre ciência, pedagogia e jornalismo. *Bakhtiniana* 11(2): 164–189.

Mueller SPM (2002) Popularização do conhecimento científico. *DataGramaZero: Revista de Ciência da Informação* 3(2): 1–11.

Muurlink O and McAllister P (2015) Narrative risks in science writing for the lay public. *Journal of Science Communication* 14(3): 1–17.

Myers G (2003) Discourse studies of scientific popularization: Questioning the boundaries. *Discourse Studies* 5(2): 265–279.

Nisbet MC and Scheufele D (2009) What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany* 96(10): 1767–1778.

Oliveira F (2010) *Jornalismo Científico*, 3rd ed. São Paulo: Contexto.

Pieczka M and Escobar O (2012) Dialogue and science: Innovation in policy-making and the discourse of public engagement in the UK. *Science and Public Policy* 40(1): 113–126.

Santos BS (1988) Um discurso sobre as ciências na traição para a ciência pós-moderna. *Estudos Avançados* 2(2): 46–71.

Santos BS (1989) *Introdução a uma Ciência pós-Moderna*. Rio de Janeiro: Graal.

Scharrer L, Rupieper Y, Stadtler M, et al. (2016) When science becomes too easy: Science popularization inclines laypeople to underrate their dependence on experts. *Public Understanding of Science* 26(8): 1003–1018.

Silva AEFA (2019) *A ciência em circulação nas esferas públicas: O jornalismo científico em universidades de Minas Gerais e suas repercussões*. PhD thesis, Federal University of Lavras, Brazil.

Author biographies

Ana Eliza Ferreira Alvim da Silva (PhD, Federal University of Lavras, Brazil) is a journalist at the Federal University of Lavras. She coordinates projects related to the public communication of science. She holds a PhD degree in administration, a master's degree in communication and society and a degree in social communication. Her field of research covers issues such as the public communication of science, scientific journalism, deliberative democracy, social mobilization, social management, public administration and critical discourse analysis.

José Roberto Pereira (PhD, Federal University of Lavras, Brazil) was a postdoctoral student in social sciences at the Center for Social Studies, University of Coimbra (2017–2018), Portugal. He holds a PhD degree in sociology. He is an adviser for the professional master's degree in public administration, for the master's and academic doctorate in administration at the Federal University of Lavras, and for the postgraduate programme in public policy management at the Federal University of Tocantins. He is a full professor in public administration and social management at the Federal University of Lavras. He has coordinated research projects and guidelines in the areas of participatory and deliberative democracy, public administration and social management. His theoretical focus is based on the theory of communicative action aimed at the construction and delimitation of research fields in social management and public administration.

Luiz Flávio Felizardo (PhD candidate, Federal Univeristy of Lavras, Brazil) has been an information technology analyst at the Federal University of São João del Rei since 2013. He graduated in computer science from the Federal University of Itajubá (2012) and holds a master's degree in computer science and technology from the Federal University of Itajubá (2016). He is a project management specialist (2014). Since he started his PhD studies in the field of administration at the Federal University of Lavras in 2019, he has been working on projects in the social sciences. The main focus of his work is public administration and social management. Some of his research projects are in the areas of participatory and deliberative democracy, public administration and social management, using Habermas's theory of communicative action.

Cultures Of Science
cos.cnais.org.cn

Journal Description

Cultures of Science is a peer-reviewed international Open Access journal. The journal aims at building a community of scholars who are expecting to carry out international, inter-disciplinary and cross-cultural communication. The topics include: cultural studies, science communication, the history and philosophy of science and all intersections between culture and science. The journal values the diversity of cultures and welcomes manuscripts from around the world and especially those involving interdisciplinary topics.

Aims and Scope

Cultures of Science is an international journal that provides a platform for interdisciplinary research on all aspects of the intersections between culture and science. It is published under the auspices of the China Association for Science and Technology.

It welcomes research articles, commentaries or essays, and book reviews with innovative ideas and shedding a fresh light on significant issues. Research articles report cutting-edge research developments and innovative ideas in related fields; commentaries provide scientific perspectives on emerging topics or social issues; book reviews evaluate and analyze the contexts, styles and merits of published works related to cultures of science.

The topics explored include but are not limited to: science communication, history of science, philosophy of science, sociology of science, science education, public understanding of science, science fiction, political science, indicators of science literacy, values and beliefs of the scientific community, comparative study of cultures of science, public attitudes towards a new scientific and technological phenomena.

Cultures of Science is published 4 times a year in March, June, September and December.

Contact Information

Address: 3 Fuxing Road, Haidian District, Beijing 100038, China.
Email: culturesofscience@cnais.org.cn

Disclaimer

Any opinions and views expressed in the articles in *Cultures of Science* are those of the respective authors and contributors and not of *Cultures of Science*. *Cultures of Science* makes no representations or warranties whatsoever in respect of the accuracy of the material in this journal and cannot accept any legal responsibility for any errors or omissions that may be made. The accuracy of content should be examined independently.

© National Academy of Innovation Strategy 2022
All rights reserved; no part of this publication may be reproduced, stored, transmitted or disseminated in any form or by any means, without prior written permission of the publisher.



Volume 5 . Issue 1 . March

Commentary

3 Open science: The science paradigm of the new era
Ke Gong

Articles

10 Co-construction and sharing of a Chinese medical case repository helps medical workers strengthen capacity for clinical practices
Junmin Wei, Jing Li, Xibin Shen and Qihang Tian

16 The political background of a pattern transformation in the Chinese system of science and technology during the 20th century
Guangbi Dong

33 From experience to theory: Science recreation workshops as a practice-led approach in informal environments for science learning
Miguel García-Guerrero and Bruce V Lewenstein

50 Science popularization from the perspective of the theory of communicative action
Ana Eliza Ferreira Alvim da Silva, José Roberto Pereira and Luiz Flávio Felizardo

SAGE www.sagepublishing.com
Los Angeles | London | New Delhi | Singapore | Washington DC | Melbourne

cos.cnais.org.cn

ISSN 2096-6083

9 772096 608224 03>

国内定价：60元