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CASE STUDIES OF COMPUTATIONAL THINKING EDUCATION AND ROBOTICS EDUCATION IN CHINA

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INTRODUCTION

Computational thinking is the core of IT literacy for students, and robots are key support equipment for advanced manufacturing as well as an important vehicle for improving human lifestyles. Both computational thinking education and robotics education are now highly valued in China. In 2017, computational thinking, as a core disciplinary element of IT curriculum, was written into the *Information Technology Curriculum Standard for General Senior High Schools* (2017 edition) (Ministry of Education of the People's Republic of China 2017, 6) and has been formally introduced into the primary and secondary school curriculum in China since then. Robotics education in China has an even longer history starting in 2003 when it was required to be included in IT curricula (Ministry of Education of the People's Republic of China 2003a, 9–10) and physics curricula for senior high schools (Ministry of Education of the People's Republic of China 2003b, 28), but it had not received sufficient attention until July 2017 when the State Council issued the "Development Plan for the New Generation of Artificial Intelligence" (The State Council of the People's Republic of China 2017), which clearly states that promotions of AI science should be widely carried out and AI-related courses should be offered in primary and secondary schools. Since then, artificial intelligence and robotics have been taught in senior high school IT courses (Ministry of Education of the People's Republic of China 2017, 26–30). The Chinese government is now aware of the importance of computational thinking and robotics education, but policies and curriculum standards for both are developed in a relatively conservative manner.

Chinese academia also attaches great importance to computational thinking education and robotics education, and studies on both have advanced increasingly in depth and extent. In China, the study of computational thinking education in primary and secondary schools formally began in 2012, and since then the number of academic papers in this area has been increasing year by year. Studies in the area mainly fall into three categories: (1) literature reviews that elaborate on the developments and concepts of computational thinking; (2) research on the impact of computational thinking on the IT curriculum; and (3) research on locating computational thinking elements in the IT curriculum (Wang 2017, 21–25). The studies on robotics education in primary and secondary schools in China started roughly in 2002, and they mainly concentrate on four aspects: (1) robotics teaching, including research on teaching vehicles (different types of robots), teaching modes, teaching strategies, learning environment, and so on; (2) educational robots proper, that is, different "robotics technologies" and user experiences; (3) curriculum development and interdisciplinary teaching, that is, to implement robotics education through school-offered robotics courses, STEM-based interdisciplinary education, science education, robotics competitions, and so on; and (4) values and curriculum objectives of robotics education, mainly including cultivating students' innovative thinking, creativity, engineering thinking, problem-solving skills, and so on (Science Promotion Committee of the Chinese Institute of Electronics 2018, 34–35).

A CASE STUDY OF COMPUTATIONAL THINKING EDUCATION

Teaching of computational thinking in primary and secondary schools in China is achieved through two approaches: (1) Computational thinking is integrated into existing subjects: for in-school education, it is integrated mainly into IT courses, sometimes also into other subjects such as mathematics and Chinese (Liu and Zhou 2018, 42); for out-of-school education, it is mainly integrated into programming teaching, robotics education, and so on. (2) Computational thinking is taught through school electives, which mainly include school-based courses developed by the school itself and courses offered by some enterprises. Of these approaches, the integration of computational thinking into IT courses is the area where the largest number of research papers is generated.

Moreover, three vehicles are employed to cultivate computational thinking: (1) screen-based programs, which are primarily written by the use of such programming tools as Scratch, Alice, Python, and so on to create simulations, achieve screen control, or display results on a computer screen; (2) digital tangibles such as circuits and programmable robots, which are mainly used to serve the purpose of developing students' computational thinking through designing and controlling physical robots' activities; and (3) a generic problem-solving approach that focuses on the logic and design of the algorithm and the sequence of steps executed by a computer (Gadanidis et al. 2017, 78). Of all the studies on these three vehicles, cultivating computational thinking through programming has been most studied in China, and Scratch programming in particular is the subject of about 30 percent of all research in this area (Liu and Zhou 2018, 42–43). Scratch programming is relatively easy and can be applied to create interesting games, stories, animations, and other works by combining a series of visual code blocks; therefore, it is suitable for primary and secondary school students to learn. It can not only satisfy students' desire to create and express but also allow them to experience the shift from everyday thinking to computational thinking (Liu and Zhou 2018, 43), improve their analytical and problem-solving abilities, and help develop their mindset. Therefore, this paper chooses to study a case of training students' computational thinking through Scratch programming in primary and secondary schools since it belongs to the most researched and representative type of case studies on computational thinking education.

Following the project-based learning (PBL) approach, a researcher designed an eight-lesson elective Scratch course to develop junior school students' computational thinking (Huang 2019, 36–37). Its instructional design follows six principles: (1) students should propose a project theme first and, under the guidance of the teacher, work out a semi-open project worth exploring; (2) context and problems created for the project should effectively engage students; (3) available resources must be provided for students to understand and solve problems; (4) students are enabled to experience the entire process of learning computational thinking during the project by answering the driving questions that are designed to focus on the process of computational thinking and its application; (5) students are instructed to use Scratch software to produce project works; and (6) evaluation of the project consists of both process evaluation and summative evaluation, with an emphasis on critical thinking. Table 13.1 is an example of the instructional design of a lesson where students learn to create a "drawing board program."

In this case, students' computational thinking is evaluated from two perspectives: (1) an evaluation indicator system is established for Scratch project works, and the computational thinking evaluation is realized in the form of project works evaluation; and (2) A five-dimension computational thinking scale is created covering creative thinking, algorithmic thinking, collaborative learning, critical thinking, and problem-solving. The results showed that the students' computational thinking had improved in general, with problem-solving being the most significantly improved and algorithmic thinking being the least improved. There is a significant gender difference in students' critical and algorithmic thinking but not so in creative thinking, collaborative learning, and problem-solving.

A CASE STUDY OF ROBOTICS EDUCATION

Robotics education has been implemented in China for more than twenty years. The past two decades have witnessed rapid development of robotics education, as exemplified by the change in the types of robots used, from mainly LEGO robots in the past to today's various robots produced by numerous robotics companies. At present, there are principally two ways to implement robotics education in primary and secondary schools in China: (1) to integrate robotics education into other subjects' curriculum, for example, to integrate it into comprehensive practice courses in primary and junior high schools and information technology courses and general courses in senior high schools; and (2) to offer elective courses specialized in robotics education, which may be developed separately or

Table 13.1 Instructional design of creating a drawing board program (Huang 2019, 40–44)

Category	**Scratch events**	
Requirements	After learning how to apply Broadcast and Brushes, students are required to create a simple drawing board program and a target shooting program with Scratch. Through this problem-solving project, students experience the importance of programming events, further understand what sequence control is, and learn how to achieve sequence control and how to apply it in different programs, comprehend the function of each code block, and grasp how to test and adjust a program in the program-making process.	
Core knowledge and skills	1. Learn how to use the code blocks of "When the character is clicked, broadcast . . ." and "When receiving . . ." in the Events category. 2. Understand the functions of each code block. 3. Apply sequence control to the drawing board program. 4. Transfer skills sequence control to the target shooting program.	
Computational thinking	1. On analyzing the actual needs of painting and entertaining activities, determine the theme of the project and find out the key to problems-solving. 2. Use mind map approach to draw a problem-solving flowchart. 3. Solve the problem of sequence control in the project by producing works with Scratch tools. 4. Be able to apply such problem-solving skills to similar problems (e.g., in the context of the target shooting program).	
Implementation procedures	Instructional activities	Embodiments of computational thinking
(1) Display project cases to engage students in project planning.	Introduction: The drawing board program writing competition is to collect students' works. Introductory activity: Ask students to use the drawing board tool in the computer to draw a simple animal so as to have them familiar with the drawing board.	Identify real-life needs; determine a project theme; analyze task requirements; and search the key to problem-solving.
(2) Discuss and adjust the task list to ensure its availability.	Driving question 1: What functions does a drawing board program need to have? Driving question 2: Can you create a drawing board program using the knowledge you have learned about Scratch? Then, students work out a task list and discuss it in groups. And the teacher provides advice for the items on the list by making suggestions concerning task requirements identification, realization of program functions, choice of characters, and script writing.	Further analyze task requirements; locate the key to problem-solving.

(*continued*)

Table 13.1 (continued)

Category	Scratch events	
(3) Draw, discuss, and adjust the flowchart in groups to improve its feasibility and availability.	Draw a flowchart for the project based on the adjusted task list to visualize the problem-solving process. Upload the flowchart to the works-display section of Cloud Share and adjust the flowchart after in-group discussions.	Draw a problem-solving flowchart using the mind map approach. Acquire knowledge and skills needed for problem-solving.
(4) Produce project works according to the flowchart.	Design the overall layout of the drawing board, finish the preliminary preparation of the project work (have ready the drawing board background, Brush, Eraser, Paint Board, etc.), write Brush scripts (to enable drawing), Eraser scripts and Paint Board scripts (enable filling of different colors), and display the works.	Develop learners' logical thinking through writing sub-task scripts; train learners' problem-solving skills through creating a program with Scratch tools for visualized programming.
(5) Discuss and evaluate project works in groups.	Students display and self-critique their works, and they evaluate the works through in-group discussions.	Cultivate students' critical thinking.
(6) Transfer of the mindset developed through making the project works	Transfer the knowledge of "sequence control" to the analysis and creation of the target shooting program.	Transfer of computational thinking
(7) Submission of project works	Students submit their works online and the teacher evaluate their works.	
(8) Sustainability of the project	Students think about and answer the question "Are these functions enough for a drawing board program?" and conduct extended research.	Elevate students' computational thinking by asking them the driving questions.

collaboratively by schools and enterprises (Science Promotion Committee of the Chinese Institute of Electronics 2019, 17).

In terms of course content, robotics courses in China fall into two types: those whose main purpose is to teach students scientific knowledge and those to prepare students for robotics competitions and contests (Zhang 2013, 12–13). Robotics competitions play a pivotal role in the development of robotics education in China. In addition to promoting robotics education, such competitions are also used as an important approach to evaluate and assess robotics courses. Robotics competitions, viewed as the most representative approach of robotics education in China, are the result of the application of the "learning-through-competition" pedagogy, and they help to promote robotics education at the primary stage of education (Science Promotion Committee of the Chinese Institute of Electronics 2018, 36–37). Therefore, this paper chooses to analyze a lesson designed for a robotics competition.

China's nationwide robotics competitions for primary and secondary school students include the China Adolescent Robotics Competition (CARC), the RoboCup China Open, and so on. Take CARC as an example. It has many events, including FLL (FIRST LEGO League). Oriented at FLL, a researcher has designed a robotics competition course, as shown in table 13.2.

ANALYSIS AND CONCLUSION

COMPUTATIONAL THINKING EDUCATION

The characteristics of computational thinking education in primary and secondary schools in China can be summarized as follows:

(1) National policy is absent. Over the past decade, education researchers in China have paid increasing attention to computational thinking education, which is reflected in education policies and curriculum standards. Yet, there is still a lack of more specific and comprehensive policies to promote the development of computational thinking education.

(2) Computational thinking education is not widely implemented. Computational thinking is mainly cultivated through IT courses in primary and secondary schools, but information technology courses are valued differently in different regions of China. Generally, first-tier cities pay more attention to IT education, and accordingly the computational thinking education there is better promoted, while IT education and computational thinking education in the central and western regions still need to be vigorously promoted (Ministry of Education of the People's Republic of China 2017).

(3) There are diversified vehicles for computational thinking education. Programming, robotics, problem-solving, and so on can all be

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Table 13.2 Course design for FLL Competition on "Food Safety" (Zhang 2013, 34–46)

Principles for course design	(1) Systematized design: to integrate knowledge completely and systematically into teaching contents. (2) Step-by-step process: to break down FLL tasks into several small tasks that are easy to complete. (3) Feasibility: to take into consideration the characteristics of students, the competence of teachers, teaching equipment and other factors when designing the course. (4) Teaching objectives must be clear. (5) Personalization: to pay attention to the difference between students when organizing activities. (6) Full participation: to ensure students' widest participation into and biggest contribution to the competition.
Target students	Upper primary students with some competition experience or related programming knowledge.
Teaching objectives	(1) Knowledge and skills: be able to make small strategic objects according to the competition rules and learn to write and adjust the program. (2) Process and methods: grasp the skills for quick installation and dismantling of small strategic objects according to the competition rules and be familiar with the competition process. (3) Emotions and values: master communication skills, develop teamwork spirit, cultivate the ability to accept both success and failure, and learn to be a person who has a passion for life and is willing to share with others during the competition.
Tools	LEGO robotics components, such as sensors, motors, and various LEGO building blocks, ROBOLAB programming software, USB cables, NXT controllers, computers, and so on.
Teaching procedures	(1) The teacher proposes the theme of the competition. Students try to understand the theme and analyze the tasks including fetching pizzas, sterilizing two vending machines, controlling robots' walk, and supervising storage temperature. (2) Students acquire the theme. After discussion, students decide to combine the following small tasks together: fetching pizzas, sterilizing vending machines, remote transportation by robots, and food preservation. Reason for such combination: the robots can deal with these small tasks in sequence during their walk around the playing field, and they only need to perform two actions by the use of two small strategic objects together without interfering with each other. (3) Students learn the competition rules. The teacher or a student representative reads the rules and requirements of the competition as well as the terms and conditions to win a score. For example, when the robot is preparing to start, it must stay immobile in the starting position; any part of the robot or any item that it is going to move or use must be kept completely within the boundary of the virtual base, with no exception.

Table 13.2 (continued)

	(4) Set up different groups. The FLL competition involves a lot of work such as building robots, programming, planning, and analysis. When grouping students, the teacher should generally consider the talent of each student, taking into consideration their personalities, abilities, and strength in knowledge to ensure that every student is actively involved. (5) Teach students how to make use of the software and some robot-designing skills to lay a foundation for them to build robots. (6) Ask students to design the robot as a group. Based on the competition rules (e.g., time constraints, size requirements for the parts used), the teacher guides the students to generate several reasonable plans through brainstorms. Students build robots, write programs, and decide on the route. This is then followed by continuous debugging and optimization. In this lesson, the robotic design involves design of the robot body, planning of the route, design and assembly of small strategic objects, design of the program, and presentation of the finished product. (7) Select teams. Works and teams are selected according to the design of the robot and students' capability of both independent work and teamwork. (8) Conduct repeated training to improve students' psychological quality. Improve the robot assembled in this lesson (primarily meaning to improve strategic objects and routes, with the robot body remaining essentially unchanged,) and conduct repeated training. Ask students to optimize strategic objects and programs again in coordination with subsequent tasks and to train and adjust the robot in a holistic manner to make sure that each individual task fits perfectly into the time and route.

vehicles for developing computational thinking. The most widely used one in China is Scratch programming. There are already several versions of Scratch textbooks in China, but the way they are compiled is not conducive to developing computational thinking. Scratch textbooks need to be further developed by focusing more on improving computational thinking.

(4) Although diversified teaching strategies are employed, lack of guiding curriculum standards is still true of computational thinking education. Commonly used teaching strategies include the task-driven method, PBL method, "needs analysis + flowchart" method, and so on. In recent years, computational thinking education has been combined with maker education and STEAM education (Liu and Zhou 2018, 43). At the point of instructional design, computational thinking

is dissected and usually different components are identified and taken into consideration, and then different teaching strategies are selected for different teaching procedures to deal with different components correspondingly. Yet some of the teaching cases do not give appropriate consideration as to how to develop students' computational thinking through instructional design but rather take it for granted that students would surely improve their computational thinking through learning the programming features of Scratch. This shows that front-line teachers in China do not have a very clear idea about how to develop computational thinking through Scratch programming, and, what's worse, there is a lack of curriculum standards as well as specific guidance for implementing computational thinking education.

(5) There is no sound evaluation system for computational thinking. Evaluation tools of computational thinking used by schools mainly include computational thinking test papers, questionnaires, and evaluation of works. However, some literature does not include explanation of the reliability and validity of its test papers and questionnaires, indicating the lack of uniform and rigorous standards for evaluation and testing in China.

To sum up, this paper makes the following suggestions for computational thinking education in primary and secondary schools in China: Firstly, more specific national policies and curriculum standards ought to be formulated to lead and guide the implementation of computational thinking education in practice. Secondly, teaching materials and curriculum should be developed with focuses on the cultivation of computational thinking so as to facilitate the popularization of computational thinking education. Lastly, research on the evaluation of computational thinking needs be enhanced, and a sound evaluation system for computational thinking education must be established.

ROBOTICS EDUCATION

The characteristics of robotics education in primary and secondary schools in China can be summarized as follows:

(1) Robotics education is not widely implemented. Although China has issued many educational policies to promote robotics education and

the academic community also attaches great importance to robotics education research, the popularization of robotics education in primary and secondary schools is constrained given the fact that not all schools are able to meet the basic conditions for implementing robotics education, which requires robotics-related technologies, products, platforms, and operating environments to be in place. Currently, public schools in China do not have a sound curriculum system and evaluation system for robotics education, and many primary and secondary schools offer robotics courses through extracurricular activities and interest classes. In addition, robotics education is implemented geographically unevenly in China. In recent years, most schools in Beijing, Shanghai, Guangdong Province, Shandong Province, Hubei Province, and Heilongjiang Province have already offered robotics courses, while other regions are left behind in terms of popularity of robotics education (Zhang 2013, 12).

(2) Diversified types of robots are applied. LEGO robots were the most common type of robots applied at the very early stage of Chinese robotics education. With the development of the robot industry, there is a rapid increase in robot manufacturers in China, and they are able to produce educational robots with various functions and at a wide price range, which helps to promote robotics education (Science Promotion Committee of the Chinese Institute of Electronics 2019, 17–18).

(3) The robotics curriculum is becoming increasingly enriched. There is currently no unified robotics curriculum in China. Robotics courses fall into two types: those whose main purpose is to teach students scientific knowledge and those to prepare students for robotics competitions and contests. The latter is currently the most representative way of implementing robotics education in China (Zhang 2013, 12–13). Robotics competitions have contributed to the advancement of robotics education in China, but they also have some drawbacks. For example, robotics competitions may mislead students about their learning objectives. They prompt robotics companies to develop robot kits for competition purposes only. By purchasing such robot kits, students can easily win a competition. This kind of competition experience is not conducive to developing students' creativity, problem-solving skills, and so on. In recent years, however, robotics

education has begun to embrace new educational concepts such as STEM education and creator education and has become more curricularized and more conducive to developing students' comprehensive literacy (Qiu 2018, 19–35).

(4) There are not enough professional robotics teachers. Robotics is not a compulsory subject in primary and secondary schools, and China has not established a professional training system for STEM teachers. Most robotics teachers do not have an appropriate level of competence as they have not received a formal robotics education (Science Promotion Committee of the Chinese Institute of Electronics 2018, 38). However, robotics teacher training has appeared in some regions, and normal universities have begun to develop related training courses. For example, Hanshan Normal College in Guangdong Province has launched a series of courses to train robotics teachers (Science Promotion Committee of the Chinese Institute of Electronics 2019, 14–16).

In summary, in the future, robotics education in China can be improved in three ways. First of all, an overall robotics education curriculum system should be constructed at the national level, serving as an example for robotics curricula all over the country. Secondly, an evaluation system of robotics education should be established by which students can be evaluated not only in terms of robotics knowledge, such as the basic concepts, structure, functions, and design of robots, but also in terms of their abilities such as logical thinking, problem analysis, problem-solving, comprehensive practice, innovation, and teamwork as well as their truth-seeking spirit (Science Promotion Committee of the Chinese Institute of Electronics 2019, 19). Finally, a specialized training system should be established for cultivating professional robotics teachers to address the shortage of professional robotics teachers in China.

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