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INTRODUCTION

Siu-Cheung Kong, Harold Abelson, and Wai-Ying Kwok

Educational authorities around the world share the consensus that timely and flexible policies should be made for fostering students to start their journey of computational thinking education (CTE) in schooling life (Grover and Pea 2013; Hsu, Irie, and Ching 2019). This consensus leads to the growing need and trend of implementing computational thinking (CT) curricula in the K–12 sector around the world (Borrás and Edquist 2015; Hsu et al. 2019). The effective implementation of CT curricula in the K–12 school contexts requires coherent efforts in educational policy and curriculum development in CTE in K–12 as well as in school implementation and classroom practice of CT curricula in K–12 (Mao, Ifenthaler, Fujimoto, Garavaglia, and Rossi 2019; Williamson, Bergviken Rensfeldt, Player-Koro, and Selwyn 2019). All these efforts are important issues and deserve further deliberation in the K–12 sector. This book presents an overview of these important issues for CTE in K–12, with contributions from experts in twelve countries/regions across three continents.

This book emerged from our earlier work, *Computational Thinking Education in K–12: Artificial Intelligence Literacy and Physical Computing*. This previous collection explored classroom-level experiments and implementations of teaching CT. In the course of assembling the earlier book, we also received contributions that looked at national-level curricular implementations. These latter contributions, and the separate set of issues they

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explored, encouraged us to solicit chapters from a wider range of countries to present an early overview of CT education at a national policy level.

While more work remains to be done in providing a truly systematic and consistent analysis of CT curricula around the world, these essays provide insight into the issues, hurdles, and potentials of introducing comprehensive new curricular material in a coherent, developmentally appropriate progression across primary and secondary school grades. The chapters in this book are organized into two parts to provide policymakers, curriculum developers, school practitioners, and educational researchers with a global overview of the two focal areas important for the planning, development, and implementation of CT curricula in K–12.

PART I: EDUCATIONAL POLICY AND CURRICULUM DEVELOPMENT FOR COMPUTATIONAL THINKING EDUCATION IN K–12

The first part of this volume presents a global deliberation of the policy landscape and school planning of CT curricula in K–12. Six chapters contributed by leaders in CTE in Asia, Europe, and Oceania provide an extensive discussion in relation to this focus area.

In “Computational Thinking Education in the UK: A Teacher’s Perspective,” Scott provides a holistic overview and reflection on the policy and implementation of national CT curricula in K–12 schools in the United Kingdom. This chapter leads readers to start the volume-reading journey by looking into how the United Kingdom, a country with a long development history and many invention records in the field of computing, offers and evolves CTE among its four constituting nations—England, Scotland, Wales, and Northern Ireland. The author provides a systematic outline, conducts a meaningful comparison, and makes a critical reflection on the different approaches taken in the four nations for planning, developing, and implementing CT curricula in K–12.

The second chapter in this part—“Computational Thinking Education in Hong Kong” by Kong and Kwok—discusses and illustrates the planning, development, and implementation of the CT curriculum for K–12 schools in Hong Kong. The chapter introduces readers to a worldwide-first initiative in an important hub of e-learning in the Asia-Pacific region for pioneering the curriculum development for CTE at senior primary grades.

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The authors holistically depict the policy landscape of CTE in school education in Hong Kong, elaborately illustrate the design and implementation of the citywide CT curriculum pilot, and critically reflect on the lessons learned through the Hong Kong–based CT curriculum pilot.

"A Core-Competency Oriented Computational Thinking Education in China" by Yang and Ren introduces and illustrates how educational authorities in China adopt a core-competency-oriented perspective for the curriculum development and implementation for CTE in K–12. This chapter guides readers to look into the governmental directions and strategic plans of CT curricula in K–12 in one of the fastest-growing economies in the world in recent decades. The authors deliberate the history, rationale, and delivery of national initiatives related to curricula for CTE in K–12 schools in China and discuss the challenges faced by the different parties in the local school education sector for implementing and improving CTE.

The fourth chapter in this part—"Computational Thinking and the New Curriculum Standards of Information Technology for Senior High Schools in China" by Huang, Yang, Xiao, and Zhang—further shares a focused illustration of the new national curriculum standards designed and deployed for CTE in senior high schools in China. The authors introduce the evolution of new standards of the senior high school curriculum of information technology in China, review how CT relates to the key literacy emphasized in those new information technology curriculum standards, and discuss the deployment of teaching methods and the provision of learning environments favorable for students' CT development.

In "Computational Thinking Curricula in Australia and New Zealand," Bell, Vivian, and Falkner provide a holistic review and discussion of how Australia and New Zealand evolve and implement their national policies and curricula for CTE in K–12. The authors systematically depict and compare eight important aspects of the planning and implementation of CTE under the digital technologies subject in the two neighboring countries. This chapter serves as an informative guide for readers on the national plans and efforts for CT curricula in Oceania countries—with an inherent concern for equity, diversity, and inclusion in their curriculum efforts for CT development.

The final chapter in this part—"Computational Thinking Assessment: A Developmental Approach" by Román-González and Pérez-González—shares

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insights into the practices and instruments for the developmental approach to CT assessment, an important part of CT curricula in K–12 schools. The authors articulate and illustrate the rationales, targets, and approaches for the assessment of CT development at four schooling stages—kindergarten, elementary school, middle school, and high school. This chapter provides a theory-based guide for international readers on the design and implementation of longitudinal assessment of CT development among students.

PART II: SCHOOL IMPLEMENTATION AND CLASSROOM PRACTICE OF COMPUTATIONAL THINKING CURRICULA IN K–12

The second part of this book shares inspiring cases of the school implementation and classroom delivery of CT curricula in K–12. Seven chapters contributed by leaders in CTE in Asia and Europe present current conditions and research findings in relation to this focus area.

"Pathways of Computing Education: Formal and Informal Approaches" by Looi, Chan, Seow, Wu, and Wadhwa shares and illustrates the differentiated pathways of CTE implementation in formal versus informal learning systems in K–12 schools in Singapore. The chapter shares the experience in another important hub of e-learning in the Asia-Pacific region on the nationwide directions and efforts for CTE in K–12 through in-class and after-school initiatives. The authors first take a global angle to review the affordances of and synergies between formal and informal learning approaches to CTE; they then take a nation-specific focus to share the rationale and progress of CTE in Singapore through formal curricular and informal learning initiatives.

The second chapter in this part—"Software Education in South Korea for Cultivating Computational Thinking: Opportunities and Challenges" by So, Kim, and Ryoo—discusses and illustrates the current status, opportunities, and challenges of curricula implementation for CT development in K–12 schools in South Korea. This chapter presents readers with a reflective sharing from a technology hotspot in East Asia on the nationwide curricular initiatives for CT development under the policy on software education in K–12. The authors discuss the three unique features in the curricular directions and initiatives for software education in South Korea; they then reflect on the three major barriers and corresponding

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opportunities in relation to the capacity and perception of local K–12 teachers for software education.

In "Learning Computational Thinking in Co-Creation Projects with Modern Educational Technology: Experiences from Finland," Mäkitalo, Tedre, Laru, Valtonen, Iwata, and Koivisto discuss the cases of curriculum integration and teacher development for CTE in school education in Finland. This chapter shares inspiring experiences of CTE in a Nordic innovation hub whose education system is internationally well-recognized. The authors focus their sharing on two large-scale CTE initiatives—one about the school-based supports for fostering students' CT development through a game-based learning approach in the nonformal educational context, and the other about the national-level laboratory for preparing teachers' capabilities and beliefs for integrating CTE into everyday formal curricula.

"Integrating Design Thinking into K–12 Computational Thinking Classrooms in Taiwan: Practices of Collaborative Robotic Projects" by Shih gives a case of classroom practice in K–12 schools in Taiwan on students' synergic development of CT and design thinking. This chapter presents readers with an inspiring idea from another technology hotspot in East Asia for instructional innovation in CTE. The author introduces the theoretical background and learning model of "Situative CT" for instructional innovation in line with the existing standards and structures of Taiwanese school curricula and shares the ways and results of implementing instructional innovation in local K–12 classrooms for students to develop CT and design thinking in an integral manner.

The fifth chapter in this part—"Plethora of Skills: A Game-Based Platform for Introducing and Practicing Computational Problem Solving" by Armoni, Gal-Ezer, Harel, Marelly, and Szekely—shares a case on the experience and outcome of using a game-based learning platform in school education in Israel to develop students' skills of computational problem-solving. This chapter introduces readers to a leading tool for CTE implementation in an innovation hotspot in the Middle East. The authors articulate the philosophical principles and tool features in the design of the game-based learning platform and illustrate the use of the game-based learning platform under the novel pedagogical paradigm of "scenario-based programming" for CT development in classroom-level teaching and school-level competitions.

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In "TA to AI: Tinkering Approach to Artificial Intelligence and Computational Thinking Education in Indian Schools," Raina, Jogeshwar, Yadav, and Iyer present a case of CT development through artificial intelligence (AI) education—a focus direction of CTE in K–12 in the coming decade. This chapter shares a stimulating achievement by a technology hotspot in South Asia on the development of national initiatives and materials for a tinkering curriculum in CTE in the big data era. The authors introduce the evolution and rationale of the AI education through tinkering approach in the Indian K–12 sector, and they illustrate the latest government–academy collaboration on developing guidelines, curriculum modules, national labs, and pedagogical resources for AI education at the nationwide level.

The final paper in this part—"Case Studies of Computational Thinking Education and Robotics Education in China" by Wang and Li—shares and discusses the experience in China on the curriculum planning and implementation of robotics education for CT development through physical computing education—another focus direction of CTE in K–12 in the coming decade. This chapter guides readers to take a look at the strategic planning and curricular initiatives for CT development through robotics education among K–12 students in China. The authors elaborate on the policy background, curriculum rationales, and syllabus structures in China for CT development through robotics education in primary and secondary schools, with a discussion about the cases of in-school and after-school robotics education activities for CT development in K–12.

THE INSIGHT INTO THE GLOBAL DIRECTIONS OF COMPUTATIONAL THINKING CURRICULA IN K–12

This section—taking the Darmstadt Model (Hubwieser 2013; Raman, Venkatasubramanian, Achuthan, and Nedungadi 2015) into consideration—grounds the chapters within a unifying framework for a critical highlight of visions, challenges, and initiatives in the development and implementation of CT curricula on a global basis. Table I.1 provides a critical highlight of the main issues in the development and implementation of CT curricula across the Asian, European, and Oceanian countries/regions covered by this volume.

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Table I.1 The state of CT curricula implementations across the Asian, European, and Oceanian countries/regions covered by this volume

Countries/Regions (in alphabetical order)	Main issues in the development and implementation of CT curricula
Asia China *[CTE for primary and secondary school sectors (equivalent to grades 1 to 12)]*	• CT development is built through information technology education. • An official strategy with CTE-focused concerns was released in 2012. • CT is a noncompulsory curriculum component—allowing flexibility for the development and implementation of CTE-related initiatives at statewide, citywide, or school-based levels. • Inquiry-based learning for problem-solving is emphasized in the design of CTE-related initiatives. Unit-based teaching is advocated for CT cultivation through programming education and robotics education.
Hong Kong *[CTE for senior primary school sector (equivalent to grades 4 to 6)]*	• CT development is built through the coding education track under STEM education. • An official strategy with CTE-focused concerns has been released since 2015. • CT is a noncompulsory curriculum component—allowing school-based development and implementation of CTE-related initiatives. • Student-centered learning is emphasized for the design of CTE-related initiatives. Theme-based teaching is advocated for implementing CTE-related initiatives.
India *[CTE for upper primary to senior secondary school sectors (equivalent to grades 6 to 12)]*	• CT development is built through computer education and AI education. • An official strategy with CTE-focused concerns has been released since 2016. • CT is an elective component in the higher secondary curriculum and a noncompulsory component in the primary and middle school curriculum; yet it is an independent module in a national AI-education scheme across grades 6 to 12. • Active learning for problem-solving is emphasized for the design of CTE-related initiatives. An experiential teaching approach in authentic problem-based learning tasks is advocated for the implementation of CTE-related initiatives.
Israel *[CTE for elementary, middle, and high school sectors (equivalent to grades 1 to 12)]*	• CT development is built through the computer science program. • An official strategy with CTE-focused concerns has been released since 2012. • CT is a compulsory component in the high school curriculum and a noncompulsory component in the elementary and middle school curriculum. • The ability of computational problem-solving is the emphasis on CTE-related initiatives. A scenario-based programming approach is advocated for the cultivation of computational problem-solving.

(*continued*)

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Table I.1 (continued)

Countries/Regions (in alphabetical order)	Main issues in the development and implementation of CT curricula
South Korea *[CTE for upper elementary, middle, and high school sectors (equivalent to grades 5 to 12)]*	• CT development is built through the *software education* curriculum. • An official strategy with CTE-focused concerns has been released since 2014. • CT is a compulsory curriculum component—as in the *software education* subject for grades 5 to 12. • Software education is the main approach to CTE, which integrates with science, technology, engineering, arts, and mathematics (STEAM) education and maker education for an emphasis on students' development of CT together with creativity and communication skills.
Singapore *[CTE for primary and secondary school sectors (equivalent to grades 1 to 12)]*	• CT development is built through computing/computer science education. • An official strategy with CTE-focused concerns has been released since 2014. • CT is a noncompulsory curriculum component—offering CTE-related initiatives to students at various ages through various touchpoints on campus and after school. • The approaches of inquiry-based and project-based learning for problem-solving are advocated for the design and implementation of CTE-related initiatives in a school-based manner.
Taiwan *[CTE for primary and secondary school sectors (equivalent to grades 1 to 12)]*	• CT development is built through the *information technology* track and *life and technology* track under the technology learning area of the national curriculum. • An official strategy with CTE-focused concerns has been released since 2014. • CT is a noncompulsory curriculum component—school-based approaches to integrating CTE-related initiatives into cross-field learning with real-life scenarios. • Situated learning through problem-solving tasks is emphasized for the design of CTE-related initiatives. A theme-based teaching approach is advocated for the implementation of CTE-related initiatives.
Europe Finland *[CTE for basic education sector (equivalent to grades 1 to 9)]*	• CT development is built through the *computing* cross-curricular topic, which is integrated in all subjects in the national core curriculum for basic education. • An official strategy with CTE-focused concerns has been released since 2014. • CT is a compulsory curriculum component—as in the *computing* cross-curricular topic for grades 1 to 9. • The design and implementation of CTE-related initiatives emphasizes the human-driven, design-driven, and discipline-driven perspectives for a holistic understanding of CT.

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Table I.1 (continued)

Countries/Regions (in alphabetical order)	**Main issues in the development and implementation of CT curricula**
United Kingdom *[CTE for primary and secondary school sectors (equivalent to grades 1 to 12)]*	• CT development is built through computing/computer science education. • An official strategy with CTE-focused concerns has been released since 2012. • CT is a compulsory curriculum component in England and Scotland but a noncompulsory curriculum component in Wales and Northern Ireland. • Problem-solving elements is emphasized in the design and implementation of CTE-related initiatives.
Oceania Australia *[CTE for primary and secondary school sectors (equivalent to grades K to 10)]*	• CT development is built through the *digital technologies* curriculum. • An official strategy with CTE-focused concerns has been released since 2011. • CT is a compulsory curriculum component—as in the *digital technologies* subject for grades K to 10. • Both plugged and unplugged approaches are emphasized in the design and implementation of CTE-related initiatives.
New Zealand *[CTE for primary and secondary school sectors (equivalent to grades K to 12)]*	• CT development is built through the d*igital technologies* curriculum. • An official strategy with CTE-focused concerns has been released since 2011. • CT is a compulsory curriculum component—as in the *digital technologies* subject for grades K to 12. • Both plugged and unplugged approaches are emphasized in the design and implementation of CTE-related initiatives.

School education in countries around the world calls for the cultivation of students' CT, with a vision that CT is an essential skill for everyone in the digital society. Between 2011 and 2016, CTE started to become a globally emergent focus in curriculum planning, development, and implementation in K–12 schools. The countries/regions covered by this volume document official strategies for CTE mostly across grades 1 to 12. For the Oceanian countries of Australia and New Zealand, CT curricula start as early at grade K. In Hong Kong, South Korea, and India, the introduction of CTE elements into school curricula starts in senior primary schooling, in grades 4, 5, and 6, respectively.

Almost all countries/regions covered by this volume take the existing curricula in the disciplines related to computing, computer science, information technology, and digital technologies as a foundation when

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designing K–12 curricular initiatives for CT development. This direction in curriculum design leads to the popularity of the pedagogical emphasis on the problem-based learning approach for problem-solving in CTE, as the goal of these disciplines commonly targets the use of digital technologies to solve problems. Theme-based inquiry tasks are commonly arranged in CTE-related initiatives in this regard. Israel makes a noteworthy innovation of using the scenario-based programming approach in CTE-related initiatives for the cultivation of computational problem-solving.

Nearly half of the countries/regions covered by this volume do not require K–12 schools to compulsorily deliver subject curricula for CTE. For the remaining countries/regions, the governments set CT to be a compulsory component in the school education curriculum. In the United Kingdom, CT is a compulsory curriculum component in two of its constituting nations: England and Scotland. In Israel, CT is a compulsory component in the high school curriculum, not in the elementary and middle school curriculum. In Finland, South Korea, Australia, and New Zealand, schools are required to deliver CT-related curricula components in all schooling grades covered by the national CTE policy: the *computing* cross-curricular topic with a human-driven, design-driven, and discipline-driven concern in the Finnish core curriculum for basic education; the *software education* subject in the South Korean national curriculum for developing CT, creativity, and communication in upper elementary, middle, and high school sectors; and the *digital technologies* subject with plugged and unplugged activities in primary and secondary curricula in Australia and New Zealand.

This volume provides insights into the promising directions of computational thinking curricula in K–12. The curricular implementation of CT education in school education should be started as early as at the kindergarten level, for providing students with a coherent development of CT throughout their four schooling stages—kindergarten, elementary school, middle school, and high school. Students at the kindergarten stage are able to enjoy CT education through symbolic plays that involve the prerequisites of CT (decomposition and pattern recognition), based on the discussion by Román-González and Pérez-González.

The experience in the United Kingdom (as shared by Scott), New Zealand, and Australia (as shared by Bell, Vivian, and Falkner) as well as China (as shared by Yang and Ren) demonstrates the feasibility for policymakers

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and school leaders to plan and implement CT curricular initiatives covering grades K through 12. In China, there is a revamp of national curriculum standards for implementing CTE (as shared by Huang et al.).

From the sharing among all Asian, European, and Oceanian countries/regions covered by this volume, the stages of elementary schooling and middle schooling are considered to be a natural timepoint for promoting students' development of CT in school education; and the approach of problem-solving in the theme-based inquiry process when learning computer programming is popularly chosen for CT curricular activities to develop students' CT. These CT curricular focuses concur with the global meta-review findings in Grover and Pea (2013) and Hsu et al. (2019).

Apart from the stream of programming education, this volume presents various growing concerns for CT curriculum implementations: CT development through robotics education (experience in China as shared by Wang and Li); CT development through AI education (experience in India as shared by Raina et al.); CT development through STEAM education (experience in South Korea as shared by So, Kim, and Ryoo); CT development with an emphasis on human-driven, design-driven, and discipline-driven perspectives (experience in Finland as shared by Mäkitalo et al.).

Most countries/regions set CT as a compulsory component in the school curriculum, while three Asian countries/regions covered by this volume—namely Hong Kong (as shared by Kong and Kwok), Singapore (as shared by Looi et al.), and Taiwan (as shared by Shih)—opt to arrange CT to be a noncompulsory curriculum component. Schools in these three places are allowed school-based flexibility to develop and implement CTE-related initiatives on campus and after school.

On top of sharing global experience in CT curricula implementations with the conventional focuses, this volume also provides an alternative perspective for curriculum developers and school practitioners to diversify the pedagogical designs for CTE integration in K–12 school curricula. The Israeli experience, as shared by Armoni et al., reframes CT to be "computational problem-solving" and innovates the pedagogical paradigm of "scenario-based programming" for CT development. Curriculum developers and school practitioners are encouraged to think outside the box to go beyond the focus on imperative sequential programming when they design and implement CT curricular initiatives in school education.

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In summary, policymakers, school leaders, and school teachers in K–12 sectors around the world are creating promising change at the levels of education system, school implementation, and classroom practice for the planning, development, and implementation of CT curricula. The goal of this volume is to inform and advance debate and discussion about CT curricula in K–12. This volume organizes thirteen chapters into two parts to broadly address four areas of concern in CT curricula implementations—educational policy for CTE in K–12, curriculum development for CTE in K–12, school implementation of CT curricula in K–12, and classroom practice of CT curricula in K–12. The global and representative overview provided in this volume can provide a quick reference for policymakers, curriculum developers, school practitioners, and educational researchers to develop an international perspective of and a rounded reflection on the current states and future possibilities of CT curricula in K–12 schools.

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Computational Thinking Curricula in K–12

International Implementations

Edited by: Harold Abelson, Siu-Cheung Kong

Citation:

Computational Thinking Curricula in K–12: International Implementations
Edited by: Harold Abelson, Siu-Cheung Kong
DOI: 10.7551/mitpress/14041.001.0001
ISBN (electronic): 9780262378642
Publisher: The MIT Press
Published: 2024

The open access edition of this book was made possible by generous funding and support from MIT Press Direct to Open

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The MIT Press would like to thank the anonymous peer reviewers who provided comments on drafts of this book. The generous work of academic experts is essential for establishing the authority and quality of our publications. We acknowledge with gratitude the contributions of these otherwise uncredited readers.

This book was set in Stone Serif by Westchester Publishing Services.

Library of Congress Cataloging-in-Publication Data

Names: Abelson, Harold, editor. | Kong, Siu Cheung, editor.
Title: Computational thinking curricula in K-12 : international implementations / edited by Harold Abelson and Siu-Cheung Kong.
Description: Cambridge, Massachusetts : The MIT Press, [2024] | Includes bibliographical references and index.
Identifiers: LCCN 2023027971 (print) | LCCN 2023027972 (ebook) | ISBN 9780262548052 (paperback) | ISBN 9780262378659 (epub) | ISBN 9780262378642 (pdf)
Subjects: LCSH: Computer science—Study and teaching—Case studies. | Problem solving—Study and teaching—Case studies.
Classification: LCC QA76.27 .C478 2024 (print) | LCC QA76.27 (ebook) | DDC 004.071—dc23/eng/20230905
LC record available at https://lccn.loc.gov/2023027971
LC ebook record available at https://lccn.loc.gov/2023027972

ISBN: 978-0-262-54805-2

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