Comparison Research of Scientific Thinking Cultivation in Primary and Secondary Education Between Ontario and China

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Abstract. Cultivation of scientific thinking has become an important goal in the development of primary and secondary schools in various countries. Although the cultivation of scientific thinking has been widely recognized in China, there are still shortcomings in the overall observation and research of the cultivation of scientific thinking in primary and secondary schools. In order to compare the current situation of scientific thinking education in China, this paper concludes the current situation and challenges faced by China in cultivating scientific thinking for primary and secondary school students, and Ontario's advantages in cultivating scientific thinking from the theoretical, policy and implementation levels. Through the comparative study of the two places, this paper suggests the model of scientific thinking training in Ontario primary and secondary schools can be used for Chinese primary and secondary school scientific thinking.

Keywords: Scientific thinking · Primary and secondary education · Ontario · China

1 Introduction

As science and technology influence everyone's daily life, science education has become a fast-growing branch of education, which attaches great importance to scientific thinking. As Munby defined, scientific thinking is the indirect, generalized, and dynamic reflection of the conscious human brain on the essential attributes [1]. The Chinese government has long been focusing on the development of science education, especially since the 18th National Congress of the Communist Party of China, science education has been raised attention to and been incorporated into all levels of basic education [2]. Cultivating students with scientific thinking is an essential goal. Thus, scientific thinking education plays a more and more important role in the primary and secondary curriculum in China.

The significance of scientific thinking is well acknowledged and attracts a great deal of research attention in China. Many scholars in China have analyzed the importance of scientific thinking development from a secondary school subject-based perspective. Suling Li explained that scientific thinking literacy is a core literacy in secondary school physics teaching, and that secondary school physics is a key subject for secondary

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school students to gradually develop scientific thinking, which is very important for the development of their personal thinking system [3]. Wang Gao from Jiangsu No. 2 Middle School also agrees that scientific thinking is one of the important elements of physics core literacy [4]. To summarize the expression, there is a large number of papers related to science education and discipline-based scientific thinking in China, but the holistic research and observation throughout the education process on the cultivation of scientific thinking in the primary and secondary education system is insufficient. Also, there is a lack of advanced experience in solving the problems that arise in practice regarding the cultivation of scientific thinking. Though the inquiry-based pedagogies promoting scientific thinking are well-encouraged in China, the cultural factors may also influence the implementation of such teaching strategies and reduce the effectiveness of cultivation scientific thinking style. Overall, current research on cultivating scientific thinking in China has shown a gap between theories and practices.

Since Ontario takes a leading position in the world in the field of science thinking education, this paper tries to observe analysis the current situation of scientific thinking education in China from the government policy to teaching practice and advanced experience of scientific thinking cultivation in K-12 in Ontario. By comparison, this paper tries to find a paradigm that can be used as a reference for scientific thinking education in primary and secondary school in China.

2 The Current Situation and Difficulty of Cultivating Students' Scientific Thinking in Chinese Primary and Secondary Schools

2.1 China's Policy Guidance for Science Education in Primary and Secondary Schools

Policy guidance is particularly important for the implementation of an educational concept in China. Since 2012, China has continuously implemented student training programs for the construction of basic disciplines to cultivate the scientific thinking of middle school students by benchmarking each discipline.

China's government uses relevant policies of science competitions to effectively promote middle school students' thinking ability and lay the foundation for scientific thinking. In 2013, the Ministry of Education and the China Association for Science and Technology launched the "Secondary School Students Science and Technology Innovation Reserve Talent Training Program" (referred to as the Talent Program) [5]. Since the promulgation of the policy, the Mathematical Discipline Working Committee has formed an expert team composed of famous mathematicians in China. In the following five years, it strengthened the cultivation of mathematics for young people by means of book publishing, public account media publicity, and article writing. In 2018, the Ministry of Education issued the Management Measures for National Competition Activities for Primary and Secondary School Students, guiding parents to participate in competitions reasonably and strengthening the management mechanism of competitions [6]. These policies highlight the role of science competition in promoting scientific thinking of middle school students in China. Science competition is a process of in-depth understanding, systematic arrangement, and practical application of relevant subject knowledge.

The results of competitions reflect students' ability to understand and apply subject knowledge from one aspect. In essence, subject competitions can stimulate students' strong interest in subjects, help students form a developmental knowledge structure, and help students develop exploratory intelligence and abilities. Actively participating in subject competitions can not only improve the professional quality of primary and secondary school students, but also cultivate students' good willpower and perseverance, which in turn stimulates students' enthusiasm for learning and ultimately promotes the overall improvement of comprehensive quality.

2.2 The Practice for Cultivating Students' Scientific Thinking in Chinese Primary and Secondary Schools

One of the significant features of Chinese science education is the standardization, ranging from the curriculum, performance evaluation like examinations or tests, and teachers' professionalism [7]. The Ministry of Education designs the central science curriculum and implements it on a national scale. Each province could adjust the curriculum according to the context in a marginal way and design teaching strategies in local schools. Performance evaluation is always consistent among different provinces. The evaluation of science learning is separated into two parts, knowledge acquisition and experiment application. In addition, teachers' professionalism is guaranteed by rigorous recruitment standards and continuous professional development to make sure all students gain scientific knowledge correctly standard and practice experiments critically.

The standardization does not mean there is no flexibility in the streel-level educators [8]. On one hand, teachers could design their own lesson plans after being aligned with the science curriculum in particular. They could cite academic papers or interesting episodes for grabbing attention. On the other hand, schools can design their own "textbooks" in school-based courses or curricula, which are tailored for students who have a strong interest in STEM courses. These courses are always interdisciplinary and require students to attain high levels of performance and engagement. The specific school-designed courses aim to hone their problem-solving skills and develop cross-discipline knowledge.

However, based on a large class size (in most cases, the public school accommodates 50 students in one class), it is less feasible for teachers to invite all students to discuss and debrief their experimental results. Instead, the class mode is more teacher-oriented, which means teachers deliver the basic scientific knowledge and present the experiments to arouse students' interests. But students are engaging in classroom learning and experiment participation.

To expand students' horizons, some pioneer schools in China also emphasize the importance of the application of scientific knowledge. They designed a series of science-related school activities to create an immersive learning environment [9]. For example, they invited scientific companies to host workshops or panels in school to present the most updated information in the science field. In addition, the schools took the advantage of summer break to design field trips or summer camps for those students who show great interest in science or the potential of selecting science as a career path. Through these immersive learning activities, students can gain more practical experience, enhance their critical thinking, and cultivate their ability to connect science with other contexts.

2.3 The Dilemma of Cultivating Students' Scientific Thinking in Chinese Primary and Secondary Schools

Nowadays, with the rapid development of scientific knowledge in the 21st century, the respect for science even rises to scientism. Such trend makes students rely on authorities so much that it becomes a hindrance for them to think independently [10].

The cultivation of scientific thinking is of great significance to the development of students' core literacy. Scientific thinking is formed in scientific cognition activities and runs through people's understanding of the world and transformation of the world. It can help students correctly master thinking and learning methods, develop good thinking habits, make it easier for them to succeed in learning and life, and improve student's innovation consciousness and innovation ability [11]. In today's rapid development of science and technology, these are more and more important factors for a person to make a difference. Teachers should practice the concept of focusing on cultivating students' scientific thinking in the classroom, develop the habit of scientific thinking, develop students' lifelong learning ability, and make continuous efforts to cultivate more and better learning talents and innovative talents for the country.

However, the dilemma of cultivating students' scientific thinking in Chinese primary and secondary schools is the fixed teaching pattern in Chinese primary and secondary education. Under the traditional education mode of exam-oriented education, primary and secondary school students have become accustomed to learning the content taught by teachers with fixed thoughts and ways of thinking [12]. This way of learning only allows students to copy and paste the teacher's way of thinking into their own minds and does not cultivate a form of thinking that suits them. Under this learning mode of time-fixed thinking, students will still be at a loss when they encounter new problems, and they will not be able to solve them. This is because the students' thinking has been fixed in an incorrect model and the education sector has not been reformed according to the changing times. With the development of technology, students receive more and more information. Under the impact of the huge amount of knowledge and information, if the students cannot handle the knowledge and information scientifically and systematically, it will be difficult to digest and absorb it, and it will be even more difficult to apply it flexibly. This fixed way of thinking not only lacks flexibility and innovation, but also makes students encounter many difficulties in learning, and it is difficult to break through. In Chinese schools, however, scientific teaching has long been outmoded or insufficient, with a focus on acquiring current information rather than building enthusiasm and problem-solving, interpretation, and inference abilities. To solve this problem, in the classroom, teachers must ensure that students have time to think. Teachers should not give a lot of time to repeated practice questions [13]. Too much repeating practices can only imprison the development of students' thinking, discourage students' initiative, and make students lose interest in learning. Teachers need to recognize that quality thinking is more effective than extensive practice and extension.

Scientific thinking is a style of knowledge searching that includes asking questions, testing hypotheses, making observations, finding patterns, and drawing inferences. Young children's scientific thinking is driven by natural curiosity about the world around them, and the desire to understand it and generate their own questions about it, while

formal Chinese educational contexts typically give students questions to explore or steps to follow to "do science", which potentially suppressed students' scientific thinking.

3 Ontario's Experience in Fostering Scientific Thinking in Elementary and Secondary Schools

3.1 Theories of Scientific Thinking

Modern science education not only aims to prepare students for higher education, but also meets the demands of social and economic development. As Díaz discovered, "scientific thinking" is often used interchangeably with "scientific reasoning" and is also frequently intertwined with the concept "scientific method" or the description "thinking like a scientist" [14]. However, Kuhn generalized "scientific thinking" to a common human activity for knowledge-seeking, expanding the ideology outside of science. The definition of scientific thinking in the science education field is quite different [15]. In the Oxford Handbook of Thinking and Reasoning, Dunbar and Klahr clarified scientific thinking as the thinking about knowledge of science as well as a series of reasoning processes, consisting of "induction, deduction, experimental design, causal reasoning, concept formation, hypothesis testing", which are key to critical thinking in all disciplines, not just in the domain of science [16]. Therefore, consistent with Munby, scientific thinking overlaps with critical thinking in general, but is unique by virtue of the nature of scientific knowledge [1]. Modern science education not only aims to prepare students for higher education, but also meets the demands of social and economic development. According to Broks, scientific thinking is the "backbone" of modern science education, which supports the fundamental science involving grabbing knowledge from the phenomena being observed, while applied science refers to applying newly gained knowledge into practical use [17]. Therefore, on one hand, scientific thinking could fuel scientific talents that can work for the betterment of humankind. On the other hand, it also shapes students who will not devote themselves in the science field into well-qualified citizens and preferable employees.

3.2 Educational Policy of Cultivating Scientific Thinking in Ontario

One of the goals outlined in The Ontario Curriculum Grade 1–8: Science and Technology is "to develop the skills, strategies, and habits of mind required for scientific inquiry and technological problem solving" [18]. In other words, students are required to think critically and scientifically, starting with their elementary school education. The Ontario Curriculum of Science and Technology has described "scientific thinking" explicitly as one educational goal for all students in Grade 1–8. Within the three overall goals, not only scientific knowledge, but also the habit of thinking required in scientific inquiry and problem-solving are emphasized. Although the construction of scientific worldview, advocated in Munby's discussion paper, is not explicitly written in the goal list, it is underpinned in the "big idea". The term is coined as the essential understandings that students left as some details of scientific knowledge fade in their memories. Therefore, the "big idea" is beyond the scientific facts and extends to "larger concepts, principles, or

processes", which coincides with the nature of science [1]. Developing a deeper understanding of the "big ideas" could help students construct a world of science. Hence, the development of scientific thinking takes a proper proportion in the goal of the curriculum. However, regarding the content of the curriculum, there are no signs of science history, the nature of science as well as some philosophical underpinning of science incorporated into the curriculum. As Gasparatou reviewed, all these elements are beneficial to scientific thinking. Therefore, the curriculum needs to add more materials to promote scientific thinking [19].

3.3 Practical Experience in Cultivating Scientific Thinking in Primary and Secondary Schools in Ontario

Ontario's educational mission and goal of cultivating teenagers with global perspectives guide the daily instruction of schoolwork. It focuses on practical training of scientific thinking in real life. For example, The Ontario Curriculum Grades 1 to 8: Science and Technology announced some changes to the new adjustment of de-streamed Grade 9 science courses, including the everyday use of 3D printing and genomic vaccines in science and technology teaching to align with the global economy needs and province's development strength. It places a great emphasis on critical life and job skills such as how to apply scientific knowledge with daily life and get inspired from everyday routine. The content of daily science instruction emphasizes the integration of natural sciences, social sciences, and humanities, providing students with a variety of learning experiences. This immersive learning environment enables students to explore, appreciate, and understand the relationship between science and technology in society.

In the meanwhile, the evaluation of science learning is also worthy of exploration. According to the content of science instruction, the Ministry of Education has developed a holistic achievement chart to examine students' scientific performance. The schools and teachers implement this chart and evaluate students' performance in four categories, namely knowledge and understanding, thinking and investigation, communication, and application. It aims to examine whether students are equipped with sufficient scientific knowledge as background and practice critical thinking, communication skills, and connecting science into other contexts.

Teacher plays a significant role in delivering scientific knowledge and enhancing students' critical thinking. Science teachers in Ontario are all accredited under the same standard even though they come from 16 different educational programs [20]. Before becoming a science teacher in primary or secondary schools, they are required to have "practice teaching" sessions as a practicum to earn their degrees. The professionality and rigorousness of science teaching are guaranteed to deliver quality science education lessons in Ontario. Additionally, not only for curriculum resources, but teachers can also search for other sufficient resources such as the STEM Education Toolkit to help arrange each science session and experiment. The toolkit, which is different from the tailored curriculum for each grade level, can break the grade barrier to practice students' problem-solving ability and skill development.

4 Ontario Scientific Thinking Education Paradigm: Implications for China

4.1 Theories of Scientific Thinking

Strengthening students' scientific literacy remains to be a critical aspect of China's academic discourse. However, the current policy framework has been inadequate in cultivating students' scientific literacy. Notably, China has had various curriculum reforms to improve the scientific literacy of students. For instance, in 2001, the trial version of the National Science Curriculum Standards for Full Time Compulsory Education was initiated for Grade 3–6, and it was fully implemented in 2017 from Grade 1–6 [21]. In addition, in 2006, 2010 and 2016, the National Scheme for Scientific Literacy was implemented and reformed. The policy also targeted the development of science teachers. For example, primary school science teachers, had to go through the National Teacher Training Program. For high school teachers, a bachelor's degree became necessary. However, despite the various efforts in improving scientific literacy among primary and secondary school students, there are still some shortcomings in the Chinese Science education policy.

One of the main challenges in China's Science education policy is that its approach to teacher education emphasizes building teaching skills rather than scientific knowledge. On the contrary, Canada's teacher education approach is different. According to Zhang et al., Canada closed its teacher colleges and set up a Faculty of Education for teacher training in universities. This is because universities have a greater training capacity and training resources which significantly improves teachers' scientific knowledge [22]. Therefore, the academic background of science teachers in China is quite different from that of science teachers in Canada. For instance, the study by Zhang et al. revealed that Chinese preservice science teachers lack an understanding of the history of science (H), philosophy of science (P), and sociology of science (S). HPS and the teacher education curriculum lack content knowledge on the nature of science.

4.2 Innovating Teaching Methods

The practical experience in cultivating scientific thinking in primary and secondary schools in Ontario gives inspiration to Chinese primary and secondary education. Ontario has made clear the need to establish clear standards for student and school achievement, aimed at improving service quality, as one of the core elements of transforming the government-managed education system. It should be said that the service nature of the organization has played an important role in the high quality of primary and secondary education in the country [23]. Canadian teaching practices place a strong emphasis on key life and work skills, such as how to apply scientific knowledge to and be inspired by everyday life. It follows that Canadian primary and secondary school students have a lot of time to participate in real-life activities. In fact, the reason why Canada adopts such a teaching system is to create a relaxed learning atmosphere and ensure sufficient playtime for children. This can cultivate students' good study habits and strong hands-on and brain ability, improve their interest in learning, develop their personality and imagination, and lay a solid foundation for further study or work. In view of the current situation that the

teaching methods in China's primary and secondary schools are relatively simple and students are passive in learning, teachers should be able to start from the teaching goals, understand the students' learning reality, optimize the teaching methods, and adopt a variety of teaching methods. Improve students' interest in learning. For China, in the process of teaching knowledge points, it is necessary to always combine the cultivation of scientific thinking ability, and comprehensively cultivate students' imaginative thinking ability, divergent thinking ability, and inquiry thinking ability, so that they can always use scientific thinking. Way of thinking about the problem.

4.3 Consistency of Scientific Thinking Education Between China and Ontario

The scientific thinking teaching mode of China and Canada have their consistent. The Chinese and Canadian Ontario educational models provide a teaching scene for each topic, leading students to experience the process of knowledge formation, and helping students to construct the meaning of knowledge and understand it in depth. Different situations have different learning outcomes for students. Learning is meaningful only when students learn to apply what they have learned flexibly in different situations. In addition, the consistency of Chinese and Canadian educational models lies in the fact that the teaching scenarios constructed by learning are closely related to students' daily life, which can easily arouse students' interest, stimulate students' desire to solve problems through inquiry, and help students construct in situations based on real events with applied knowledge. Therefore, in the process of inquiry, students should be given enough free space to try different solutions and build diverse solutions. In the actual operation process, students should sort out work tasks, select appropriate materials, and clarify the standards and constraints of the products to be produced. Teachers, as supporters, should improve their understanding of various disciplines to help motivate students' scientific thinking. Furthermore, the educational models of both countries emphasize that the organization of science education courses should be combined with engineering design on the basis of fully reflecting the nature of scientific research and encourage students to develop developmental training through the application of various tools and techniques to explore relevant scientific principles and technical methods. Students' multi-disciplinary perspective, engineering thinking and problem-solving skills have been effectively improved. Through various activities, primary and secondary school students can experience the relationship between their activities and scientific thinking in multiple directions, and focus on problems, link knowledge with practical life, continuously improve their ability to solve problems, and generate great curiosity and keen curiosity.

5 Conclusion

In recent years, science education has become a rapidly developing branch of education, the Chinese government has attached great importance to scientific thinking since the 18th National Congress and cultivating the scientific thinking of Chinese primary and secondary school students has also played an increasingly important role. However, there is a lack of advanced experience in a specific practice. Ontario is in a world-leading

position in the cultivation of scientific thinking, which can be used as a reference for scientific thought education in primary and secondary schools in China. The article begins with a discussion of the current state of scientific thinking cultivation in China and Ontario. In recent years, China has introduced a series of policies to cultivate scientific thinking among Chinese primary and secondary school students, and at the same time has its own system in the setting of the curriculum. However, in the process of learning, students have a series of problems such as relying too much on authority and lacking the ability to think independently. Ontario pays more attention to integrating with the profession and society in cultivating scientific thinking and pays more attention to students' critical thinking and scientific thinking ability in the curriculum. In summary, there is consistency in the cultivation of scientific thinking in China and Ontario as well, encouraging students to connect knowledge with real-life, continuously improve their problem-solving ability, and generate great curiosity and keen curiosity. This paper expands the field of research on the practice of science thinking education in China. In the future, the localized innovation research of the scientific thinking education system can be further carried out.

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