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Rational Examination of Cultivation of Talent Reserve for Scientific and Technological Innovation in China

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Abstract

It is an important guarantee for China to win the first chance in the future international competition to vigorously cultivate the talent reserve of scientific and technological innovation. This study first proposes that China urgently needs to pay attention to the early training of scientific and technological innovation talents from the international situation, existing policies, and the current educational situation. Then it dynamically examines the training theory and practical experience of scientific and technological innovation talent reserve from an international perspective, and further considers the critical understanding and key issues of early training. Finally, some suggestions are given on the cultivation in order to promote the policy designation and practical innovation in China.

Keywords

scientific and technological innovation; talent reserve; early cultivation

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Rational Examination of Cultivation of Talent Reserve for Scientific and Technological Innovation in China

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Abstract: It is an important guarantee for China to win the first chance in the future international competition to vigorously cultivate the talent reserve for scientific and technological innovation. This study first proposes that China urgently needs to pay attention to the early training of talents for scientific and technological innovation considering the international situation, existing policies, and the current educational situation. Then it dynamically examines the training theory and practical experience of the talent reserve from an international perspective, and further expounds the critical understanding and key issues of early training. Finally, some suggestions are given on the cultivation in order to promote the policy designation and practical innovation in China. **DOI:** 10.16418/j.issn.1000-3045.20210518007-en

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On May 28, 2018, General Secretary Xi Jinping delivered an important speech on the 19th Academician Conference of the Chinese Academy of Sciences and the 14th Academician Conference of the Chinese Academy of Engineering. As pointed out by him, the whole history of science and technology has proved that whoever has top-notch innovative talents and scientists will have an advantage in scientific and technological innovation. Innovation is the primary engine of development, and talents are the fundamental source of scientific and technological innovation in a nation. In the recent half century, Western developed countries have actively intervened in science education and national talent strategy from top to bottom by formulating long-term strategies, science education standards, and laws. For example, the United Kingdom rolled out the Education Reform Act, which explicitly included science, mathematics, and language (English) as the three core subjects. The United States has formulated the Federal Science, Technology, Engineering and Mathematics (STEM) Education Strategic Plan (2013–2018) to promote the full implementation of science education. China has ushered into a new development stage of building a modern socialist country in all respects, during which the improvement of citizens' scientific literacy and the cultivation of innovative ability have become the key issues. However, up to now, China has still been faced with the dilemma of lack of innovative talents in some scientific and technological fields. Training talents for scientific and technological innovation is a must-have precondition for China to win the first chance in the future's international competition, and the strength of the future comes from cultivating talents at present. Primary and secondary schools are the key period for training talents for scientific and technological innovation. In order to solve the long-term deficiency in the training of innovative talents and fundamentally address the shortage of high-level innovative talents, it is necessary to consolidate the major goal of strengthening China with science, technology, and talents, to make forward-looking arrangements for science education in primary and secondary schools, and to rebuild the basic science education system in the new era.

1 The status quo of the early training of talents for scientific and technological innovation in China

1.1 New international pattern promotes early training of talents for scientific and technological innovation in China

The new pattern of international competition highlights the importance of innovative talents. According to the 2020 Global Innovation Index, the economies with good innovation performance are mostly from high-income groups, such as Switzerland, Sweden, the United States, the United Kingdom, and the Netherlands. The only exception is China, which ranks 14th for two consecutive years and is the only middle-income economy in the top 30. However, we should be soberly aware that China has yet to improve its human

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capital. China ranks 62nd in terms of student-teacher ratio in secondary schools among 130 economies and 48th in the world with 1 307.1 full-time researchers per million people. The student-teacher ratio refers to the ratio of the number of students to the number of full-time teachers at school, an important index used to measure the level of a school in teaching evaluation. The proportion of research personnel also shows the reserve status of innovative talents to a certain extent. The two indicators suggest that China does not have an obvious advantage in the human capital of innovation. In recent years, the international community has paid special attention to the professional education of young people with scientific and technological literacy and development potential, and vigorously promoted the relevant policies and practices of personnel training. Different from the science and technology literacy education for all students, many countries advocate and practice the personalized training mode and professional path of talents for scientific and technological innovation. In order to enhance their scientific and technological strength, innovative countries such as the United States, Canada, the United Kingdom, Germany, Japan, South Korea, Singapore, and Israel attach great importance to the early cultivation of scientific and technological innovative talents [1]. They concern more on not only higher education but also STEM education and improvement of scientific literacy in primary and secondary schools [2]. The comprehensive strength and core competitiveness of a country depend on the scientific and technological innovation ability, which are fundamentally decided by innovative talents. The primary and middle school period is the golden stage and the key node of talent cultivation. Therefore, it is urgent for China to prioritize the early cultivation of talents for scientific and technological innovation.

1.2 Policy support is insufficient for science education in primary and secondary schools in China

Since the 18th CPC National Congress, China has entered a new stage of comprehensively promoting the cultivation of innovative talents, and the cultivation plan has been put forward continuously. In 2012, the Ministry of Education of China issued the Twelfth Five-Year Plan for the Development of National Education, which made a special discussion on strengthening the cultivation of innovative talents. In 2013, the Ministry of Education and the China Association for Science and Technology launched the Talents Program for Scientific and Technological Innovation for Middle School Students. In 2015, the State Council issued the Overall Plan for Promoting the Construction of World-class Universities and First-class Disciplines, which emphasizes the need to cultivate top-notch innovative talents. In 2018, the Ministry of Education and other six administrations continued to implement the Top Student Training Plan 2.0 for Basic Disciplines and put forward a guidance plan. In 2020, the Ministry of Education issued The Opinions of the Ministry of Education on the Pilot Work of Basic Discipline Enrollment Reform in Some Universities, and decided to carry out the relevant work from 2020. However, on the whole, there are few accurate policies for the training of talents for scientific and technological innovation in primary and secondary schools, and little attention has been paid to the systematic work.

1.3 Scientific career expectation and hands-on ability of primary and middle school students are not optimistic in China

According to the report of the 2015 Programme for International Student Assessment (PISA) released by the Organisation for Economic Cooperation and Development (OECD), the 15-year-old students from Beijing, Shanghai, Jiangsu, and Guangdong have superior science performance in the world, whereas their science career expectation only ranks 68th among the 72 countries and regions surveyed. *China Educational Statistics Yearbook 2018* shows that the number of science teachers is only 12% of that of mathematics teachers in primary schools. Moreover, the academic qualifications of science teachers in primary schools are the weakest among all disciplines in basic education, with a junior college degree accounting for 47% and a bachelor's degree accounting for 45%. The Quality Monitoring of National Compulsory Education in 2018 shows that the primary and middle school students have strong scientific understanding ability while weak scientific inquiry and thinking abilities. Compared with that of scientific understanding ability, the proportion of students with scientific inquiry and scientific thinking abilities reaching the middle or above level is lower. Moreover, the students have fewer opportunities to participate in hands-on experiments and practical investigations in science classes. Specifically, 46.8% of fourth-grade students often do hands-on experiments in science class this semester, and 19.0% never or hardly do so; the proportion of eighth-grade students who have done three or more hands-on experiments in biology class is 19.3%, and that of the students who have never done is 47.1%. The above problems have obviously hindered the emergence of scientific and technological talents in China, making it difficult to meet the demand of talent reserve for building a great country in science and technology.

2 Dynamic examination of the theory and practical experience of the cultivation of talents for scientific and technological innovation

2.1 Practice of creativity cultivation: From element deconstruction to coherence and emergence

The early classical research on creativity in China was conducted by Lin Chongde [3] who proposed the psychological structure of creativity, i.e., creative talent = creative thinking + creative personality. After that, the research focus transferred from cognitive and psychometric thinking to the systematic attention of ability and process, emphasizing the innovative quality system. For example, Zhang et al. [4] put forward that the innovative quality system is the result of the interaction of seven elements including knowledge, thinking, monitoring, cooperation, practice, motivation, and personality. Since then, the "5C" model of core literacy in the 21st century has been comprehensively put forward. Zhang et al. [5] believe that innovative literacy includes three elements: innovative personality, innovative thinking, and innovative practice. While innovative personality and innovative thinking are the basis of innovative practice, innovative practice is the comprehensive expression of innovative personality and innovative thinking in the scenarios of specific tasks. Generally speaking, the dynamic understanding of creativity is based on cognitive basis, non-cognitive factors, and environmental system. The 4C model developed to characterize the level of creativity is composed of mini-C, little-C, professional-C, and big-C [6]. Each person has the potential of mini-C, the ability to interpret learning experiences and activities in a meaningful, different or personal way. Little C characterizes the problem-solving ability and creativity in everyday life. Professional-C refers to the creativity of people with certain professional qualities. Big C refers to creative excellence, as demonstrated by scientists such as Albert Einstein. Each of these four stages is possible for everyone, with the pattern of development being different [7]. To protect students' mini-C, we should promote the generation of scientific culture by interdisciplinary, general, and diverse science education, and provide a broad foundation for the emergence of talents. To guide little C in the process of education, we should provide a channel for accelerated development of students who specialize in science and technology in a consistent and experiential way of learning, so that they can gradually develop their creativity in science and technology. The discovery of professional C is the educational goal of senior high schools and universities, and only a few outstanding scientists can achieve big C.

2.2 Cultivation conception of innovative talents: from one dimension to multiple interactions

There are rich training modes for innovative talents in the general field [5]. With the development of Munich model, the focus of training has gradually shifted to coherence, continuity, and the interactions among individual learning, social culture, and family climate. The dynamic model of gifted child development focuses on the combination of internal performance tendency, good personality, and environmental factors, and the child finally makes extraordinary achievements in the active learning process over time (Figure 1) [8].

The Munich model of giftedness designed by Heller et al. [9] focuses on non-cognitive personality characteristics (moderators), environmental conditions (moderators), talent factors (predictors), and performance areas (criteria). The non-cognitive personality characteristics include the ability of coping with stress, achievement motivation, learning and working strategies, test anxiety, and control expectations. The environmental conditions include familiar learning environment, family climate, quality of instruction, classroom climate, and critical life events. The talent factors include intellectual abilities, creative abilities, social competence, practical intelligence, artistic abilities, musicality, and psycho-motor skills. The performance areas include mathematics, natural sciences, technology, computer science, chess, art (music, painting), languages, athletics, sports and social relationship (Figure 2). Generally speaking, the cultivation of innovative talents in the general fields has three modes: (1) intelligence-oriented mode, involving intelligence model structure, infinite talent model, multiple intelligence model and so on; (2) comprehensive mode, including the talent search mode and whole school enrichment mode; (3) activity-oriented mode, such as autonomous learning mode, creative problem-solving model, Purdue three-stage model, Kaplan framework model, and Meck matrix model [10]. However, at present, the international academic circles mostly focus on the research of innovative talents in the general field and do not highlight the characteristics of science and technology. In the future, we still need to study the law of growth and pay attention to the innovative value orientation of the cultural influence in different countries or regions [5].

3 Early cultivation of talents for scientific and technological innovation

3.1 Critical analysis

Social culture has an impact on the implicit concepts of talent in a specific environment, and cultural values will also affect the support for the development of talents in specific fields [11]. Traditionally, the constituent elements of gifted children include general cognitive factors and non-cognitive factors [12]. From the perspective of the cultivation path of innovative talents, educators pay attention to the influence brought by the external environment, and try to prevent the external factors from hindering the development of these students through opportunity equalness, integrated and accelerated mode, as well as the learning mode with separation from normal school. What is the actual effectiveness of these methods? Whether the needs of individual development are reflected? Whether the personality development process of different students is concerned? What is the intensity of the implementation of relevant strategies? Whether the evaluation results lag behind or interfere with the implementation process? All of these questions trigger our introspection on the traditional cultivation model. The United States steps up the development of talents for scientific and technological innovation through STEM education. The early pipeline theory tries to respond to the brain drain in STEM, believing that the middle school stage sees the most serious brain drain

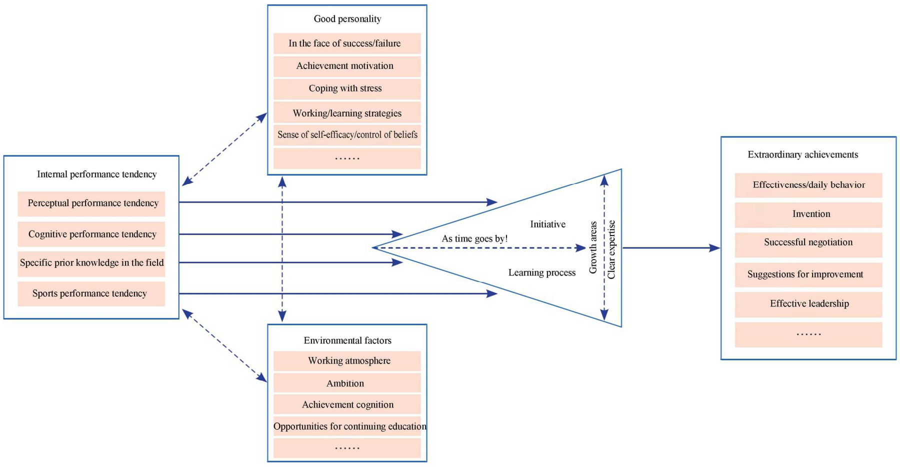

Figure 1 Dynamic model of gifted child development [8]

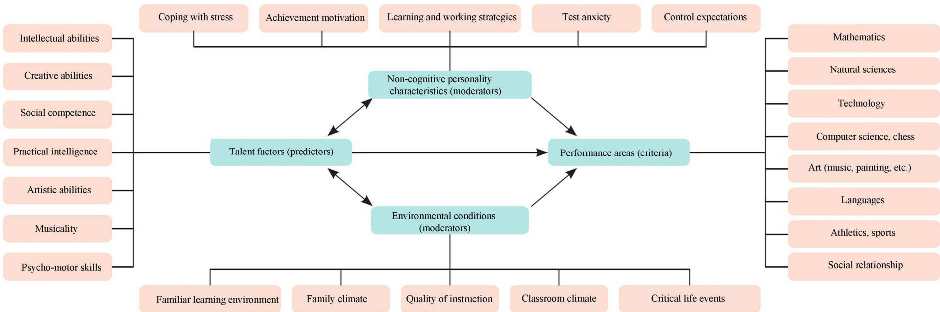

Figure 2 Schematic diagram of Munich genius model [9]

from primary and secondary school to STEM major [13], which demonstrates the importance of innovative talent training at the stage of basic education [14]. However, the pipeline theory assumes that the trajectory of learning and career development is linear and irreversible, which cannot explain the phenomenon that some of the talents turn to the STEM major halfway [15]. The Sankey diagram of STEM practitioners shows that the trajectory of students from learning to choosing a STEM career is not linear and unique, but a combination of various possible ways [16].

3.2 Key problems

In the new era, the cultivation of talents for scientific and technological innovation in China needs to pay attention to the early training in primary and secondary schools, and further consider its essential connotation and evolution. The identification and selection of talents for scientific and technological innovation has developed from natural IQ to successful intelligence, and the training mode has shifted from giftedness paradigm to talent development and differentiated teaching. The focus of the curriculum inside and outside the school has shifted from homogeneity to heterogeneity, and the training principle from achieving external goals to internal and external goals and concerning more about the value orientation [17]. The evaluation system of talents for scientific and technological innovation has also changed from unitary to multiple intelligences, and from domain exclusivity to equal emphasis on domain generality and exclusivity. Based on this, consensuses have been reached in the academic circles on five key issues concerning the cultivation of talents for scientific and technological innovation in primary and secondary schools. (1) The formation of talents for scientific and technological innovation is the result of interaction of IQ and creativity with external environmental factors. Although there is an IQ threshold for the talents, environmental factors play an important role on individuals. (2) The selection and training of talents should give consideration to the coordinated development of practical ability and comprehensive quality. (3) It is necessary to provide heterogeneous courses for talents and establish a dynamic personalized development path. (4) In the process of education, it is essential to promote the integration of external social value orientation and internal individual development demands. (5) There is an urgent need to build an omni-directional training system from primary and secondary schools to undergraduate and postgraduate students with long-term research funding provided.

To sum up, talents for scientific and technological innovation present the changes in internal structure and function during the interaction between human and external environment, as well as the external individual differences presented by such internal development, that is, excellence in specific scientific and technological fields. Education plays an important role in talent cultivation, and the assessment of talents involves many aspects, such as cognition, social and emotional skills, belief, personality and so on. The development of the talent reserve for scientific and technological innovation goes through three stages with different tasks, training modes and educational goals. (1) The stage of stimulating interest and supporting (preschool–third grade): Attention should be paid to the germination and maintenance of mini-C, to stimulate students' interest in science learning, and allow them to maintain positive learning habits and emotions. (2) The stage of self-exploration and orientation (fourth–ninth grade): Attention should be paid to the development of little C, maintain students' interest in science and cultivate positive scientific epistemology. In this way, students can explore themselves in a broader and deeper manner, and form a stable initial orientation for scientific learning, which facilitates advanced thinking and builds a solid foundation for science. (3) The stage of professional specialization and talent display (tenth grade–university): Attention should focus on the cultivation of professional C, encourage students to have more in-depth exploration in one or more fields of science and to develop innovative consciousness, scientific research spirit, and creative problem-solving ability.

4 Suggestions on the cultivation of talent reserve for scientific and technological innovation in China

Over the years, outstanding achievements have been made in the training of talents for scientific and technological innovation through Top-notch Plan, Talents Program, National Youth Science and Technology Innovation Competition, China Youth Robot Competition, and Little Scientist of Tomorrow sponsored by the Ministry of Education, China Association for Science and Technology and other departments. However, for the building of a powerful nation in science and technology, scale expansion, quality improvement, and mechanism innovation are needed for the cultivation of talents for scientific and technological innovation. In order to achieve the goal of building a powerful country in scientific and technological innovation by 2050, we must give full play to the forces of science and technology, education, and society, consolidate the foundation of science education, start from the baby in a down-to-earth manner, and deploy a new national science education system from the basic education stage.

(1) Attaching great importance to stimulating primary and middle school students' interest in science learning. We should implement the class hours of science curriculum and prioritize the development of science education in primary schools. It is advised that science should be treated as the same subject as mathematics and Chinese in the entrance examinations of junior high school, senior high school, and college. The structure of teaching content should be adjusted to strengthen the connection between primary schools, middle schools, and universities, emphasize the cultivation of interdisciplinary knowledge, practical inquiry and problem-solving abilities, and strengthen the test of non-cognitive factors in the examinations.

(2) Innovating the training of teachers in science education by means of science and education integration. The relevant departments of education and science and technology should organize science teachers in primary and secondary schools, science and technology counselors outside schools, experts from universities and research institutions to improve the ecological network and professional team construction of science education teachers. It is suggested to step up the fostering of students majoring in science education in normal universities and encourage comprehensive universities to establish science education majors. The current scientists should be encouraged to participate in the training of future scientists. A double system of science and technology experts + school science teachers should be established to innovate ways of cultivating young minds.

(3) Providing a special green channel for teenagers with special potential at the stage of basic education. Fair education makes students perform their best and provides young students with the potential of scientists to be trained as top-notch talents. It is suggested that primary and secondary school students with scientific and technological potential should be selected to set up genius classes and schools with scientific and technological characteristics. Academicians and high-level scientists are encouraged to take the lead in setting up a group of students specializing in science and technology outside schools. We should reform the talent selection mechanism in colleges and universities, set up a green channel, and make an exception for candidates with the potential of scientists, as an important supplement to the college entrance examination.

(4) Strengthening the cooperation of multiple subjects to empower the innovative development of science education. Efforts should be made to strengthen the links between all kinds of venues, research institutions, universities, and primary and secondary schools, enrich science education resources, innovate the science education mode featuring the combination of inside and outside the school, and form a coordinated mechanism. Channels should be provided for retired researchers and science education teachers to participate in science education. We should improve the docking mechanism of national science and technology programs and achievements of science foundation projects with science education, establish appropriate projects to realize the transformation of science education and facilitate the transformation of cutting-edge research achievements into science education.

(5) Combining the research and practice of scientific education. It is necessary to set up major science education research projects, build a systematic and long-term follow-up science education research system, explore the cognitive and thinking characteristics of Chinese students' scientific learning, and study the law of the growth of young talents. We should strengthen the combination of research system and practice system of science education, and bolster the research on STEM and interdisciplinary education. It is essential to adapt to the learning style in the big data era, explore the construction of the learning environment integrated with technologies as well as the learning methods (e.g., interdisciplinary learning, deep learning, and web-based learning), and strengthen the support of science education and technology.

(6) Strengthening the longitudinal research on the training of talents for scientific and technological innovation. Although the important stages and key factors of talent growth have been reported, there is a lack of empirical research. Most of the available studies, being mainly cross-sectional and retrospective studies, focus on adults and are performed in a manner of tracking causes based on phenomena. Since the growth of innovative talents is very complex, longitudinal research is extremely important, and it requires the curriculum system design with long-term educational intervention, formative tracking, and evaluation. Therefore, it is particularly important to set up a major project to study the law of talent growth and comprehensively assess the implementation effect of the top-notch talent training plan. Therefore, efforts should be made to build the science education data platform to obtain the data of talent growth performance at different stages from multiple departments, and carry out growth tracking research in coordination. Further, through establishing an evidence-based decision-making mechanism and a dynamic monitoring system for the training mode of innovative talents, we will constantly optimize the training system and the allocation of scientific and educational resources, reserve China's talents for scientific and technological innovation, and consolidate the foundation of talent training for constructing a powerful nation in science and technology.

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