



The Construction of Civil Scientific Literacy in China from the Perspective of Science Education

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Accepted: 15 July 2022

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Abstract

On 25 June 2021, the State Council issued the new *Outline of the National Action Scheme for Scientific Literacy for All Chinese Citizens (2020–2035)* (*Outline of Scientific Literacy*). In order to provide reference for its implementation, this study analyzes the achievements and obstacles in the implementation of the old *Outline of Scientific Literacy (2006–2010–2020)* based on the results of all previous surveys on civic scientific literacy (CSL) in China and from the perspective of science education. The results showed a continued steady growth in CSL, from 1.6 in 2005 to 10.56% in 2020. Specifically, male, urban, and younger adults were more likely to qualify as possessing CSL. Moreover, education level was found to be positively related to CSL. The study also found that in China, the effectiveness of formal science education has been hampered by the long-term division of the arts and sciences, examination-oriented education, the urban–rural gap, and the aging population. In terms of informal education, 37.2% of Chinese citizens visited science museums in 2020, and the Internet plays an increasing important role. Nowadays, Chinese science popularization lacks interaction, with limited opportunities for public engagement. There are deficiencies in both the country’s formal and informal science education, meaning that there is still much room for improvement in the promotion of CSL in China.

Keywords Civic scientific literacy · *Outline of Scientific Literacy* · Science education · China

1 Introduction

An infodemic—too much information including false or misleading information—has become a threat during the COVID-19 pandemic (WHO, 2020). However, the scientific community is losing the battle against digital misinformation (Thorpe, 2020). Saribas and

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Cetinkaya (2021) asserted that creating scientifically literate citizens is crucial to dealing with this infodemic. Civil scientific literacy (CSL) has become a subject of increasing attention. Policy documents in many countries emphasize the importance of scientific literacy, including the United States, Canada, and Europe (Yacoubian, 2018). CSL has both macro and micro benefits. The former involves positive effects on the national economy, the realm of science itself, political decision-making, democratic practices, and the relationship between science and culture. The latter includes increased employment opportunities for individuals, intellectual and aesthetic development, and improved living standards (Laugksch, 2000). In general, improving CSL is an important and urgent issue.

In the last decades of research in the field of science education, the concern over the indispensable need for scientific literacy in order for citizens to exercise their full rights continues to appear in many international articles and research reports (Ortiz-Revilla et al., 2021). Education is the core factor impacting CSL (Miller et al., 1997; Ren et al., 2013). Specifically, Miller (2016) found that the two strongest predictors of CSL were the level of educational attainment and exposure to college science courses. Ren et al. (2013) revealed that different education systems and curricula have led to differences in CSL between the United States and China. School characteristics are also important in predicting scientific literacy (You et al., 2020), including the school location (Panizzon et al., 2014), socio-economic status (Perry & McConney, 2010), and teacher quality (Blank & De Las Alas, 2009). In addition, the use of informal science education resources had also been found to be positively related to CSL, including science magazines, science museums, and science web sites, among others (Miller, 2002).

China also attaches great importance to the construction of CSL. Based on the American *Project 2061*,¹ China launched a *Project 2049* for all citizens in 2003, making the improvement of CSL the core of China's informal educational system (Zhang & Liu, 2021). In 2006, the State Council issued *The Outline of the National Action Scheme for Scientific Literacy for All Chinese Citizens (2006–2010-2020)* (hereinafter referred to as old *Outline of Scientific Literacy*). This document proposed the goal of attaining a level of over 10% CSL by 2020. The implementation period of the scheme came to an end in 2020, with the results of the 11th national survey on the country's CSL released on 26 January 2021. These surveys are tools used by the Chinese government to test the implementation effects of the scheme.

At the same time, on 25 June, 2021, *The Outline of the National Action Scheme for Scientific Literacy for All Chinese Citizens (2021–2035)* (i.e., the new *Outline of Scientific Literacy*) was issued, aiming to raise China's CSL to 25% by 2035. In order to provide reference for the implementation of this new outline, this study analyzes the implementation of the old *Outline of Scientific Literacy* over the past 14 years. Specifically, based on the results of national CSL surveys, this study tries to summarize both improvements and obstacles in CSL in China from the two aspects of formal and informal learning.

¹ In the 1980s, the USA launched *Project 2061*, in order to help all Americans become literate in science, mathematics, and technology.

2 Core Concept Definition

2.1 Scientific Literacy

The concept of scientific literacy (SL) originated in the field of science education, proposed by the American educational reformer James Bryant Conant in 1952. Hurd, an expert in science education, later discussed the significance of SL for American schools, defining it as an understanding of science and its application in society (Hurd, 1958). In 1975, Shen (1975) divided it into three levels: practical or functional literacy, civic literacy (or literacy as power), and cultural or ideal literacy. Given the difficulty of measuring functional literacy and achieving cultural literacy, Miller focused more on civil literacy (Chen et al., 2009).

Nowadays, there is no universally accepted definition of CL. In the field of education, Roberts (2007) organized the multiple conceptions of SL into two main visions: Vision-I and Vision-II. The former is rooted in the products and processes of science, while the latter is anchored in social situations with a scientific component, which students will face as citizens. Compared to Vision-I, Vision-II recognizes that science is not merely isolated but also involves a context of cultural connotations (Valladares, 2021). Since the last decade, Vision-III has developed, which emphasizes scientific engagement (Liu, 2013; Yore, 2012) and “knowing-in-action” (Aikenhead, 2007). It brings the aims of science education closer to those of citizen education (Bybee, 2016; Yore, 2012). Lau (2009) considers the following as core abilities for SL: (1) scientific concepts and their applications in real-life contexts, (2) scientific inquiry processes, (3) understanding of the nature of science, and (4) understanding of the relationships between science, technology, and society. Science education researchers have long advocated the central role of the nature of science (NOS) for the understanding of scientific literacy (Williams & Rudge, 2016). *Science for All Americans* stated that the NOS has three principal components, a scientific world view, scientific methods of inquiry, and the nature of the scientific enterprise (American Association for the Advancement of Science, 1990).

In China, the old *Outline of Scientific Literacy* defined CSL as understanding the necessary scientific knowledge, mastering the basic scientific method, establishing scientific thinking, advocating for the scientific spirit (four essential elements), and having the ability to apply the above to practical problems and to participate in public affairs (two abilities) (The State Council of PRC, 2006a, 2006b). The above interpretations denote the formal understanding of the concept of CSL in China. In 2021, the new *Outline of Scientific Literacy* has slightly adjusted this concept. More specifically, the order of the four basic elements is completely reversed, with the scientific spirit being placed first. The ability to participate in public affairs shifts to the ability to analyze and judge matters.

2.2 Civil Scientific Literacy Survey

The United States (US) was the first country to focus on SL, due to the public interest and political panic that followed the Soviet Union’s success with Sputnik in 1957 (Paisley, 1998; Ren, 2010). A few months before the launch of Sputnik, the National Association of Science Writers (NASW) investigated the understandings and attitudes of the public toward scientific technologies in the US (Miller, 2004); this is considered to be the origin of the civil scientific literacy survey (CSL survey). In the 1970s, the National Science Foundation (NSF) began to support CSL surveys chaired by Miller on an ongoing basis.

CSL surveys moved towards institutionalization. Miller (1983, 1992) defined CSL as a three-dimensional construct encompassing the vocabulary of scientific terms and concepts, the understanding of the process of science, and the awareness of the impact of science and technology on both individuals and society.

In light of international competition and national development, other countries emphasized CSL and launched successive surveys. In 1989, based on Miller's survey, Durant et al. (1989) conducted a survey in the UK, the results of which fuelled the "public understanding of science" movement (Stockmayer & Bryant, 2012). Similar surveys have been conducted in Japan, China, and other countries. Most of these questionnaires have followed the example of the surveys led by Miller or Durant et al. (Wu et al., 2018). In cross-national surveys of CSL, Miller et al. (1997) found that the third dimension varies substantially among nations, resulting in the adoption of a two-dimensional system. However, in the overall field of CSL studies, only a few studies have made cross-national comparisons (Wu et al., 2018).

In China, the construction of CSL has been embedded in science popularization. In 1950, the predecessor of the China Association for Science and Technology (CAST) was formed, which is dedicated to popularizing science to the public. Zhang Zhongliang, a researcher at CAST, is considered to be the founder of the CSL survey in China, who conducted an unofficial CSL survey in 1989 (Ren, 2010). In 1992, CAST implemented China's first official survey under the approval of the National Bureau of Statistics. However, the earlier surveys showed that there was a deep gap between the level of SCL of Chinese citizens (only 1.6% in 2005) and developed countries. Therefore, the old *Outline of Scientific Literacy* was formulated and issued by the State Council in 2006. It made general arrangements for the construction of CSL in China, including goals and implementation plans.

2.3 Formal and Informal Learning

The European Council (2000) classifies learning into formal, non-formal, and informal learning, distinguished mainly by whether it is organized, intentional, and whether it leads to a certificate. OECD (2007) summarized five previous criteria² for differentiation of above-mentioned three types of learning and simplified them into learning objectives and intentionality. At the same time, some scholars have adopted a bifurcated approach, dividing learning into formal learning and informal learning. For example, Yu and Mao (2005) merged formal and non-formal learning into formal learning. They posit that formal learning mainly refers to academic education at school and continuing education after joining the workforce, while informal learning occurs at informal learning times and places, where knowledge is transmitted through non-teaching social interactions. Cross (2011) likens the difference between formal and informal training to riding on a bus vs. riding a bike. With the formal learning/bus analogy, "The driver decides where the bus is going; the passengers are along for the ride," whereas for the informal learning/bike comparison, "The rider chooses the destination, the speed, and the route." Zhang et al. (2012) found that the dichotomous classification comes mainly from the fields of educational technology and science education, while the trichotomy comes mainly from the concept of lifelong learning in the field of adult and vocational education. Therefore, this paper adopts a dichotomous approach.

² Organized, learning objectives, intentional, duration, leads to a qualification.

In the field of science, Wellington (1990) argued that the key features of formal science learning are that it is compulsory, structured, certificated, teacher-centered, planned, and classroom- and institution-based, whereas informal science learning has the opposite characteristics. Liu (2007) referred to learning that takes place in places other than the classroom as informal science learning. The “places” include everyday experiences (e.g., hunting, walking in the park, watching a sunrise), designed settings (e.g., visiting a science center, zoo, aquarium, botanical garden, planetarium), and programs (e.g., after-school science, environmental monitoring through a local organization) (Bell et al., 2009).

3 The Present Situation of CSL in China

3.1 Basic Description

In the time period running up to 2021, China has conducted 11 national surveys on CSL. The first three were conducted by the State Scientific and Technological Commission, while subsequent ones were led by the China Association for Science and Technology (CAST) and implemented by the China Research Institute for Science Popularization (CRISP). The data in this article were mainly collected and compiled from the publicly available data released by the CRISP.

In terms of measurement of CSL, China has gone through three phases (He, 2019). In the first phase, comprised of the first six national surveys, China used the Miller three-dimensional system and calculation methodology and the international generic questions. Specifically, Miller (1983) set a single measure that required a minimally acceptable score in all three dimensions for an individual to be considered scientifically literate. In the second phase, which was comprised of three surveys from 2007 to 2013, the test questions began to better reflect the Chinese context. China developed a series of local questions, combined with international generic questions. Using the IRT method, citizens with a score above 70 out of 100 were identified as possessing CSL. In the third phase, China has begun to develop a six-dimensional assessment system based on the two dimensions of knowledge and ability³ since 2015. The judging criteria remained the same with a score of over 70 (He, 2019).

Figure 1 shows an overall upward trend in China’s CSL. In 2020, 10.56% of Chinese citizens were identified as possessing CSL, successfully completing the target of 10% that had been set in the old *Outline of Scientific Literacy*. The data further show that CSL in China has increased by 8.96% since the issuance and implementation of the scheme posited in the old *Outline of Scientific Literacy in 2006*, with continuous and steady growth after 2006.

Slanted lines indicate that the data were not publicly available

As shown in Table 1, the proportion of men qualifying as possessing CSL has consistently been higher than that of women, and its improvement among men has grown significantly over the years. The implication here is that men are more likely to possess CSL than women. With regard to the type of area, the rate of urban residents identified as having CSL increased from 3.06 in 2005 to 13.75% in 2020, while the same proportion among

³ The knowledge dimension covers content knowledge, procedural knowledge, and cognitive knowledge. The dimension of ability encompasses three aspects: daily life, participation in science, and scientific decision-making.

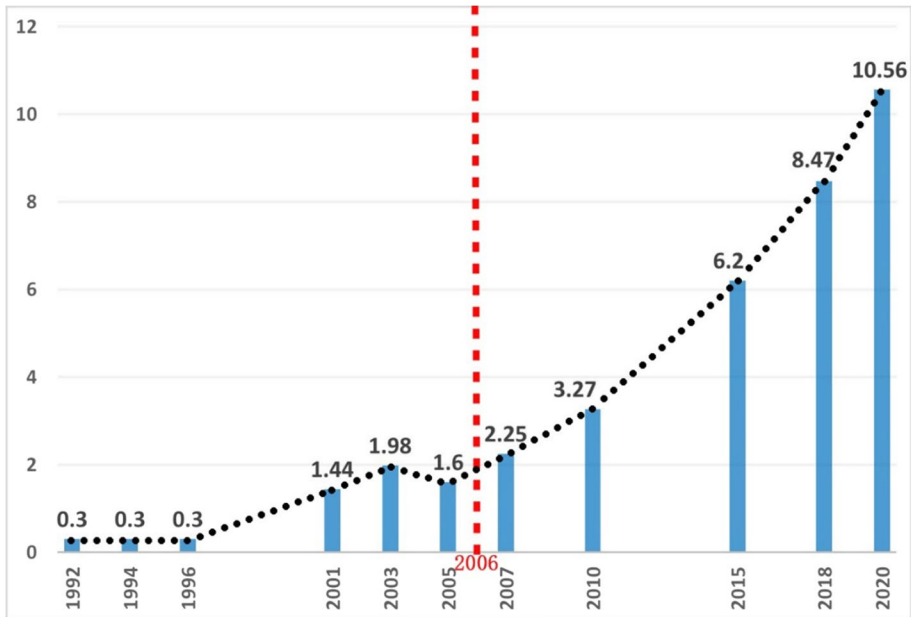


Fig. 1 Proportion of citizens possessing civic scientific literacy in China

Table 1 Percentage of different groups identified as possessing CSL

Type	Categories	2005	2007	2010	2015	2018	2020
Gender	Male	1.73	2.9	3.69	9.04	11.13	13.12
	Female	1.13	1.6	2.59	3.38	6.22	8.82
Area	Urban	3.06	3.6	4.86	9.72	11.55	13.75
	Rural	0.38	1.0	1.83	2.43	4.93	6.45
Age	18–29	/	3.5	5.12	11.59	16.91	18.31
	30–39	/	3.0	3.88	7.16	12.39	13.68
	40–49	/	1.9	2.78	4.71	6.95	8.42
	50–59	/	1.5	1.65	1.45	3.08	5.48
	60–69	/	1.3	1.25	1.22	1.62	3.52
Degree	Undergraduate and above	/	18.7	13.17	40.47	37.12	38.89
	Junior college	/	8.6	8.88	20.83	17.83	21.26
	High school	/	4.7	3.88	10.4	9.74	14.30
	Junior middle school	/	1.5	1.64	1.93	2.28	6.01
	Elementary school and below	/	0.1	0.64	0.28	0.41	2.11

rural residents rose from only 0.38 to 6.45%. The gap between urban and rural areas in terms of CSL thus remains marked.

From the perspective of age, the 18–39 group emerged as the most qualified, with an increase in age entailing fewer CSL-qualified people. Nevertheless, all age groups improved to varying degrees over the years, with the 18–29 age group showing the

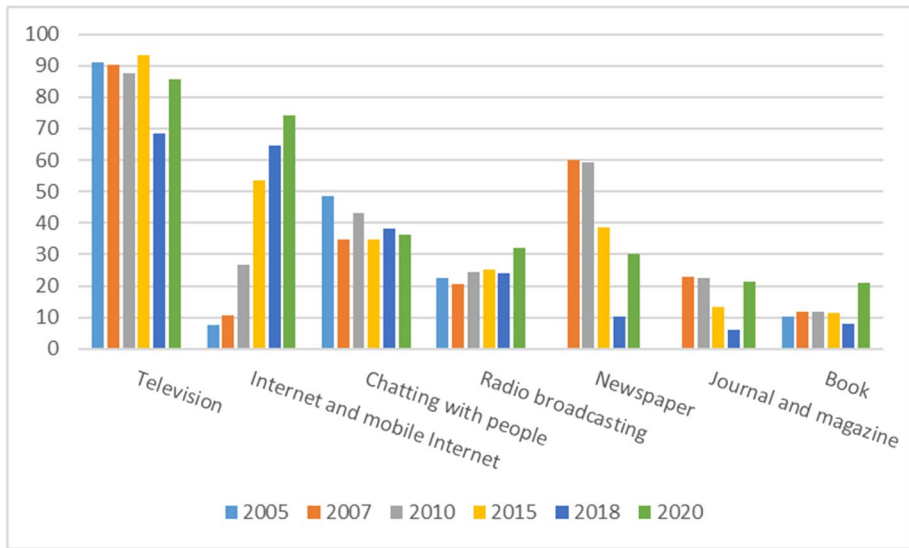


Fig. 2 Main sources of public access to scientific information. Note: The horizontal axis follows the values in 2020 from highest to lowest. In 2005, “newspaper” and “magazine” are combined, accounting for a total of 44.9%, while in other years, the two are calculated separately. Data for two columns, “newspaper” and “journal and magazine,” are missing for 2005 because the data were missing from our sources

fastest growth rate. Fewer than 5% of citizens aged 60 to 69, and people with elementary school education and below, were found to be CSL-literate, suggesting an urgent need to strengthen the relevant education for these groups. It is worth noting that compared to the old *Outline of Scientific Literacy*, the new *Outline of Scientific Literacy* specifically adds the elderly as a priority group.

3.2 Formal Science Education

Science education is a key project determined for implementation in the *Outline of Scientific Literacy*. As shown in Table 1, citizens with a bachelor’s degree or above always account for the largest proportion of people possessing CSL. There is a large gap between the group with junior middle school education and below and the national average (10.56%), especially for the elementary school and below education group. In general, the higher the level of education, the greater the number of people possessing CSL. In 2007, 18.7% of people with a bachelor’s degree and above qualified as having CSL, while less than 14.9% of people with lower education met this standard; these respective rates had increased to 38.89% and 43.68% by 2020, indicating a significant improvement in CSL in recent years.

The Ministry of Education also issued the *Compulsory Education Primary School Science Curriculum Standards (New Curriculum)* in 2017, a revision and improvement of the 2001 curriculum standards (*Old Curriculum*). In the *New Curriculum*, the start of science classes was moved earlier, from Grade 3 to Grade 1, with the science course in primary school becoming a major course rather than a subsidiary one. Since then, science education has been incorporated into all stages of basic education in China. In addition, the *New*

Table 2 Visits to science-related facilities by Chinese citizens (%)

Year	2005	2007	2010	2015	2018	2020
Infrastructure						
Zoo, aquarium, botanical garden	30.3	51.9	57.9	53.7	58.1	54.9
Library	26.7	41.0	50.3	40.4	46.7	51.1
Museum of natural history	7.1	13.9	21.9	22.1	29.5	40.1
Science museum	9.3	16.7	27.0	22.7	31.9	37.2
Art gallery, exhibition hall	11.2	17.5	26.4	20.5	27.5	25.0
Laboratories in universities and research institutes	/	2.7	11.2	9.7	12.0	24.1

Curriculum added technology and engineering to all stages of primary school, in line with international trends pertaining to STEM education, and emphasized inquiry-based learning (Ministry of Education of PRC, 2017). In general, the importance ascribed to science education, and its relation to the international field of science, has greatly increased in China.

3.3 Informal Science Education

In this section, the discussion focuses on two relevant secondary indicators of the 2020 national survey of CSL in China: “citizens’ access to information on scientific and technological developments”(Fig. 2) and “citizens’ visits to and use of science venues” (He et al., 2021).

In addition to formal school education, the media provides a key source of access to scientific information for the general public. As shown in Figure 2, in 2005, the top three mainstream “media” channels were television (91%), word of mouth (48.7%), and newspapers and magazines (44.9%), with the Internet accounting for the lowest percentage (7.4%). In 2020, TV (85.5%) and Internet (74%) became the top two channels for scientific information. Among these, the Internet has become the first choice for Chinese citizens (49.7%), while only 31.9% preferred TV. Overall, TV has always been the main channel, but the role of the Internet is rapidly growing.

Visiting science-related facilities is also an important element of informal education. As shown in Table 2, the zoo, aquarium, and botanical garden have long been top of the list of all such facilities visited by the public, closely followed by the library. The museum of natural history and the science museum maintain a tied position in third and fourth place. In 2005, only 9.3% of people visited the science museum, while 56% did not go owing to no local museum being available (Ministry of Science and Technology of PRC, 2007). In contrast, by 2020 the rate of visits had increased to 37.2%, mainly because the Chinese government had constructed many such museums precisely as a means of promoting informal science education. The number of science museums grew from 1477 in 2019 to 1525 in 2020 (Lei, 2021). In addition, the State Council (2006) has issued a policy document that suggests that research institutions and universities should open up to society by November 2006, allowing the public to visit laboratories and facilities, see research processes, etc. In 2019, state key laboratories, major scientific and technological infrastructures, and other research institutions and universities opened their doors, resulting in sustained growth in the number of science activities (11,600) and visits (9,479,700) (Ling, 2020).

4 Obstacles to the Improvement of CSL

4.1 Utilitarian Science Education

4.1.1 History and Tradition

Science education in China lacks cultural grounding and roots. Traditional Chinese culture attaches more importance to the humanities than to science and technology (Peng, 1999). For more than 2000 years, Confucianism played a dominant role in Chinese school education, while science was always regarded as work for inferior craftsmen (Wang et al., 2020). This deep-rooted history makes it difficult for Chinese society to form a scientific cultural atmosphere very quickly. Moreover, modern science education is linked to national salvation and prosperity. Utilitarian aspirations tend to neglect education on the nature of science, scientific thinking, etc.

Specifically, in feudal society, which lasted more than 2000 years, Confucianism played the dominant role, and the five Confucian classics (Shi, Shu, Li, Yi, and Chun-qi) monopolized school curricula. Even though the “four great inventions”—the compass, gunpowder, paper-making, and printing—were produced, modern science did not emerge in China. Why? This is the famous “Needham’s Grand Question”. Zhang (2006) summarized the explanations of other scholars, one of which is that Confucianism rejects natural science. Specifically, Confucianism is essentially an ethical philosophy that values moral self-cultivation, while science was always regarded as “the craftsmen’s work unqualified to take its place in the higher circles” and even as something that should be forbidden through political power. Moreover, Confucianism emphasizes the acquisition of knowledge through reading and moral practice and focuses on the interpretation and examination of classical historical books, while suppressing the exploration and practice of natural scientific issues (Zheng & Yang, 2003).

In modern China (1840–1949), science education has gone hand in hand with the thought of saving the nation from foreign invasion and colonial rule. From the 1860s to the 1890s, several of the awakened intellectuals began to call for learning from the advanced technologies of the West as a way to resist. They attributed the fundamental reason for Westerners’ strength to their technological advances. In the context of China’s saving the nation from subjugation and ensuring its survival, science education focused on the technical level with high practicability. In 1915, the New Culture Movement, an ideological liberation movement that embraced democracy and science, was launched. After this, modern science took root in China. Since the founding of the People’s Republic of China (1949), China has gradually developed the mainstream value of science and technology, which are the most important productive forces. In general, science culture is weak and science education is utilitarian in China.

Furthermore, Confucianism emphasizes hierarchy and obedience to authority. Teachers play the role of authority in the classroom, while students are passive receivers who are more inclined to believe what the teachers say instead of trying to derive their own conclusions (Maftoon and Shakouri 2012). Lee and Kim (2019) stated that when teachers adhere to their authority and power based on Confucianism, science teaching and learning face serious difficulties. In such a situation, students’ independent thinking, creativity, and autonomy are inhibited, to the detriment of the quality of science, which is not conducive to the development of CSL. For example, Chinese students, on average,

scored well ahead of the world average in science on the 2012 PISA tests, but not so well with regard to inquiry and problem-solving ability (Ren et al., 2016).

4.1.2 Examination-Oriented Education

China is a country of examinations. From the ancient imperial examination to the contemporary college entrance examination, assessments have been an important force in shaping Chinese education (Yao & Guo, 2018). The imperial examination system, which began in the Sui Dynasty (581–618) and ended in 1905, was used to select officials through assessments. Specifically, studying and being an official were closely linked, and school education revolved around the content of imperial examinations. Although there are examinations in other countries, the results of the college entrance examination have been the only criterion for students to enter university in China since 1905. The college entrance examination is thus considered to be “one test for life.” China’s exam-oriented education has a tendency to deviate from the needs of students and society, forcing students to simply cope with exams and single-mindedly pursue high scores and promotion rates.

In recent years, there have been some attempts at change. In 2017, the *New Curriculum* promoted the concept of inquiry-based teaching and STEM education. However, there are problems such as difficulty in implementing scientific inquiry, poor efficiency of experiments, and lack of student initiative (Zhang, 2018). In October 2020, the *Guideline for Deepening the Education Evaluation System in the New Era* was released, calling for a resolute end to the “scores-only” and “college enrollment rate only” evaluation. In July 2021, the “Double Reduction” policy was issued, reducing both the burden of homework and out-of-school training on students. Zhou and Qi (2021) argued that this policy provided an important opportunity to deepen education evaluation reform, but it is difficult to completely reverse the “scores-only” evaluation system in a short period of time.

In an exam-oriented education, education is reduced to “teaching to the exam,” and getting high grades becomes the purpose of education (Ran, 2010). Exam-oriented education has three negative effects on science education. First, test-oriented education is an education for the top few students at the expense of the majority. Many students who are interested in science and have a talent for it may be overlooked by their teachers or even lose the opportunity to continue studying science just because of their low grades. Second, due to the status and weighting of marks for the compulsory subjects of language, mathematics, and foreign languages, schools are given priority in the allocation of teachers and teaching resources in those fields in preference to natural science. Third, in order to cope with exams, teachers only teach exam content. Most Chinese teachers focus on exercise-centered teaching methods and instilling scientific knowledge in their students, neglecting the cultivation of the scientific method and scientific spirit. Simple indoctrination and rote memorization may stifle students’ interest in science, creativity, imagination, and innovation. Students are thus treated as nothing more than learning and examination machines.

Maienschein et al. (1998) argued that there are two different definitions of SL. One emphasizes the short-term effects of gaining scientific knowledge, while the other emphasizes the long-term process of thinking critically and creatively. The pursuit of short-term, rapid scores and talent output in China’s exam-oriented education system makes it difficult to achieve the long-term goals of scientific literacy. Recently, a role for NOS in supporting scientific literacy has become widely institutionalized in curriculum standards internationally (Allchin, 2014). In China, *Science Curriculum Standards for Compulsory Education (Grades 7–9)* also clearly states that the science curriculum should lead students to an

initial understanding of the nature of science. However, given the pressure of examinations, teachers are more likely to focus on inculcating science knowledge and rote learning. Education in the nature of science is often overlooked (Xiang, 2002). In addition, contents of science exams that rely on curriculum standards are often detached from real social issues and do not contribute to the development of practical problem-solving skills.

Even if exam-oriented education has many obvious drawbacks and has adversely impacted the effectiveness of science education, it will not be easy to change even in the long term. One important reason is that the examination is fair, objective, and open to all, especially for lower-class people.

4.1.3 The Division of Arts and Science Education

At the beginning of human civilization, there was no division between the arts and sciences. As the total amount of knowledge expanded, schools began to implement the division of arts and sciences (Cai & Wang, 2009). After the Opium War in 1840, China began to learn science and technology from the West for the survival of the nation. In 1909, the Qing government studied the German educational system and introduced the division of arts and sciences. Since then, the arts and sciences have been divided and combined several times. However, the two have been separated more often than they have been joined. It was not until after the founding of the People's Republic of China in 1949 that the division of arts and sciences was steadily enforced.

The Soviet Union was the first country to establish diplomatic relations with the People's Republic of China in 1949. Relation between the two countries was in a honeymoon phase. During the World War, the Soviet Union lost a large number of scientists and intellectuals, so after the war, it implemented the division of arts and sciences to train people for social and economic development. At this time, the Chinese education system was Sovietized. Specifically, China steadily implemented a division between the arts and science in senior high school from 1954 to 2014. In addition to the three compulsory courses (language, mathematics, and English), the other courses were divided into arts (politics, history, and geography) and science (physics, chemistry, and biology), whereby students were only required to select one of the two categories to study. Zhu (2004) argued that this division of the arts and sciences was a cancer in China's basic education, leading to a lack of humanistic literacy among students majoring in science and a lack of scientific literacy among students majoring in the arts. Ren et al. (2013) found that students majoring in science have a higher level of SL than students majoring in the arts.

In 2014, the State Council abolished the division of arts and science. This was followed by reforms in various provinces, the most influential of which was the "3+3" model in Zhejiang, which meant that in addition to the three compulsory courses, students were free to choose any three of the remaining six subjects. However, problems and critiques have also arisen. For example, reforms lead to an increased utilitarian bias in subject selection (difficult subjects, such as physics, tend to be dropped), an increased student burden, and more complex operations (i.e., various subject combinations, grade allocation, and the walking class system⁴) (Liu, 2019). In addition, due to the constraints of classrooms, teachers, and other resources, schools can only introduce popular combination options rather

⁴ Students move to different classrooms depending on the subject they choose.

than true freedom of choice (Dong et al., 2017). For quality reasons, universities tend to make distinctions between arts and sciences in admissions, further limiting flexibility.

Ren et al. (2013) found that educational factors influenced CSL to a lesser extent in China than in the United States, which he attributed to the latter's early division of arts and science and the lack of general science education in college. The division of arts and sciences in high school has blocked access to science classes for students majoring in arts. After entering university, students majoring in science also only study sub-disciplinary knowledge, making it difficult to form an integrated perception of science. Conversely, in the United States, college students are required to take a general science course, which is one reason driving these students' slim lead in CSL (Miller, 2007). The division of arts and sciences has left students with a structural bias in their knowledge and qualities, with students in the arts having shortcomings in scientific knowledge and methods, while students in the sciences are prone to a lack of understanding of the impact of science on individuals and society and of the relationship between science and the humanities. For example, the birth of gene-edited babies is against social ethics, and the use of nuclear weapons in World War II caused huge casualties.

4.2 Uneven Development

As shown in Table 1, the rates of CSL in rural areas and elderly groups are always the lowest; although they have increased in recent years, they are always well below the national average. The elderly and rural citizens have always been a weak link in improving SCL. The unbalanced development of urban and rural areas and different age groups is not conducive to the improvement of the overall CSL of the nation.

4.2.1 The Gap Between Urban and Rural Areas

The rural areas are the short slab in the construction of CSL. Zhu and Wang (2019) argued that science education currently is a form of elite education and that there is an imbalance between urban and rural children.

There exist significant differences in science education resources between urban and rural areas, such as in education funding, laboratory equipment, professional teachers, and education methods. For example, science teachers in rural areas often work part-time and possess low levels of education themselves (Zhang, 2020). It is also difficult for rural children to get into urban schools and enjoy their resources. This is because China's long-standing household registration system has strictly separated urban and rural areas, which has been directly linked to social welfare systems such as education. For example, out-of-town students have been required to pay a certain amount of fees to attend school. Although the system is currently being reformed, tens of millions of migrant children are still facing serious difficulties, including a lack of equal access to school and social integration (Han, 2021). Yuan and Mu (2018) argue that governments often go against national policy to defend or expand local interest in cities, making it difficult or impossible for rural farmers' children to enter city schools.

Furthermore, in addition to formal education, informal educational resources such as science museums, planetariums, and access to online science resources are also lacking in rural areas. Take web resources as an example. As shown in Table 1, the Internet has become the first choice for Chinese citizens to get scientific information. Moreover, the positive impact of Internet use on SCL among citizens has been highlighted (Luu &

Freeman, 2011). However, rural areas have much less access to Internet resources than urban areas. As of December 2006, urban Internet users accounted for 82.9% of all Internet users, while rural Internet users accounted for 17.1%. After 15 years, rural Internet users still account for only 27.4% as of December 2021, at a time when the rural Internet penetration rate is 57.6% (CNNIC, 2022).

There is a large gap between urban and rural areas in both formal and informal science resources, resulting in an uneven distribution of national CSL. The latest survey showed that the size of the rural population has remained high, at 36.11% of the total population (National Bureau of Statistics, 2021a, 2021b). Improving the CSL of rural citizens is thus important to improving the overall CSL.

4.2.2 Growing Aging Population

In China, the proportion of citizens over the age of 60 has been rising, from 10.33 in 2000 to 18.7% in 2020, while the proportion of those aged 65 and over went from 6.96 in 2000 to 13.5% in 2020 (National Bureau of Statistics, 2021a, 2021b). The declining birth rate is the reason for the graying of China's population (Wu et al., 2004). In 2020, China's birth rate reached its lowest ever rate of 8.52‰ and a total fertility rate of 1.3, which is below the alert level of 1.5 (National Bureau of Statistics, 2021a, 2021b). The declining trend is closely linked to China's long-standing family planning policy, which was listed as a basic state policy since the 1980s: the state limited a couple to only one child. It was not until November 2013 that the two-child policy was gradually implemented. This new policy has led to a small short-term increase in the birth rate, but the overall trend continues to decline (National Bureau of Statistics, 2021a, 2021b). In general, Meng et al. (2016) found that the two-child policy does not have a significant mitigating effect on population aging. Thus, in May 2021, China adopted a three-child policy, allowing a couple to have three children.

Wang (2021a, 2021b) argued that only by improving the CSL of the elderly can China adapt to the new challenge posed by an aging society and ensure a steady increase in SCL. However, the CSL of the elderly is low nowadays, and there are also many other problems in the improvement of CSL for this group. Wang (2021a, 2021b) discovered the seriously inadequate supply of science education resources and an unbalanced urban and rural configuration for the elderly. Research on the preferences and needs of the elderly is insufficient, and market supply capacity is low. Suitable science venues and platforms are limited. Overall, the growing number of elderly and inadequate education constrains the growth of overall CSL.

4.3 Limited Participation Mechanisms

After the founding of the People's Republic of China, a planned economy system gradually emerged, in which governments determined and arranged the allocation of resources directly. It was not until the reforms and opening up to the outside world of 1978 that the planned economy began to change into a market economy. However, Wu et al. (2005) stated that the construction of CSL in China is still too political and planned. Specifically, the construction of CSL is motivated by the need to revitalize the country rather than the citizens' own development, and the government still has an important dominant role even in the market economy.

More specifically, in China, science popularization has always been highly organized, conducted by a specially established government agency (CAST). CAST includes national

and local associations of science and technology at all levels. In general, at present, science popularization is generally enacted from the central to the local level, and the local governments follow the instructions of higher authorities rather than responding to the needs of the public, with unclear interaction with the public in terms of the relevant policies (Li et al., 2018). The result is that public interest and needs are not well attended to and met, thus limiting the improvement of CSL. This includes two specific points, as follows.

4.3.1 A One-Way Science Communication Model

One-way, top-down communication of prepackaged scientific information does not work in Western countries (Trench, 2008). However, this model has always dominated China. The one-way communication model tends to ignore public concerns, resulting in a misalignment between what is communicated and what is needed and what would hold the public interest. It is difficult to guarantee that the science being disseminated is being followed and absorbed, which can affect CSL.

There are three main models of science communication, namely, the central broadcast model (Liu, 2009), the deficit model, and the dialogue model (Trench, 2008). The central broadcast model is unique to China, in which science communication takes the method of cramming teaching. The deficit model is a form of one-way communication from experts who possess the relevant knowledge to the mainstream public that does not. In contrast, the dialogue model engages the public in two-way communication, drawing on the latter's own information and experiences. Compared to the dialogue model, the first two models do not take a public stand and emphasize the one-way flow of knowledge from communicator to audience. Today, the central broadcast and deficit models remain the main models implemented by Chinese government, with relatively weak interaction with the public (Yan et al., 2019). For instance, Wu and Luo (2019) found that the deficit model has been applied to socio-scientific issues, while the dialogue model was not really utilized.

The deficit model has been criticized on empirical and theoretical grounds. One assumption of the model is that the general public's knowledge deficit can be remedied by one-way science communication. However, it neglects a possible mismatch between what the public expects from science and what a scientist can legitimately tell them (Ahteensuu, 2012). This model gives the impression that the knowledgeable social elite can "condescend" to the public to instill science (Zhai, 2008). One-way communication does not provide insight into the real needs and interests of the public, thus limiting the effectiveness of science communication and knowledge uptake.

4.3.2 Lack of Public Engagement Platforms

A number of science educators and policy documents have claimed that scientifically literate citizens must be able to engage in making decisions on science-based social issues (Yacobian, 2018). The definition of CSL in the *Outline of Scientific Literacy* includes the ability to participate in the affairs of society. It was found that citizen engagement in science significantly improved their attitudes towards science and their understanding of scientific processes and situations (Bonney et al., 2016; Queiruga-Dios et al., 2020). However, the Chinese currently lack the opportunity to participate, limiting the development of the competencies required for CSL.

In China, the forms of public understanding and participation in science are seriously inadequate (Wang et al., 2016). Moreover, the lack of demand orientation and the

superficiality of the activities have led to a weak vitality and low willingness for grassroots science and technology activities (Huang, 2011). Specifically, China's science popularization projects or activities are mainly driven by national policies, led by CAST, and jointly implemented by local governments and responsible departments. The National Science Popularization Day and Science & Technology Week are important science and popularization activities in China,⁵ the themes of which are closely related to the hot topics of national science and technology and economic and social development. Most of these activities take the form of lectures and exhibitions, and other forms include expert consultation, scientific training, open access to research institutes, etc. Field surveys reflect the fact that the public's demand for science popularization has diversified and a few lectures can no longer meet the real demand (Qi et al., 2015). Other activities include the "National Mobile Science Museum" and "Popularization of Science in China: Action of a Hundred Cities, Thousands of Schools, Ten Thousand Villages." Despite of this wide geographical coverage, such projects or activities in China have mainly taught or disseminated scientific knowledge, and have not given citizens the opportunity to participate in scientific research, decision-making in public affairs, or democracy building.

In Western countries, over the past 20 years, thousands of citizen science projects engaging millions of participants in collecting and/or processing data have sprung up around the world (Bonney et al., 2016). The term "citizen science" (CS) was coined by Irwin in 1995, which commonly refers to the involvement of the general public in different stages of the scientific process, often during data collection or analysis (Bonney et al., 2009). For example, the Cornell Lab of Ornithology (CLO) has operated numerous citizen science projects about birds (e.g., *Project PigeonWatch*, *eBird*), and citizens have provided a vast quantity of data about species occurrence and distribution. Citizen science emphasizes the collaboration between non-expert citizens and specialist scientists. However, scientists rarely interact with the general public in China, let alone collaborate. In a survey of nearly 700 Chinese scientists, 74.37% of them were not motivated to participate in science communication, because no assessment mechanism has been included thus far (Wang & Jia, 2017). Many funding applications in developed countries require a specific portion of the funding to be spent on public education, such as with the National Science Foundation of the United States; many research institutes also provide systematic support. Such measures promote the public participation of scientists, but this approach is lacking in China. In general, there is a lack of citizen engagement projects like citizen science in China.

5 Conclusion and Discussion

During the implementation of the policy established in the *Outline of Scientific Literacy*, CSL in China increased from 1.6 to 10.56%, still showing a big gap with developed countries. For example, CSL in the United States was close to 10% in 1988 and reached 28% in 2008 (Miller, 2016). CSL in Canada had reached 42% in 2014, 35% in Sweden in 2005, and also remained above 10% in Ireland, Finland, Germany, France, the UK, and Italy in 2005 (Council of Canadian Academies, 2014). Liu et al. (2018) argued that even though Miller's three-dimensional construct was abandoned internationally, China continued to use it to test CSL, making the

⁵ The former is on the third public holiday in September each year since 2003, and the latter is in the third week of May each year since 2001.

results meaningless for the purposes of international comparison. Specifically, the first nine surveys (1992–2013) on CSL in China made direct use of this construct. Nevertheless, the United States had a CSL rate of close to 10% in 1988, when the US used the same construct—Miller’s—that was also adopted in China, indicating that China was at least 30 years behind. Since 2015, China has begun to develop a six-dimensional assessment system based on the two dimensions of knowledge and ability. How to make this measurement both suitable for China and internationally comparable is currently a major challenge.

Today, China’s informal science education resources are underutilized. It was once believed that the use of science museums and the Internet were positively correlated with CSL (Miller, 2002). To date, China has established numerous science museums, but the current study found that only 37.2% of Chinese citizens visit them. Conversely, a survey conducted in 2005 showed that 61% of Europeans visited science museum because this interested them (Eurobarometer, 2005). This may be seen as somewhat different to the context in China as, at present, Chinese science museums place a greater emphasis on educational functionality and rarely consider their entertainment value (Tong, 2009). This lack of entertainment may thus be affecting the public’s interest in science museums. Schwan et al. (2014) found that visiting science venues (e.g., science museums, zoos) can bring not only knowledge acquisition in a narrower sense but also changes in interest and beliefs. Improving the attractiveness of science venues may be a good course of action for China.

This study also found that the Internet was an important source of access to scientific information for the general public outside of school, of which WeChat, a social media platform, accounted for the largest proportion. A study showed that students with prior experience of ICT (information and communication technology), who browse the Internet more frequently, earned higher scientific literacy scores (Luu & Freeman, 2011). At present, many areas in China still do not have Internet coverage, especially in rural locations. Moreover, the fact that everyone can be a communicator makes the quality scientific information on the Internet somewhat dubious at times, with rumors prone to being spread. For example, Li and Yu (2018) found that scientific rumors accounted for 47.1% of the 4160 most widely circulated rumors in China. Thus, given the current extent of Internet coverage in China alongside the existence of such science rumors, the value of improving CSL via the Internet might be limited in this country context. In particular, rumor has been found to proliferate significantly further, faster, deeper, and more broadly than the truth in social media (Vosoughi et al., 2018). Therefore, social media platform needs to be used dialectically in order to enhance CSL.

At present, China’s drive towards science popularization is mainly one-way and knowledge-based, with weak possibilities for mainstream citizens to participate in social decision-making and the construction of democracy. Wang et al. (2016) argue that Chinese citizens face institutional obstacles to science participation. Specifically, Chinese policy making and risk assessment in the field of science and technology is controlled by experts. There also exists the preconceived notion that citizens lack scientific knowledge, in turn making the institutional design lack a platform for citizen participation. In contrast, gathering citizens to initiate dialogue and decision-making is a common practice in developed countries, such as consensus conference (Joss & Durant, 1995), citizens’ juries (Kenyon et al., 2003), and citizen science projects (Bonney et al., 2016). Moreover, the construction of CSL in China is rooted in collectivism that may affect individuals’ participation. Tian et al. (2006) found that western countries place more emphasis on the individuals and their interests, while China tends to ask its citizens to improve CSL for national and ethnic revitalization. Nowadays, Vision-III of SL is more in line with the challenges of the twenty-first century (Valladares, 2021), which should be characterized by what is called a

“science engagement” compared to Vision-I and Vision-II (Liu, 2013). Thus, China should pay more attention to engagement in its construction of SCL.

There were two main limitations to this study. First, because the specific data of every SCL survey is not open data, reliance on these simple, publicly available data has limited our ability to perform an in-depth analysis. Second, the discussion of obstacles in Sect. 4 relies on generalizations from existing research, and no quantitative research has yet been conducted to demonstrate the relationship between these factors and CSL. Considering the difficulty of conducting a national survey on an individual basis, small-scale surveys could be conducted in collaboration with local governments in the future.

In general, while China’s CSL rate is steadily improving owing to the promotional drive of government policies, there remains a major gap between China and developed countries due to the low starting point of CSL itself in the former. In addition, there are limitations in both the country’s formal and informal science education, meaning that there is still a long way to go for the construction of CSL in China.

Acknowledgements We would like to thank the China Association for Science and the Technology and China Research Institute of Science Popularization for providing the national survey data on CSL. In particular, we thank Dr. Ren Lei from CRISP for providing the latest 2020 survey data.

Funding The research was supported by the Key Project of China National Social Science Fund (grant 20FXWA003).

Declarations

Ethics Approval and Consent to Participate Not applicable.

Competing Interests The authors declare that they have no conflict of interest.

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