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A CORE-COMPETENCY-ORIENTED COMPUTATIONAL THINKING EDUCATION IN CHINA

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THE IMPORTANCE OF COMPUTATIONAL THINKING AT THE K–12 STAGE

After moving into the twenty-first century, information technology has been constantly changing with the times, and information society has undergone fast-paced development. While shifting the center from computers and the Internet to data centers, people's work and lives have met with different changes (Ravenscroft 2001). In the meantime, due to the advancement of artificial intelligence of a new generation, information technology has enhanced social productivity and production relations differently and is transforming students' everyday lives, learning styles, thinking patterns, values, and viewpoints (Nouri et al. 2019). Contrary to such a temporal background, the education on information technology is infused with different missions and implications. Reinforcing education on information education and developing students' survival skills and significant personalities in an information society have been accepted as critical issues in the context of existing primary education (Mannila et al. 2014).

Papert (1990) was the first to put forward computational thinking (CT). Subsequently, its definition, teaching, and assessment have been extensively used. Plenty of scholars have analyzed CT (Grover and Pea

2013). Wing (2008) stresses that CT should be among everyone's daily life skills rather than being limited to the programming skills that computer scientists exercise exclusively. The role played by the social development of courses is manifested in the cultivation of digital citizens and in students' awareness of the rights, obligations, and opportunities while they live, study, and work in an interconnected, digitized world so that they can take measures and act in a safe, legal, and sensible way.

Many nations around the world have turned their attention to the teaching of computational thinking at the stage of primary education. In October 2016, the directing committee of the K–12 Computer Science Framework in the US released the "K-12 Computer Science Framework" (abbreviated as the American K–12 CS Framework) (Love and Strimel 2016). As computers are made an integral part of the world, there is an increasing demand for computer science education. At present, plenty of students apply computer science to advance their future professional careers. Nevertheless, the opportunities to study computer science fail to satisfy the demands of the public. Despite access to computers by more and more students on campus, not everyone can have the chance to study computer science. The objective in designing the "K–12 Computer Science Framework" is to present all states, areas, and organizations with requisite construction elements in the development of their own computer science and facilitate the enforcement of construction means, promoting professional advancement as a foundation.

In 2011, the International Society for Technology in Education (ISTE) entered into cooperation with the Computer Science Teachers Association (CSTA) in the provision of an operational definition of the expressive characteristics of computational thinking: "Computational thinking refers to a process of resolving problems that involves the six elements of describing the problem, analyzing data, abstraction, designing algorithms, assessing the optimal proposals and working out solutions" (Grover and Pea 2013).

In September 2013, the Department for Education in the UK published "Computing Program of Study: Key Stages1–4." The existing ICT courses developed in the UK were met with both doubt and criticism (Brown et al. 2014). Many middle school (K6–K9) and primary school (K1–K5) students in the UK felt discontent with the original ICT courses and consider them inflexible and boring. The experts in information technology take the view that British middle schools and primary schools need to teach more serious computer science courses. The relevant courses to computer education are purposed to allow students to gain understanding of and make changes to the world by cultivating computational thinking and creativity. Computer science is put at the center of computing, inclusive of information and computer principles, number systems, and programming. Students should learn how to use information technology for the development of programs and systems according to their personal knowledge and understanding of computer science. In addition, computer education can ensure that students master digital literacy and applyICT to express their own ideas, which enables them to develop adaptivity to future work and play an active role in the digital society. This reflects the essence of ICT courses. Back in 2012, the British Computing at School Working Group stated in its research report that computational thinking represents the process of employing computing tools and technologies to comprehend artificial and natural information systems. It fully manifests logical ability, algorithmic capabilities, recursive facility, and the power of abstraction (Brown et al. 2014).

The Australian Curriculum, Assessment and Reporting Authority (ACARA) released a report in 2014 specifying that digital and technological courses need to serve as a discipline that instructs students on how to apply computational thinking and information systems to address problems (Falkner, Vivian, and Falkner 2014). In 2011, the Department of Curriculum Planning and Development, Ministry of Education, Singapore published a “Computer Application Syllabus,” requiring that computer application be a mandatory discipline for all students. The courses in primary schools are all-inclusive disciplines, and all other courses taught in middle schools and high schools (K10–K12) are independent disciplines (Chai, Koh, and Tsai 2013). The courses taught at the primary stage focus on the cultivation of fundamental ICT skills in students to provide support for their study of other disciplines and make a difference to their personal lives. The courses in high schools are required to lay emphasis on advanced thinking skills and concentrate on resolving problems and comprehending basic programming concepts and skills. This is conducive to students’ learning of programming and prepares them for future careers.

It is understood that such nations as the UK and the US have offered the technology-oriented information technology courses and have begun to proactively advance the relevant programs and plans so as to incorporate "computer science" into the curriculum of middle schools and primary schools. The development of number literacy and computational thinking capability has grown into an emerging trend of information technology education across not only middle schools but also primary schools (Heintz, Mannila, and Färnqvist 2016).

COMPUTATIONAL THINKING EDUCATION IN CHINA

The progress made in information technology education across China is an integral part of the development of information technology education across the globe. From the end of the 1970s, as computer technology and the Internet developed, information technology education has undergone three phases: early computer education, computer application education, and information technology education. Every single stage has its unique characteristics. These crucial points reflect not only the characteristics of technological development in different historical stages but also the different value orientations adopted in information technology education. During the late 1970s, the emergence of personal computers attracted attention from across the international education community. Many countries around the world incorporated computers into primary and secondary education. In 1981, at the Third World Conference on Computer Education Applications (WCCE/81) in Lausanne, Switzerland, the prominent scholar Yelshoff proposed the idea that human beings live in a "programming world." This view reflects the idea of "computer culture" and lays emphasis on the cultivation of computer culture by delivering programming education.

Subsequently, programming started to be recognized as a significant part of computer teaching. To carry out international education reform, China launched the "BASIC Programming Language" course in five priority universities, including Tsinghua University, Peking University, Beijing Normal University, East China Normal University, and Fudan University in 1982. In addition, China started to practice computer teaching in primary and secondary schools, which is viewed as the prelude to the test.

With the continuous progress made in teaching experiments, the Ministry of Education held two computer education work conferences in primary and secondary schools in 1983 and 1984, respectively, to summarize and reflect on the experimental work. In the meantime, the working principles and syllabus were determined for computer education in primary and secondary schools.

What is most worth noting is that in 1984, when conducting an inspection of children's computer activities in the China Welfare Association Children's Palace in Shanghai, Deng Xiaoping proposed that "the popularity of computers should start from the children." This sentence has turned out to be a historical milestone in the development of computer education for China. Not only does it establish the significant position of the computing curriculum in primary and secondary schools but it also transformed computer teaching from experimental trials to large-scale promotion across the country.

In the years after the mid-1980s, as computer application software increasingly matured, the scope of computer applications expanded rapidly, which prompted many non-computer professionals to start employing these tools in work. At the Fourth World Conference on Computer Education Applications (WCCE/85) held in Virginia in 1985, some scholars proposed an educational goal of using computers as a tool for improved efficiency, with the emphasis placed on the application of computers as a tool to resolve practical problems.

At this time, the focus of computer education had shifted from programming to computer application education based on operational skills training. Under the influence of this "computer tool theory," the former State Education Commission made a decision to increase computer application software education content (such as databases, spreadsheets, and so on) at the "National Secondary School Computer Education Third Work Conference" held in 1986. Premised on the original syllabus, the "Syllabus for the Elective Course of Electronic Computers in Ordinary Middle Schools (Trial)" appropriately reduced the requirements for the programming skills section and incorporated some educational contents for the introduction of computer application software in 1987.

In the same year, to implement the instructions issued by Comrade Deng Xiaoping that "education needs to face modernization, face the world, and face the future," the National Middle School Computer Education Research Center was officially established, while the Beijing Research Department and Shanghai Research Department were established respectively at Beijing Normal University and East China Normal University. As computer education was carried out on a large scale in primary schools, it was subsequently renamed the "National Primary and Secondary School Computer Education Research Center." The establishment of the center has promoted the implementation of information technology education across primary and secondary schools in China while laying a solid foundation for the development of the follow-up curriculum guidelines.

In the late 1980s, China started informatization measurement, assessing the potential development force of the information industry by the number of college students per one hundred people and the proportion of scientific and technological personnel, and so on. In the later rounds of informatization composite index evaluation, the level of information subject and information talents have been paid increasing attention. Since the 1990s, the development of network technology has led to the rapid growth of global information, which makes the effective acquisition and application of information an important capability for social survival. The abundant information resources provide a strong support for people to solve the problems they encounter. In the meantime, however, this also imposes more psychological burden on people and makes their work more stressful. As the basic qualification required for citizens living in the information society, the educational goal of information literacy training has been gradually established. In October 2000, the Ministry of Education held the "National Primary and Secondary School Information Technology Education Work Conference," propagating the "Guidelines for the Information Technology Curriculum for Primary and Secondary Schools (Trial)," "Notice on the Popularization of Information Technology in Primary and Secondary Schools," and "About Primary and Secondary Schools." The important guidance documents such as the "Notice on Implementing the School-School Project" clearly state the necessity to "train students' good information literacy."

In the meeting, it was also decided to use the information from five to ten years in the national primary and secondary schools (including secondary vocational and technical schools) to publicize information from

2001 onward. Since then, the name "Computer Education in Primary and Secondary Schools" has been officially changed to "Information Technology in Primary and Secondary Schools." Technical education and information technology courses are listed as compulsory courses for primary and secondary schools. This conference marks the start of the basic education curriculum in China to embrace a broad, forward-looking vision and the proactive response made by the nation to the fast-paced development of information technology. Information technology education has since been put on a fast track of development.

In 2003, the Ministry of Education promulgated the "Standards for Senior High School Technical Courses (Experiment)" including general technology and information technology, hereinafter referred to as the course standard (experiment). The course standard (experiment) explains the basic concept, course objectives, and course content of the high school information technology course. Its introduction facilitates the development of information technology education in primary and secondary schools in China.

In China, the construction of education informatization has also achieved remarkable progress in the field of basic-level education, as reflected in the significant improvement made to teaching conditions for the development of information technology courses. Since 2000, China has enforced an educational system of information technology where information technology courses are regarded as the primary courses. With the launch of engineering projects such as the "School-to-School Link" project, "Modern Remote Educational Project in Rural Middle Schools and Primary Schools," the information-based facilities in middle schools and primary schools have consistently improved to the extent that the needs of information technology education can be basically met on the whole.

According to the statistics released by the Ministry of Education, by the end of the fourth quarter of 2017, 92.1 percent of the primary and secondary schools nationwide (except for teaching points) had gained access to the Internet, 3.03 million classrooms had been equipped with multimedia teaching equipment, and 86.7 percent of the primary and secondary schools had already been complete with multimedia classrooms. Among them, 62.2 percent of the schools had achieved the full coverage of multimedia teaching equipment. By 2015, 100 percent of high schools, 95 percent of junior high schools, and 50 percent of primary schools offered compulsory courses in relation to information technology. These statistics show that the information technology curriculum implemented in schools has been popularized nationwide.

With respect to teachers, there has been a consistent increase in the overall number of teachers teaching lessons on information technology. The teacher–student ratio has been in decline on an annual basis, and the gap between urban and rural areas has been gradually closed. Overall, China has 108,000 full-time teachers of information technology in primary schools, 88,000 in middle schools, and 38,000 in high schools. In 2012, as revealed by a survey conducted on the implementation of information technology curriculum criteria published by the Ministry of Education, up to 90.9 percent of high school information technology teachers had attained bachelor's degrees or above in the relevant disciplines to computer science, educational technology, and mathematics. A large proportion of high school students had studied information technology courses in primary schools and middle schools, among whom up to 44.3 percent of students believed that the overlapping rate between "information technology basics" and the content they had learned in middle schools ranged between 20 and 50 percent. Though high school students who were not beginners accounted for a large proportion, their understanding of information technology courses remained operational. From a hardware perspective, the conditions of information technology education have improved significantly. Moreover, the overall qualities and capabilities of the teaching and research group have been enhanced, thus laying a solid foundation for the further development of computational thinking education on information technology across both middle schools and primary schools.

Computational thinking has been officially recognized as one of the critical qualities of information technology courses in the curriculum standards of Chinese high schools (Wang 2019). Computational thinking refers to a series of thinking activities performed in the process of coming up with solutions by individuals who apply the means of thinking in the field of computer science. Students capable of computational thinking can define problems, abstract features, construct structural models, and organize data in a reasonable way by using computers to perform information activities. They can work out solutions by making judgments, conducting analyses, consolidating various information resources, and applying suitable algorithms. Moreover, they are able to summarize the process and methods used to solve problems with the assistance of computers and extend them to solving other relevant problems.

CHANNELS FOR PRACTICING COMPUTATIONAL THINKING EDUCATION

Computational thinking represents a core element of computer science. It is interconnected with various layers of K–12 learning, with the emphasis placed on abstraction, automation, and analysis (Lye and Koh 2014). As required by the curriculum standard, students shall acquire the following skills: (1) developing and executing algorithms including sequence, cycle, and conditions to accomplish tasks with or without the assistance of computing equipment; (2) analyzing and debugging algorithms of sequence, events, cycle, conditions, concurrence, and variables; and (3) developing models for the working principles of computer systems. In addition, courses in social development include the influence of computation. A knowledgeable and responsible person should understand the social influence of the digital world, including fairness and the exercise of computation.

Computational thinking refers to a series of thinking activities performed by individuals coming up with solutions through thinking from the perspective of computer science (Brennan and Resnick 2012). It is an explicit skill shown in abstracting the problems and automating solutions, consisting of concrete components and practices that are observable and measurable. It is also a term used to describe a growing focus on students' knowledge development, design computational problem-solving, algorithmic thinking, and coding. The core concepts of computational thinking include algorithmic thinking, abstraction, decomposition, and generalization.

The four characteristics (formalization, modeling, automatic, and systematic) of computational thinking are defined in the China information technology curriculum standards released in 2017. Formalization means that computers can be applied in the process of information activities to define problems, identify crucial elements, and conduct analyses of the relationship between different elements by following the way a computer operates. Modeling refers to the construction of models of information processing, the organization of data in a sensible way, and the ability to propose solutions to problems through judgment, analysis, and a combination of various information resources. Automatic refers to the process and means of resolving problems by applying information technology and realizing automation in the solutions to those problems. Systematic refers to the systematic process of developing solutions and transferring them to the solving of other relevant problems.

Based on the requirements for the cultivation of comprehensive information literacy, unit teaching design is worth emphasizing. A unit refers to a learning unit that revolves around knowledge, skills, comprehensive themes, and project activities based on curriculum standards in the selection of learning materials for the structural organization. The teaching of information technology units focuses on the critical concepts of the discipline, encouraging students to become flexible technology users who are not only capable of understanding and developing information technology with computational thinking but also responsible as the users of information. As for the improvement of information literacy among students, the focus should be placed on the expression of core concepts and the overall conception of knowledge systems. The curriculum needs to revolve around the problem-solving process and give consideration to the expression of information consciousness, computational thinking, digital learning, and innovation in unit teaching. In addition, it needs to reflect on the expression of information security consciousness, information using standards, and information morality principles in unit teaching from the perspective of information social responsibilities.

The core concepts need to be put at the center of design for unit learning activities, problem-solving ought to be regarded as the focus, and the learning requirements of putting it to practice need to be clarified to demonstrate what one has acquired and learning to reason, which is because students' understanding as to the way of thinking is embedded in science and technology. Besides, the threads of technological developments start with the understanding of the significant characteristics of core concepts, and the improvement of computational thinking is closely associated with the process of solving problems by employing information technology tools. Though it starts with the demonstration of teachers, it is necessary to be adapted to students' thinking. Therefore, when the learning activities of units are designed, core concepts shall be focused on and the critical questions shall be raised for them to explore the core concepts and content. In doing so, students can be guided to gain an in-depth understanding of the core concepts through a continuous process.

RECOMMENDATION FOR COMPUTATIONAL THINKING EDUCATION

The prevalence of digital tools allows the program-driven technical tools to penetrate all aspects of people's lives, and the means of computing they apply internally are imperceptibly integrated into the problem-solving process by taking advantage of information technology. Therefore, not only could understanding the significant characteristics of digital tools and cultivating computational thinking achieve the effective use of information technology but it is also conducive to averting the danger of "being manipulated by technical tools."

As young people grow up in a digital environment, they develop proficiency in applying digital technologies and employing technical tools to better adapt to the digital environment. Nevertheless, in an information society, educators need to be aware that the widespread application of digital technology not only creates a diverse environment of technical application but also leads to the emergence of new core concepts, methods of solving problems with technology, and unique technical application standards. Therefore, as qualified "digital citizens," educators are supposed to gain understanding as to the core concepts, disciplinary methods, and corresponding communication forms of digital technology in practice; solve realistic problems by applying scientific methods in a sensible way; perform information activities in a responsible way in line with the behavioral standards that apply to the information society; and cultivate the basic literacy of survival, innovation, and development in the information society.

How can we plan well when faced with the future? In an era that is characterized by artificial intelligence, it is necessary for us to place the focus on the development of new computational thinking skills. The pressure coming from business and industry to transform has prompted all countries to shift their attention to the transformation that AI technologies can achieve in different fields. Artificial intelligence has been made a new focal point of international competition. In the meantime, there is a new opportunity for development presented to all people around the world (McArthur, Lewis, and Bishary 2005). As a major developing country, China is viewing its resources from a different perspective—whether human, natural, data, or intelligence—and the relationships between them (Jiang et al. 2017). Elementary education plays a crucial role in solving the question of what kind of people society wants to create, and AI has a substantial impact. Training people who are irreplaceable by AI is a critical problem that needs addressing. By learning an AI course module, students can understand the concepts and historical development of artificial intelligence while developing the capability to describe the process of developing common AI algorithms. Through a module where they develop their own simple intelligent technology applications, they can acquire hands-on experience with techniques and learn about the basic process to design and create a simple intelligent system, which is conducive to reinforcing their sense of responsibility in applying intelligent technologies to serve humans. Through STEM education, the combination of AI and the exploration of other courses can allow students to develop the capability of interdisciplinary thinking, while the basic mode of thinking behind AI can exert influence on students for their academic study and daily life.

However, the content of AI involves a wide range of subjects and is still in the process of exploration and improvement. This affects the development of curricula for primary and middle school students and may also lead to the lack of cohesion of artificial intelligence courses and the disconnection of course contents from the actual educational goals. To develop artificial intelligence education, it is necessary to make clear the practicality and systems of the educational setting. Artificial intelligence education in primary and secondary schools should focus on cultivating students' information literacy, aiming at improving students' understanding of information awareness, computational thinking, digital learning, and innovation. Attention should be paid to the laws of cognitive development, and the value of science and technology should be highlighted. In China, in recent years, relevant policies have been introduced focusing on artificial intelligence education in primary and secondary schools, and a series of artificial intelligence textbooks covering primary schools as well as junior and senior high schools have been published. The textbooks attach importance to the consistency of the content while setting different teaching objectives and strategies according to different sections.

What is the most urgent implementation path for computational thinking education for all? Firstly, "digital indigenous" does not automatically become a digital citizen. It is wrong to assume that the next generation can automatically become a qualified digital citizen by living in an information-rich environment, with thinking and ethics included (Ginsburg 2008). There are various aspects of information literacy that need to be taught in a systemic way. Secondly, computational thinking is regarded as an essential part of literacy for citizens involved in any work in the future. At present, the most feasible way to implement the curriculum is through programming and algorithmic training assisted by different tools for the cultivation of computational thinking. The programming training emphasized by the new curriculum standard is not limited to simple programming—not programming for the sake of programming—but developing students' computational thinking through programming. Therefore, it is just the starting point for the textbook reform, teaching reform, teacher education reform, and evaluation reform that we will need in the future. Nowadays, in the transformation of information technology that is improving the living standards for Chinese people, the reform to education and teaching has been deepened on a continued basis so that every single student is entitled to receive education in information technology.

For middle schools and primary schools, information technology courses provide the basic way to deliver information technology education. They need to be adaptive to the characteristics of the times so as to accomplish the crucial task of developing computational thinking for students and cultivating qualified digital natives.

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