CoolThink@JC
賽馬會運算思維教育
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Global Benchmarking of Computational Thinking Education in Primary Schools

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CoolThink@JC is created and funded by The Hong Kong Jockey Club Charities Trust, and co-created by The Education University of Hong Kong, Massachusetts Institute of Technology, and City University of Hong Kong.

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EXECUTIVE SUMMARY

In company with other leading jurisdictions around the world, Hong Kong is taking important steps to mainstream computational thinking education (CTE) into the primary grades curriculum. At the vanguard of this movement in Hong Kong, CoolThink@JC[1] is a 3-year course sequence for upper primary students designed to develop computational thinking skills and digital creativity, problem-solving, and other 21st century skills. After a successful 4-year pilot, CoolThink@JC is scaling within Hong Kong and receiving increasing recognition on the global stage. This benchmarking report uses publicly available reporting to compare Hong Kong's CoolThink initiative to analogous experiences in three leading jurisdictions (the United Kingdom, Singapore, and the two cities of Guangzhou and Shenzhen in Guangdong Province, China). Looking across five dimensions that are fundamental to successful adoption at scale, the report offers a framework for reviewing CoolThink@JC's accomplishments to date and CTE initiatives in other jurisdictions.

CoolThink@JC among global CTE leaders

- **Scope and goals of CTE at the primary grades.** With CoolThink@JC, Hong Kong joins other leading jurisdictions in prioritizing computational thinking within technology education at the primary level. Encouraging student agency (students as makers and creators rather than solely consumers of technology) is a key rationale for CTE in the benchmark jurisdictions. CoolThink@JC targets primary grades to nurture proactive use of technologies from a young age; other jurisdictions have promoted primary CTE initiatives to develop a CTE progression and pipeline to the secondary level and beyond.
- **National policy context.** Hong Kong currently encourages CTE instruction through its primary school curriculum framework. Other benchmark jurisdictions use national curriculum and compulsory education requirements to communicate priorities for CTE, with the UK leading the way in 2014 and Singapore mandating CTE instruction at the primary level in 2020. Benchmark jurisdictions also recognize the growing strategic importance of artificial intelligence (AI) and have aligned goals for primary and secondary technology education with national AI strategies, especially in China.
- **Scaling strategies.** CoolThink@JC began with a 32-school pilot phase and is scaling to reach a critical mass of schools that can spur the

[1] CoolThink@JC was developed beginning in 2016 by the Hong Kong Jockey Club Charities Trust (the Trust), in partnership with Education University of Hong Kong (EdUHK), Massachusetts Institute of Technology (MIT), and City University of Hong Kong (CityU).

adoption of territory-wide CTE instruction. In the other benchmark jurisdictions, early adopter schools and classrooms have also served as proof of concept for broader-scale adoption in later phases. Across benchmark jurisdictions, cross-sector coalitions of government agencies, schools, private sector companies, teachers' associations, and other non-governmental advocates have collaborated to lead the charge for CTE.

- **Resources to support implementation at scale.** The primary levers for CoolThink adoption are a set of high-quality, award-winning lesson materials and aligned professional development, whereas other jurisdictions offer a broader range of teaching resources that teachers can choose from. Each initiative includes in-service professional development offered at scale, typically through networks of experienced teachers or industry partners. Integration of CTE into pre-service training is less common.
- **Sponsored research.** CoolThink@JC and the United Kingdom have invested in independent, third-party evaluations to assess progress toward scaling goals. Of these initiatives, only CoolThink@JC has reported on primary students' CTE learning.

Distinctive features of CoolThink@JC

Compared with other CTE initiatives, CoolThink@JC offers several distinctive features:

- **Fully articulated course sequence with aligned professional learning and supports.** CoolThink@JC offers high-quality curriculum materials with aligned professional learning and in-class supports that equip teachers to offer high-quality computational thinking instruction from the start. This integrated package alleviates the initial burden of lesson curation or design and may promote instructional equity across schools.
- **Outreach, awareness-raising, and training that reaches beyond in-service educators.** CoolThink@JC offers a robust parent outreach and education campaign as part of its scaling strategy. Teacher preparation programs in Hong Kong use CoolThink materials to introduce pre-service teachers to CTE concepts and pedagogy.

Elevating Hong Kong as a global leader in CTE

Over the next several years, CoolThink partners and key stakeholders can take the following steps to elevate Hong Kong's status as an international CTE leader:

- Position CoolThink@JC as part of a **vertically aligned CTE progression** that covers the full primary and secondary spectrum.
- Support the development of a **territorial AI education plan** to highlight the economic importance of CTE.
- Continue to **expand teacher networks and leverage** teacher **professional associations** to sustain and advocate for high-quality CTE instruction across the territory.
- Accept some trade-offs, as benchmark jurisdictions do, between standardization, equity, and quality of instruction and the flexibility to support scaling on the other. **Attend to these trade-offs** in Hong Kong as CoolThink scales.

INTRODUCTION

In 2016, the Hong Kong Jockey Club Charities Trust (the Trust) partnered with the Education University of Hong Kong (EdUHK), Massachusetts Institute of Technology (MIT), and City University of Hong Kong (CityU) to develop and pilot CoolThink@JC, a 3-year course sequence for upper primary students designed to develop computational thinking skills and digital creativity, problem-solving, and other 21st century skills. CoolThink@JC aims to nurture students' proactive use of technologies for social good from a young age, preparing them for a fast-changing digital future through hands-on, minds-on, and joyful learning experiences. In addition to comprehensive instructional materials that include teacher and student guides, detailed lesson plans, and formative assessments, CoolThink@JC offers intensive teacher professional development (PD) courses to support effective CoolThink instruction, parent workshops to support engagement in computational thinking education (CTE), and other supports for adoption (see *Scaling CoolThink@JC* box).

Scaling CoolThink@JC: Key features and progress to date

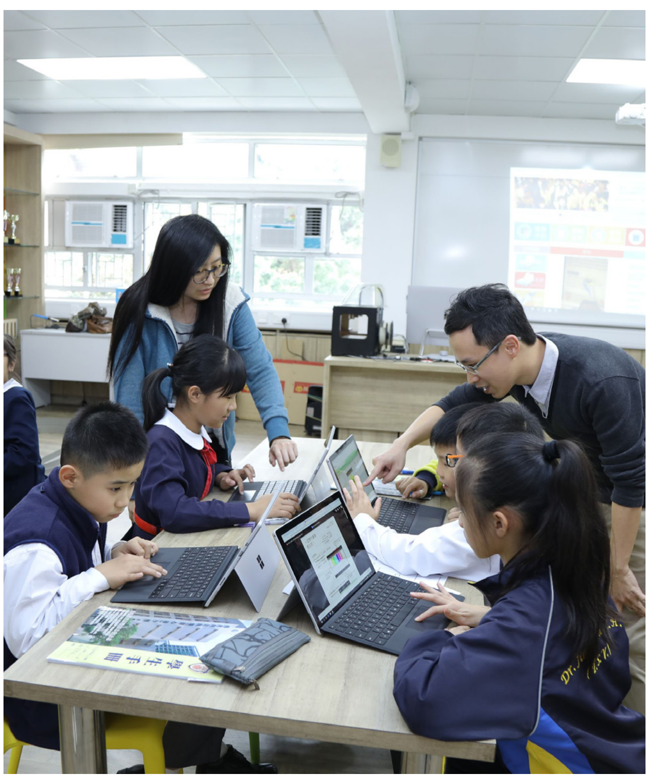
The key components of CoolThink@JC as it was designed for scale include three 14-hour lesson sequences and accompanying instructional materials for students in Primary 4–6, along with support for school-level tailoring of the CoolThink curriculum. To support full adoption of these lesson sequences in a critical mass of "CoolThink network" schools, CoolThink@JC offers four 12-hour foundational teacher development courses, teaching assistants to support CoolThink instruction during teachers' first year in the program, mentor teachers who conduct peer observations and provide feedback, and cluster-level communities of practice (CoPs) that convene CoolThink teachers within a geographic region to collaborate and share resources.

CoolThink@JC began a 32-school pilot in 2016. Since 2020, the CoolThink network has grown from 32 pilot schools to 190 in 2021–22 and will include 200 schools in total by the end of the initiative's scaling phase in 2024. These 200 CoolThink network schools will represent about 40% of all Hong Kong primary schools.

To support more flexible adoption of CoolThink materials in an additional 168 primary schools, CoolThink@JC has convened an "InnoCommunity" network supported by CoolThink mentor teachers and collaborates with multiple partners to offer additional teacher PD to these schools (for example, workshops sponsored by the Hong Kong Education Bureau (EDB) and workshops led by InnoCommunity teachers). In 2021–22, 48 schools participated in InnoCommunity workshops, and teachers from 192 schools attended EDB workshops and other 3-hour workshops led by InnoCommunity teachers. By summer 2022, the Trust estimated that it had reached nearly 80% of Hong Kong primary schools, either as members of the CoolThink network, via InnoCommunity activities, or in curriculum workshops designed to introduce schools to CoolThink materials for initial pilot testing.

CoolThink@JC also sponsors parent engagement workshops, coding fairs, and student competitions that reach a large number of Hong Kong primary schools. In addition, CoolThink@JC partners, led by the Trust, have entered into strategic partnerships with Hong Kong's EDB, school sponsoring bodies (SSBs), and non-governmental organizations to develop a territory-wide ecosystem in support of computational thinking education.

Over the course of a 4-year pilot, 32 Hong Kong primary schools adopted CoolThink lessons for more than 20,000 Primary 4–6 students. A rigorous independent evaluation of the pilot found that CoolThink@JC had a large positive impact on students' computational thinking practices and a smaller impact on their understanding of computational thinking concepts, compared with business-as-usual ICT instruction in other Hong Kong primary schools (Shear et al., 2020). The initiative has since won international recognition: for example, in 2021, the International Society for Technology in Education (ISTE) certified that CoolThink materials were aligned to ISTE Student Standards and that they contributed to pedagogically robust use of technology for teaching and learning, and Reimagine Education awarded CoolThink@JC both a silver medal in the category of Engineering & IT and a bronze medal in Presence Learning (ISTE, 2021; QS-Reimagine Education, 2021).



Beginning in 2020, CoolThink's co-creators, led by the Trust, have undertaken an ambitious initiative to take CoolThink@JC to scale within Hong Kong, supporting its full adoption in 200 primary schools by 2024 and laying a foundation throughout the education system for the adoption of CoolThink materials in some form by all Hong Kong primary schools. By demonstrating success at scale, CoolThink partners hope to create a new paradigm for CTE at the upper primary level that will serve as an international model for other jurisdictions (cities, regions, and countries).

To capture the lessons learned from this effort, the Trust has engaged SRI International to study the implementation of CoolThink@JC at scale. As part of this study, this report benchmarks CoolThink@JC against similar efforts to expand CTE to all primary schools in leading jurisdictions worldwide, with a particular focus on initiatives in England, Singapore, and two cities in China. This benchmarking exercise is intended to provide a framework for comparing scaling strategies in different national contexts and to inform ongoing research on CoolThink's impact. Table 1 summarizes the benchmarking results.

Table 1. CoolThink@JC Global Benchmarking Summary

	CoolThink@JC/Hong Kong	Guangzhou/Shenzhen	Singapore	United Kingdom
I. Primary grades CTE scope and goals	Emphasis on creativity, problem-solving, and transferable thinking skills; early efforts are exploring expansion to other grade levels	CTE more present in secondary curriculum; programming education guidelines for primary school introduce concepts needed for later success	ICT education redesigned to focus on computational thinking in 2014, with a focus on age-appropriate learning activities designed to cultivate student interest beginning in pre-school	ICT education redesigned to focus on computational thinking in 2014; CTE in primary grades is part of a defined progression through secondary school
II. National policy context	CTE encouraged, not mandated, within the curriculum framework; CoolThink has added AI-related student projects and teacher development to existing CTE content	Information technology topics recommended in national curriculum guidance for Primary 3–6; AI is a strong national strategic priority, and the focus of a five-city educational pilot	Smart Nation initiative aimed at students' "computational capabilities," shifting the focus from use of applications to creation of digital artifacts; AI concepts addressed in an optional supplement	CTE incorporated into compulsory primary curriculum in 2014, with the goal of increasing the number of students sitting for the General Certificate of Secondary Education (GCSE) computer science exam in secondary school
III. Scaling strategies	4-year, 32-school pilot began in 2016, expanding to 190 schools by 2022 in the initiative's scaling phase; development and implementation led by a private charity (the Hong Kong Jockey Club Charities Trust), in partnership with leading universities, the HK Education Bureau, and teachers' associations, with parent outreach as a core component	Five pilot cities are developing and testing curriculum materials and teacher training strategies, through multi-sector partnerships between schools, research institutes, and large technology companies	Code for Fun 10-hour enrichment class piloted in 117 schools by 2016 and made mandatory in 2020; CTE is supported by a broad multi-sector coalition that includes the Ministry of Education, Infocomm Media Development Authority (IMDA), universities, industry partners, and others	Scaling driven though networks of master teachers that have trained 29,000 primary and secondary teachers; CTE efforts began with a grassroots coalition and later funded by Department for Education in partnership with regional agencies

	CoolThink@JC/Hong Kong	Guangzhou/Shenzhen	Singapore	United Kingdom
IV. Resources to support implementation at scale	Adoption driven by high-quality instructional materials; robust aligned teacher professional learning; co-teaching support by teaching assistants in the first year of adoption; parent workshops; support for purchases of new hardware; pre-service training; and aligned student assessments.	Pilot districts and schools provide funding for materials and teacher training. AI textbook compiled by the Guangzhou Research Institute coupled with asynchronous, online professional development (42 hours) offered by the Guangzhou Education Bureau	With funding from IMDA, teachers attend workshops offered by educational technology vendors and make selections of instructional materials and accompanying technology	Teachers develop their own instructional materials or select from commercially available alternatives. The National Centre for Computing Education (NCCE) has trained almost 30,000 teachers nationwide with funding of £84 million
V. Sponsored research/ evidence of impact	Pilot phase impact study, scaling phase implementation study, and ongoing research by university partners	In pilot phase, no sponsored research available	No published research on the implementation or impact of Code for Fun	Comprehensive evaluation by the Royal Society of progress toward national goals for CTE

Benchmarking CoolThink@JC

As CoolThink@JC scales within Hong Kong, and its co-creators consider the ways in which the CoolThink experience might inform efforts to scale computational thinking education in other countries, questions about how CoolThink@JC compares to other leading efforts to establish CTE as a key learning objective in the compulsory primary school curriculum assume increasing importance. Therefore, this benchmarking exercise addresses the following:

- In what ways is CoolThink@JC similar to initiatives undertaken by other global leaders to expand high-quality CTE to all students at the primary level?
- In what potentially promising ways is CoolThink@JC unique or distinct from other initiatives?

The United Kingdom (UK), Singapore, and two cities in Guangdong province, China (Guangzhou and Shenzhen) serve as the international benchmarking examples for this report. Like CoolThink@JC, these initiatives are designed to scale CTE to all primary students within their jurisdiction. The United Kingdom was one of the first countries to adopt policies mandating CTE instruction in primary schools; other countries can learn from its long track record of scaling efforts. Singapore, Guangzhou, and Shenzhen are Hong Kong's near neighbors and global cities with student populations roughly similar in size to Hong Kong (each jurisdiction serves students in 180 to 850 public sector primary schools). Although their education systems differ in some key respects, the challenges of scaling to this number of primary schools are similar. In addition, because the United States is a leader in computer science education, we have included some selected examples of U.S. initiatives where they are particularly relevant to CoolThink@JC; however, because the national government has no role in guiding local curriculum decisions and because widely adopted approaches to CTE at the primary level have not yet emerged in the U.S., it is not included as a primary benchmarking example.

Data sources and methods

This report is based on a review of publicly available peer-reviewed reports, policy documents, curriculum frameworks, and government agency websites describing efforts to promote CTE at the primary grades in the benchmark cities and states. Beginning with key features of the CoolThink@JC program, we reviewed the public record of CTE initiatives in other counties to understand the extent to which they shared those same features and the ways in which they differed. This review yielded a list of five dimensions for the benchmarking exercise:

- Scope and goals of CTE at the primary grades
- National policy context, including: (1) priorities for technology education and (2) the mechanisms by which local curriculum decisions are made
- Scaling strategies, including the design of pilots to support the adoption of CTE by individual teachers and schools
- Resources to support implementation at scale, including (1) teacher professional development and (2) instructional materials
- Sponsored research/evidence of impact

This report considers each of these dimensions in turn. In the sections that follow, we compare CoolThink@JC with CTE initiatives at the primary level in other leading jurisdictions on each of these benchmarking dimensions, presenting key findings under each dimension in highlighted statements. Rather than striving to be comprehensive, we have presented only the most relevant examples under each dimension. In some cases, we don't include a benchmark country because we lacked sufficient information to make a well-informed comparison.

I. SCOPE AND GOALS OF COMPUTATIONAL THINKING EDUCATION AT THE PRIMARY GRADES

Efforts to promote CTE in the benchmark countries are unfolding in the context of technology education more broadly, which encompasses a variety of topics, content, and skills (see the *Key Terms and Concepts* box). New CTE initiatives must account for existing curriculum frameworks, instructional time, and pedagogical approaches to teaching the array of topics that fall within the domain of technology education; the extent to which CTE is promoted relative to these other topics and priorities is an important consideration for scaling efforts.

I.1. With CoolThink@JC, Hong Kong joins other leading jurisdictions in placing computational thinking front and center in technology education at the primary level.

Computational thinking concepts, practices, and perspectives are the core of **CoolThink@JC's** learning goals for primary students. CoolThink materials are designed to introduce computational thinking as a learning objective in basic primary education, with the goal that students would become more creative, innovative, and competent in collaborative problem-solving, in addition to learning to code. CoolThink's learning objectives include key computational thinking concepts (abstraction, conditionals, sequencing) but also computational thinking practices (iteration, testing, debugging) and computational thinking perspectives (development of digital identity and agency). Although not intended

to replace existing ICT lessons, the adoption of CoolThink lessons requires primary schools to place new emphasis on computational thinking as a key learning goal for students. At its core, CoolThink@JC is designed to develop thinking skills that support creativity, innovation, and problem-solving for students in all fields, whether they go on to enter one of the STEM professions or not.

Curriculum guidance issued in 2020 by the Hong Kong Education Bureau (EDB) is well-aligned with CoolThink@JC's emphasis on CTE (EDB, 2020). Recommended learning objectives included basic computational thinking concepts (abstraction, algorithms, and automation), understanding the problem-solving process, connecting coding with real-life problems, and solving problems through communication and collaboration. The guidance argues that computational thinking is a problem-solving methodology that can be transferred and applied in different contexts and that allows students to become "tool builders" rather than just tool users.

Key terms and concepts in technology education

The disciplines, topics, content, and skills included in the general domain of “technology education” in the benchmark countries go by many names. Key terms and concepts referenced in the policy documents reviewed for this benchmarking exercise suggest a wide range of possible learning goals for students.

Information and Communication Technology (ICT) or **Information Technology (IT)** in primary and secondary education is a school subject covering the use of wide variety of technologies—including computers and software programs, networking systems and protocols, hand-held digital devices, digital cameras and camcorders, and other technologies—to access, manage, create, and communicate information (National Assessment Governing Board, 2018). ICT courses often seek to develop students' digital competence or digital literacy skills.

Digital competence or **digital literacy** is the confident and critical usage of the full range of digital technologies for information, communication, and basic problem-solving in all aspects of life (School Education Gateway, 2020).

Information literacy is a set of skills enabling students to seek out information, understand how information is produced and valued, and use information to create new knowledge and participate ethically in learning (e.g., without plagiarizing) (ACRL, 2016).

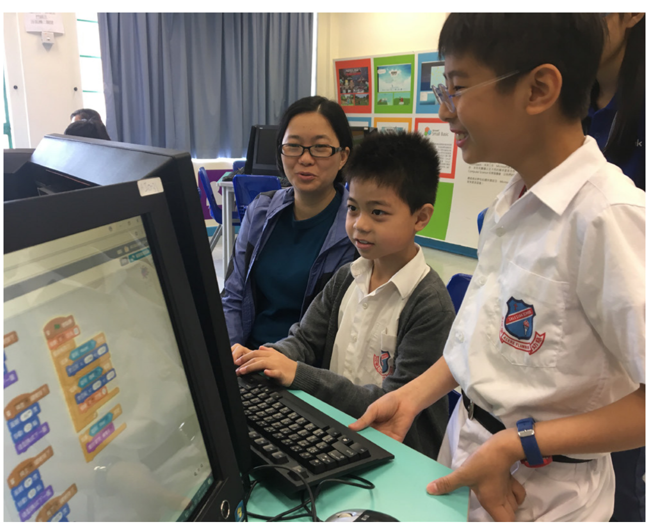
Computer science is an academic discipline covering the study of computers and algorithmic processes. Potential topics in primary and secondary education include programming, programming languages, logic, software design, hardware design, networks, graphics, databases and information retrieval, computer security, the limits of computation (what computers can't do), and related social issues (Internet security, privacy, intellectual property) (Tucker, 2003).

Computational thinking encompasses the thought processes and strategies required to understand, formulate, and solve a problem in such a way that a computer can carry out the solution (Wing, 2006). Central to current conceptions of computational thinking is the idea that computing is a means of self-expression and creativity. Elements of computational thinking as defined in CoolThink@JC include computation thinking: (1) Concepts, or the content knowledge required for developing computational artifacts; (2) Practices, or the problem-solving and logical thinking skills characteristic of computational thinking; and (3) Perspectives, or students' interest in and motivation for computational thinking, as well as perceptions of its nature and utility (Brennan & Resnick, 2012).

Programming or **coding** is the process of developing a fully functioning software solution (Franklin, 2019).

Artificial intelligence (AI) in primary and secondary education is the study of how computers perceive the world, construct representations using data structures, learn from data, and interact with humans, as well as how AI technologies impact society and closely related ethical considerations (AI4K12, n.d.a).

Compared with CoolThink@JC, CTE initiatives in the benchmark countries represent an explicit pivot to increase priority for CTE in the primary curriculum, where ministries of education redesigned existing ICT courses to introduce instruction in computational thinking. In 2014, following the publication of a widely disseminated report that was highly critical of traditional computing education (The Royal Society, 2012), the **United Kingdom** rebranded its ICT program of study to place a greater emphasis on computational thinking and other computer science topics. The goal was to promote computer science and the ability to create, rather than the digital competence emphasis of the ICT program. Similarly in **Singapore**, the Smart Nation initiative aimed to develop students' "computational capabilities," including computational thinking, problem-solving, algorithmic thinking, logical thinking, and AI and machine learning (Seow et al., 2019; Smart Nation Singapore, 2019). In both primary and secondary education, Singapore transitioned traditional ICT courses to shift the focus of ICT instruction from the use of applications to computational thinking. In these countries, ICT provided a toehold for computational thinking in an already crowded primary level curriculum.

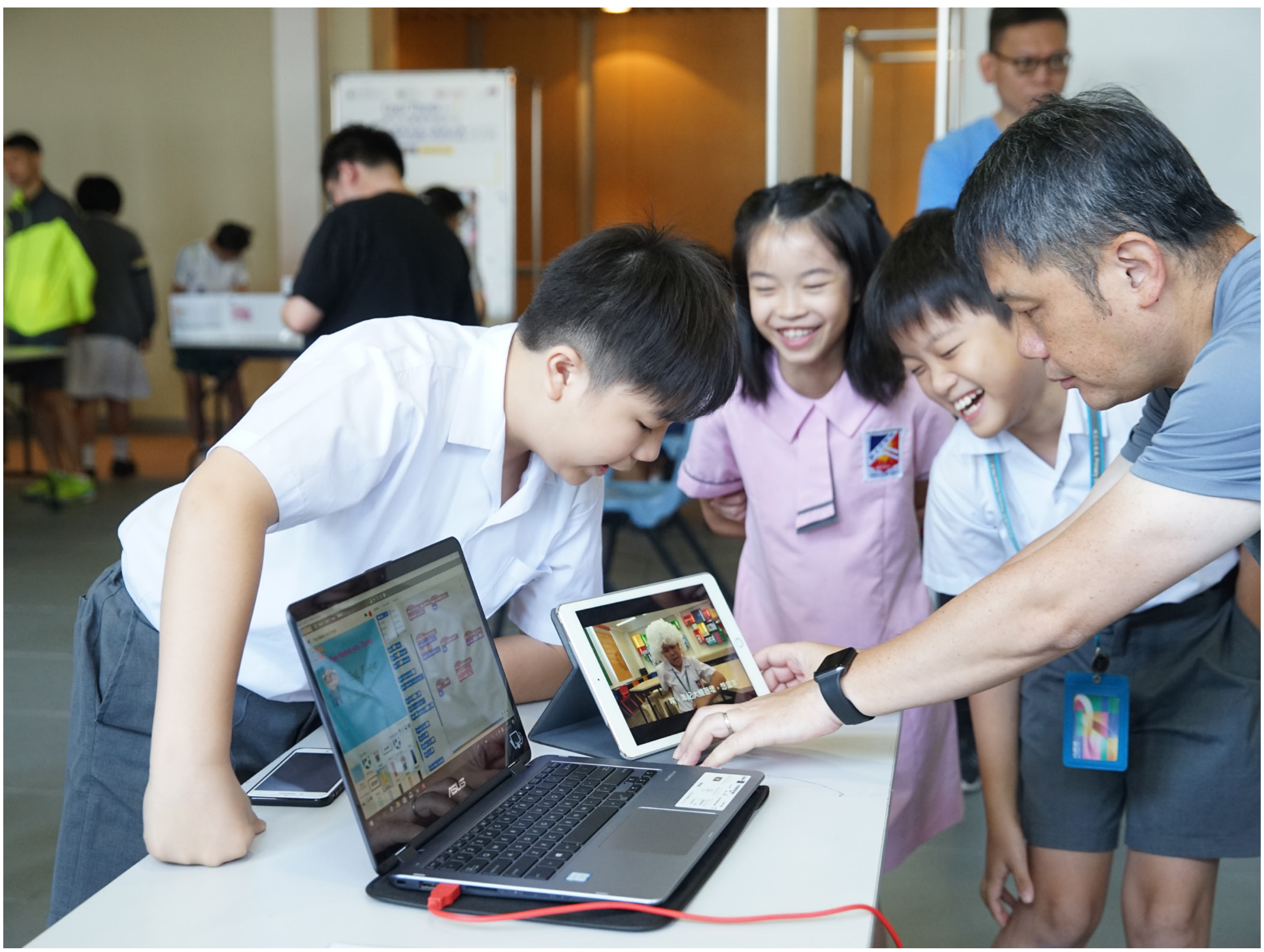


In **Guangzhou** and **Shenzhen**, the Ministry of Education of the People's Republic of China (China MOE) included computational thinking as a topic in secondary school information technology course standards published in 2017 (China MOE, 2020). However, computational thinking as it is defined and described in policy documents in the other benchmark countries is not an explicit goal of technology education at the primary level in these cities. Instead, curriculum guidelines for Primary 3–6 emphasize programming, information literacy, and AI awareness (e.g., Liu, 2017).

I.2. Computational thinking initiatives at the primary grades are often one component of a larger aligned reform effort encompassing both primary and secondary education.

CoolThink@JC currently offers lesson sequences for upper primary grades only, although co-creators are exploring options for an aligned course sequence that begins with CoolThink@JC for the primary grades. The Trust has also launched projects targeted at early primary grades and begun collaborating with teachers at the junior secondary level to pilot test CoolThink lessons in secondary schools.

Other jurisdictions typically promoted computational thinking education in the primary grades as part of a longer progression with the goal to develop a robust pipeline of students interested in studying computer science in secondary school and beyond. In **Singapore**, the general computational progression starts in preschool (ages 3–6) with cultivating students' interest in age-appropriate tools and continues through the upper primary grades with engaging play-based and maker-based enrichment activities designed to foster interest in computational thinking (Hsu, Irie & Ching, 2019; IMDA, n.d.a). In Singapore's ecosystem for computational thinking learning, exposure to computational thinking and computer science topics at the primary level is intended to support enrollment in computing as an O-level subject in secondary school (Seow et al., 2019). In the **United Kingdom**, compulsory education in computer science targets key stages 1 (ages 5–8) to 4 (ages 14–16), culminating in an elective computer science General Certificate of Secondary Education (GCSE) course and exam. GCSE course-taking and exams are a primary metric to evaluate the curriculum's implementation success. In **China**, curriculum standards published in 2017 and revised in 2020 addressed both secondary and primary education. China's *General High School Curriculum Program and Chinese and Other Subject Curriculum Standards* established information technology as a required course in secondary school and updated requirements for programming and computational thinking (China MOE, 2020). At the same time, to ensure that students would be prepared to succeed in the new information technology course, the China MOE issued guidelines for introducing programming to students in Primary 3–6 (Liu, 2017).



II. NATIONAL POLICY CONTEXT

In all benchmark countries, leaders have pursued strategies to incorporate computational thinking into instruction during the regular school day, rather than solely as an optional afterschool enrichment activity. National curriculum frameworks, policies governing mandated coursework, and other guidance documents shape scaling efforts by clearly communicating national priorities for technology education and setting parameters for schools' local adoption decisions.

II.1. Among benchmark countries, the United Kingdom was the first to make computational thinking part of the compulsory curriculum in the primary grades beginning in 2014. More recently, other global leaders have also included CTE in the mandatory curriculum for the primary grades via enrichment programs or curriculum guidance.

The **United Kingdom** mandated CTE for the primary grades in 2014. Curriculum frameworks for primary education specify the content and learning goals related to CTE for each grade level (Department for Education, 2013). These curriculum frameworks are aligned vertically, to prepare students for the General Certificate for Secondary Education (GCSE). In **Singapore**, the Ministry of Education (Singapore MOE) and the Infocomm Media Development Authority (IMDA) began piloting the Code for Fun Enrichment Programme in all MOE primary schools in 2014 (Hsu, Irie & Ching, 2019). Code for Fun is a 10-hour computational thinking and coding enrichment curriculum that introduces baseline computational thinking and programming concepts via visual block-based programming (e.g., Scratch) and robotics kits (e.g., Arduino, Raspberry Pi), as well as emerging technology concepts such as AI. In 2020, the Singapore MOE included Code for Fun in the mandatory curriculum for all primary schools (IMDA, n.d.a). In addition to Code for Fun, educators and researchers are also exploring ways to integrate CTE with compulsory subjects like mathematics (Ho et al., 2018; NIE, n.d.a, n.d.c; Tan & Chan, 2021).

Hong Kong schools set their own school-based curriculum, following frameworks developed by the Education Bureau of Hong Kong (EDB), and they have considerable latitude to adjust the breadth and depth of content presented to students and to offer learning experiences tailored to their students' particular strengths and needs. Hong Kong encourages CTE in the primary grades via curriculum guidance. In 2017, the Hong Kong EDB issued a draft supplement to the primary school curriculum framework that recommended that schools allocate 10–14 hours annually to CTE in the upper primary grades, either in a stand-alone class or by integrating the content into other subjects. The EDB published the final version of the supplement in 2020 (EDB, 2020).

In **China**, CTE is mandated for all schools at the secondary level but is not named as a learning objective in curriculum guidance at the primary level. In 2017, the China MOE included standards for programming, computational thinking, and algorithmic thinking in a mandated information technology course in its *General High School Curriculum Plan and Curriculum Standards for*

Chinese and Other Subjects (China MOE, 2020). At the primary level, the China MOE recommended specific learning units for information technology courses for Primary 3–6 in its *Curriculum Guidance for Comprehensive Practical Activities in Primary Schools* (Liu, 2017). Recommended units included 3D design and introduction to programming, but none with an explicit focus on computational thinking.

II.2. National AI policy and related goals for developing a strong pipeline of AI engineers have spurred innovation in technology education at the primary and secondary levels, especially in China.

Over the last 5 years, **China**'s national government (China State Council) has established national goals for the development of its AI technology sector intended to position the country as the global leader in this field (China State Council 2017 a, 2017b). In the service of these larger economic goals, China MOE has adopted policies and guidelines for primary, secondary, and post-secondary education to strengthen the pipeline of computer science and artificial intelligence engineers (Peterson et al., 2021); these new MOE guidelines are driving IT course redesigns and pilot programs in Guangzhou and Shenzhen at both the primary and secondary levels (see the *National AI policies and local demonstrations* box). Both the **United Kingdom** and **Singapore** have published national AI strategies that lay out actions for government agencies to take that regulate commerce, private tech companies, and post-secondary research and development institutes. These strategies also mention the call to expand digital literacy and AI readiness education at the primary and secondary levels (Secretary of State for Digital, Culture, Media, and Sport, 2021; Smart Nation Singapore, 2019).

National AI policies and local pilot demonstrations spur innovation at the primary level in Guangzhou and Shenzhen

In 2017, China's State Council issued a development plan laying out priorities to develop a new generation of artificial intelligence (AI) experts. The plan set priorities for establishing AI-related courses in post-secondary education and for promoting programming education at the primary and middle school levels. It also encouraged other sectors, including provincial governments, municipal governments, and technology firms, to participate in the development and promotion of new approaches to programming education (China State Council, 2017a, 2017b). In 2019, the China MOE directed local education agencies to include AI concepts in programming education at the primary and middle school levels (China MOE, 2019a).

To advance these national goals, the MOE selected five cities (Beijing, Guangzhou, Shenzhen, Wuhan, and Xi'an) in 2019 to develop and pilot new approaches AI in programming education. These pilot cities, along with local education research institutes, co-developed a research project titled AI Education for Primary and Middle School Education and co-designed a variety of AI instructional resources for use by schools (e.g., toolkits, AI curriculum for grades 3–8, curriculum guides) (Wu, 2019).

The MOE also selected Guangzhou to become the nation's first "Smart Education Demonstration Zone" (China MOE, 2019b) As a demonstration zone, the municipal government has undertaken the development of curriculum, instructional materials, and teacher training to support AI education in primary and middle schools as one of its most important priorities. For example, Guangzhou developed China's first textbook series for AI education, which was published in 2021 by the Guangdong provincial education agency. Guangzhou recruited 147 schools to pilot AI lessons and provided professional development to 1,500 teachers in August 2021 to develop the content and pedagogical knowledge needed to teach AI at the primary and secondary school levels (Guangzhou Bureau of Education, 2019; Guangzhou Institute of Educational Research, 2021).

To better prepare students to flourish in a world powered by rapidly evolving AI technology, other benchmark counties have taken steps to introduce AI content and AI-powered tools in computational thinking and coding lessons at the primary level as well. For example, In the **United States**, educators are collaborating on the development of standards that seek to incorporate AI into existing computer science education courses (see the *Innovation in AI education* box). Beginning in 2021, **CoolThink@JC** added student projects to existing units that allow students to use tools powered by AI to develop computer programs and has developed a 12-hour course for CTE teachers on AI awareness in the context of advanced applications of the MIT App Inventor programming language in 2021. In addition, the Trust funded and developed the first AI curriculum for Hong Kong secondary schools in 2019.[2] **Singapore** added a student activity book introducing AI concepts as a supplement to its Code for Fun program (IMDA, n.d.b).

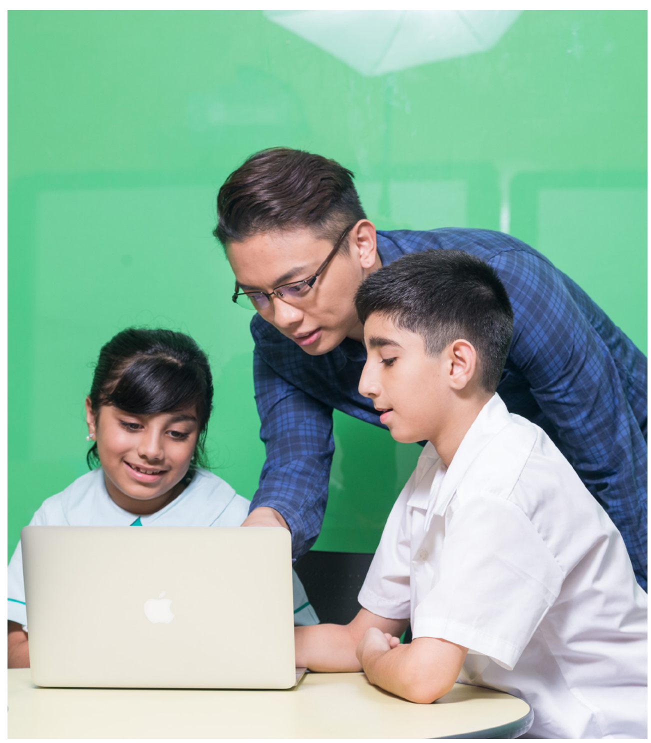
2 For additional detail, see https://cuhkjc-aiforfuture.hk/index.php/en/ai-teaching-and-learning-pack-en/.

Innovation in AI education led by standards development in the United States

The United States is experimenting with AI education curricula and industry partnerships through programs and standards that vary by state. Because computer science (CS) is viewed as a first step towards an AI specialization, these initiatives typically emphasize AI instruction in the context of existing CS education (Peterson et al., 2021). Currently, fewer than half of U.S. states (22 of 50 in total) have adopted policies to provide all upper secondary students access to CS courses, and 9 have mandated CS instruction for all primary and secondary students (Code.org, n.d.). Integration of AI curricula into existing courses in the U.S. is uneven, as it remains the work of states and local school districts to finalize and implement curriculum standards. Some AI education initiatives prioritize CS, programming languages like Java and Python, math, and data science, while others emphasize non-technical areas such as societal and ethical impacts of AI applications, art, and multimedia.

Artificial Intelligence for K–12 Initiative (AI4K12) is an initiative born from a partnership between the Association for the Advancement of AI (AAAI) and the Computer Science Teachers Association (CSTA) and was funded by the National Science Foundation (NSF) and Carnegie Mellon University (AI4K12.org, n.d.b). AI4K12's goal is to develop national AI education guidelines and learning progressions for all primary and secondary grades. It currently serves as an online repository of resources for educators. The private sector is also supporting CS and AI integration into primary and secondary education through a number of different initiatives in formal and informal contexts.

Although efforts to advance AI education as a national priority vary in scope across countries, they reflect a growing consensus within the benchmark countries that AI technology will play an increasingly critical role in shaping daily life, economic growth, and national security in the 21st century. Recognizing the importance of AI as an emerging technology, these benchmark countries have taken steps to incorporate AI concepts and skills into national CTE goals. In this respect, **Hong Kong** lags behind global leaders like China and the United States in the development of robust AI strategies as part of its CTE and CS education goals. Unlike these countries, Hong Kong does not yet have a specific policy for comprehensive AI education, nor a city-wide strategic plan for developing a strong pipeline of AI talent.



III. SCALING STRATEGIES

All of the benchmark countries included in this report have adopted strategies for incremental scaling of new CTE requirements and initiatives, beginning with voluntary adoption of new standards and instructional materials on a small scale and building over time toward mandates for the compulsory curriculum that apply to all primary schools. Although the scaling strategies differ across contexts, all of the benchmark countries adopted strategies that acknowledged the importance of demonstration sites that can serve as incubators for new instructional materials and the role of highly experienced master teachers who can speak to the value of CTE for other schools and teachers.

III.1. Like other leading jurisdictions, CoolThink@JC has begun scaling by recruiting "early adopter" schools to serve as a proof of concept for broader scale adoption in later phases.

CoolThink@JC began piloting CTE lessons in 12 schools in 2016, expanding the pilot to 32 schools and 3 lesson sequences by 2019. CoolThink teachers in pilot schools received intensive training (up to 78 hours), and a select group of master teachers received additional training on-site from CoolThink's development partners at MIT. After the pilot period, pilot schools and specially trained teachers serve as resources for other CoolThink network schools; they also disseminated CoolThink materials and provided training to out-of-network teachers through the CoolThink InnoCommunity.

In other jurisdictions, early, voluntary adoption in a critical mass of classrooms or schools also paved the way for later systemwide implementation via government mandates. For example, **Singapore** introduced Code for Fun as an optional enrichment program for all Singapore MOE primary schools in 2014. The Singapore MOE designed this opt-in model to allow each school to select a program aligned with student needs and interests, as well as one that teachers were willing to learn and adopt. The IMDA provided 70% of the funding required to purchase the hardware and software required for each program, with the balance of the funds provided by the school, on the condition that a minimum number of students would participate. Teachers were also required to attend training conducted by the technology vendors. By 2016, 117 schools had adopted a Code for Fun program (Seow et al., 2019). After this long pilot period, a 10-hour coding enrichment class was piloted for Primary 6 students in 2019 and mandated for all upper primary grades in 2020. Although now mandated for all Singapore MOE primary schools, education leaders in Singapore built a robust CTE ecosystem during this 5-year opt-in period.

The five-city pilot that includes **Guangzhou** and **Shenzhen** is somewhat broader in scope than school pilots in Singapore and Hong Kong because pilot cities are engaged in developing and testing new curriculum materials, technology education courses, and teacher training strategies, in addition to supporting schools. Municipal education bureaus in Guangzhou and Shenzhen spearheaded the selection of experimental areas and schools to develop new AI curriculum reforms (Guangzhou Bureau of Education, 2019; He, 2021). Under this approach, schools, research institutes, and tech companies are collaborating as developers and incubators of new approaches to CTE and coding education, rather than simply supporting schools to adopt fully developed programs. Guangzhou's pilot includes about 100 experimental schools to carry out the implementation and research on course materials for AI instruction in Primary 3-8. These experimental areas and schools will carry out school-based curriculum pilot experiments drawing on the content of the AI textbook compiled by the Education Equipment Research and Development Center of the Ministry of Education. One of the selection criteria specified that districts and schools need to provide guarantees in terms of funding, teachers, and equipment (Guangzhou Bureau of Education, 2019).

III.2. In other benchmark countries, establishing robust teacher networks has been a central scaling strategy.

The **United Kingdom** built its scaling strategy around efforts to train networks of teachers, rather than schools, to support the adoption of instructional materials and pedagogies focused on computational thinking outcomes throughout the system. To accompany the launch of new national standards for computer science education in 2013, England's

Department for Education (DfE) established a teacher training network (Network of Excellence) to train 400 master teachers by 2015 (Fowler & Vegas, 2021). After falling short of this initial goal, a large and well-funded training center launched in 2018 and increased the number of master teachers to 540; these teachers have in turn trained 29,000 primary and secondary computing teachers nationwide.

In the **United States**, the central government has no role in setting content standards or issuing curriculum guidelines, and individual school districts make all curriculum decisions with a high degree of local autonomy. This highly decentralized system presents a special set of scaling challenges for advocates of CTE. In CS and other subjects, U.S. teachers' associations are leading advocates for curriculum reform and play a key role in developing content standards that shape the development of new curricula (see Teacher networks box), and in supporting their adoption by local schools.

Teacher networks as agents of change in the United States: The Computer Science Teachers Association

The Computer Science Teachers Association (CSTA) is a teacher-led organization in North America, primarily the U.S., that focuses on creating a strong environment to support K–12 educators. They share various CS teaching resources and the latest best practices in CS education with K-12 educators via their website, newsletters, conferences, and teacher community meetings. Local CSTA chapters across the U.S. and Canada link every CS teacher with a community even if they are isolated in their individual schools and connect local teacher voices to the national CS education community. The CSTA is committed to equity and strives to build diverse and inclusive communities at the local, national, and global levels. They partner with corporations and foundations such as Microsoft, Google, Cognizant Foundation, and the Association for Computing Machinery to organize the largest teacher-led CS professional development event in the world each year and offer teachers exclusive discounts on courses and teaching tools.

CSTA educators also authored a set of universal outcomes for student learning in the form of K-12 CS standards that were released in 2017 to provide the foundation for a complete CS curriculum and its implementation at the K–12 level (CSTA, 2017). These standards currently form the basis of most state-level CS content standards in the U.S. Further, the CSTA also published *Standards for Computer Science Teachers* to establish robust teaching standards for the teachers who will prepare their students to meet these learning outcomes (CSTA, 2020).

III.3. To varying degrees across the benchmark countries, computational thinking initiatives have been led by cross-sector coalitions of government agencies, schools, private sector companies, teachers' associations, and other non-governmental advocates.

CoolThink@JC is led by a coalition of university partners (EdUHK, CityU, and MIT), the Hong Kong EDB, and two teachers' associations (Association of IT Leaders in Education, and the Hong Kong Association of Computer Educators). Perhaps unique among all of the benchmark countries, this coalition was convened and is coordinated by the Hong Kong Jockey Club Charities Trust, a private charity with significant investments in education programs. The Trust has established a multi-level governance structure for CoolThink@JC to coordinate the work of each partner organization and ensure shared leadership and buy-in for the initiative's scaling goals (see appendix for an illustration of this governance structure).

In **Singapore**, the ecosystem supporting CTE in primary schools includes the Singapore MOE, the IMDA, local universities, technology training partners and providers, informal education agencies (for example, a science center), and industry partners. These public and private agencies have worked both together and independently to support different phases of the Code@SG national plan and Code for Fun primary school initiatives (Seow et. al., 2019). For example, the IMDA and individual schools share the cost of Code for Fun materials, with the IMDA covering 70% of the per-student cost. Technology vendors provide training on robotics kits (Arduino, Raspberry Pi), and programming platforms (Scratch) to support schools' purchase and adoption of these materials.

Private companies also play key roles in coding education initiatives in **Guangzhou** and **Shenzhen**, as in Singapore. Schools in these cities are responsible for raising 100% of the funding to secure the hardware, software, and instructional materials needed for the development of new coding education lessons. Large technology companies partnering with municipal governments on these citywide pilot initiatives have provided funding and other resources to individual schools (e.g., He, 2021).

Cross-Sector Collaboration in the United Kingdom

Computer science education reforms in the United Kingdom have been led by the national education ministry (Department for Education, or DfE) in collaboration with a large and diverse coalition of non-governmental organizations. The earliest grassroots advocacy group, Computing at School (CAS), was founded in 2008 by a coalition of teachers, parents, representatives from the DfE, and big tech companies with the goal of establishing CS as the "fourth science" in English schools alongside biology, chemistry, and physics (Jones Peyton et al., 2013). CAS lobbied for greater emphasis on CS education and for the DfE to include CS as a secondary school exam subject (Jones Peyton et al., 2013).

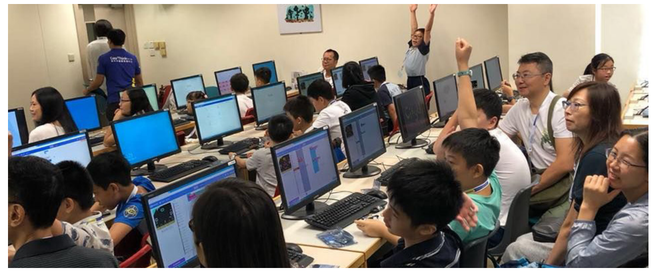
In 2012, the DfE invited the British Computing Society (BCS) and the Royal Academy of Engineering to coordinate a broad group of stakeholders charged with writing a new study program for computing (Jones Peyton et al., 2013). These stakeholders included representatives from the BCS, the Royal Academy of Engineering, the Open University's ICT teacher professional development program, the Association for Information Technology in Teacher Education, Next Gen (an industry campaign representing video game and visual effects companies), CS academics, CS school teachers, and representatives from university teacher education programs (Larke, 2019).

In the early stages of national scaling, DfE partnered with non-governmental organizations to provide instructional materials and training to teachers seeking to align their instruction with national CS education standards. CAS ran the Network of Excellence to support teacher PD until 2018, with funding from the DfE and by partnering with English universities to serve as regional training centers. The Barefoot Computing initiative provided instructional resources on computational thinking across subjects that are designed to be accessible to teachers with no prior experience in CS education. DfE launched Barefoot Computing in 2014 before handing it over to BCS and BT, a British telecommunications company (The Royal Society, 2017).

Since 2018, the DfE has funded the National Centre for Computing in Education (NCCE) to provide training and instructional materials to computing teachers. NCCE is run by a consortium of non-governmental organizations that includes STEM Learning, the Raspberry Pi Foundation and the BCS's Chartered Institute for IT (www.teachcomputing.org).

III.4. Among the benchmark countries, CoolThink@JC is a leader in developing a robust parent outreach and education campaign as part of its scaling strategy.

As a key component of its scaling strategy, **CoolThink@JC** has engaged a local university to offer parent workshops in all schools that have adopted CoolThink materials. The CityU runs 50 parent workshops annually that are expected to reach 10,000 parents over 4 years, with an additional set of 12 workshops annually targeted specifically to parents of students in historically underserved schools. These parent workshops are designed to communicate the benefits of CTE for students, including relevance to many career fields, and to empower parents to support their students in completing assigned programming tasks at home. In addition, CityU runs summer camps and EdUHK runs coding fairs that offer students additional opportunities to engage in computational thinking activities and that help to raise the profile of CTE in the wider community. Among global leaders, **Hong Kong** is unique in this regard, as other benchmark jurisdictions have not invested in similar parent outreach campaigns.



III.5. In schools seeking to expand CTE offerings, existing hardware and connectivity are important conditions for success. In the benchmark countries, schools adopting new CTE programs have required some upgrades to existing hardware and software.

CoolThink@JC provides a subsidy to upgrade existing hardware for in-network schools where needed. These subsidies have supported the installation of CoolThink Studios in network schools with the infrastructure needed to teach CoolThink successfully. Although one-to-one computing is common in Hong Kong primary schools, the use of the MIT App Inventor platform requires that students have access to mobile devices for testing their apps, and schools must often purchase these devices to implement CoolThink App Inventor lessons. In **Singapore**, coding enrichment programs at the primary level are designed around the use of robotics kits and other maker tools; adoption of these kits typically requires that schools apply for funding from the IMDA to support their purchase (e.g., IMDA, n.d.a). In **Guangzhou** and **Shenzhen**, primary schools have partnered with industry to improve the infrastructure for new coding education initiatives. Schools joining pilot programs must provide guarantees in terms of funding, teachers, and equipment/infrastructure; technology firms help to provide these upgrades where necessary (e.g., Guangzhou Bureau of Education, 2019).

IV. RESOURCES TO SUPPORT IMPLEMENTATION AT SCALE

National content standards and curriculum guidelines communicate the importance of CTE in the primary school curriculum and, coupled with assessments and other accountability measures, can create incentives for schools to adopt new approaches to CTE. However, standards alone are not enough to support implementation, and each of the benchmark countries has also taken steps to provide practice resources to promote scaling of new CTE programs, typically in the form of high-quality instructional materials and training for CTE teachers.

Instructional Materials

IV.1. CoolThink@JC is a materials-led reform; adoption of high-quality instructional materials supported by robust teacher professional development is the primary lever for introducing computational thinking education in primary classrooms. Other leading jurisdictions have relied primarily on content standards and curriculum guidance to communicate goals for CTE, although the UK recently established a national center to disseminate comprehensive instructional materials aligned to national computing curriculum.

At the inception of **CoolThink@JC**, MIT and the EdUHK collaborated to develop three 14-hour lesson sequences to introduce computational thinking concepts, practices, and perspectives to upper primary students. The materials are comprehensive, including lesson plans, student guides, and formative assessments, and were developed according to design principles aligned with the co-creators' goals for CTE. After some refinement of the CoolThink materials during the pilot phase, they are now intended to be taught as designed in a 14-hour course or lesson series. Schools within the CoolThink network may adjust the lesson sequence to better align with their school-based curriculum, but CoolThink lesson sequences are intended to be taught essentially as designed, as a series of eight units leading to a final project completed over multiple class meetings. This materials-driven approach to introducing CTE as a primary school subject makes CoolThink unique among the benchmarking examples profiled in this report. Although the other benchmark countries have also taken steps to ensure that teachers have materials to support computational thinking and coding education, teachers and schools in these countries must pick and choose from among the various offerings to design courses aligned with national content standards.

In the **United Kingdom**, the DfE funds NCCE to offer a "Teach Computing" curriculum and associated resources for each key learning stage (early primary, upper primary, early secondary, upper secondary); these materials are available for download free of charge to all UK primary and secondary computing teachers. Resources for each key stage are built around a learning progression framework and include a curriculum map, teachers' guide, lesson plans, slides, activity sheets, homework assignments, and assessments. Teachers of students in key stage 2 (upper primary grades) can download 144 lessons organized into 24 units (www.teachcomputing.org/curriculum). Demand for these materials appears to be high—UK teachers downloaded 125,000 units in the first few months after their release in September 2020 (NCCE, 2020). Before 2020, primary school computing teachers accessed materials from the Barefoot Computing initiative or selected from many commercially available alternatives, often relying on virtual social and professional networks to exchange sample lesson plans or make recommendations to peers.

In China, the **Guangzhou** Institute of Educational Research compiled a textbook titled Artificial Intelligence, which has become the first available set of teaching materials for AI for primary and secondary schools in China (Guangzhou Institute of Educational Research, 2021). The textbook is comprehensive and addresses many more topics than most primary teachers have time to cover in their computing classes; teachers using the textbook must therefore select from the wide range of units and lessons offered. In **Singapore**, teachers attend workshops offered by educational technology vendors and make selections of instructional materials and accompanying technology (robotics kits, Arduino, micro:Bit, Raspberry PI) based on those workshops, with funding from the IMDA (Seow et. al., 2019).

Teacher Professional Development

IV.2. Like CoolThink@JC, initiatives in other leading jurisdictions have included comprehensive and sustained professional development for in-service teachers. All benchmark jurisdictions have sought PD solutions that can be delivered at scale, to thousands of teachers annually.

CoolThink@JC teachers receive up to 48 hours of foundational training in four teacher development courses which can be selected and arranged in a sequence aligned to each teacher's experience and needs. These modular courses were introduced in 2020 to support CoolThink scaling and require less time from teachers than the training offered during the initiative's pilot phase. To supplement these offerings and ensure that PD can be scaled beyond the 50 schools recruited to join the CoolThink network each year, the Trust has established a CoolThink InnoCommunity that offers monthly workshops to teachers outside of the CoolThink network who are interested in piloting CoolThink materials in their schools. CoolThink@JC has also partnered with the Hong Kong EDB to offer workshops on CTE by InnoCommunity teachers drawing on CoolThink materials to illustrate key concepts and instructional practices.

Like CoolThink@JC's InnoCommunity strategy, the **United Kingdom** relied on a network of master teachers to deliver teacher training to all primary school teachers responsible for CS instruction (estimated at 25,000 teachers nationwide). The British Computing Society (BCS) was commissioned in 2013 to provide training for volunteer master teachers that included 120 hours of professional development and subsequent coaching. When insufficient numbers of teachers were trained, the DfE made a much more substantial investment in 2019 to take teacher preparation to scale, including continuing PD, a teacher certification program, computing hubs, and peer support communities (see *Scalable teacher professional development* box).

Scalable teacher professional development for primary teachers in England

To achieve their ambitious goal of universal CS education across the country, England's Department for Education funded the BCS to establish the "Network of Excellence" in 2013. The network was a system of learning hubs and "master teachers" who offered professional learning opportunities to the 25,000 teachers who were suddenly tasked with teaching CS. This program was designed so that every CS teacher would have a local master teacher to support them, rather than relying on webinars or school-level training, and to increase teaching capacity across the country. It would ideally be a scalable network to extend its reach farther than more centralized government programs. Master teachers received 120 hours of guided learning in their first year to prepare them to mentor and teach other teachers. By the time the program ended in 2018, the network had trained 540 master teachers (Fowler & Vegas, 2021).

Despite the Network of Excellence's investment in regional leaders, the program did not meet its goals. Its 540 teachers could not meet the individualized needs of 25,000 teachers across the country, some of whom omitted CS from their curriculum entirely despite the mandate. Teachers have professional discretion, and many did not teach the mandated curriculum because they did not have the requisite background content knowledge (Larke, 2019). Additionally, computing is not included in standardized tests at the primary level, further removing incentive to teach the subject.

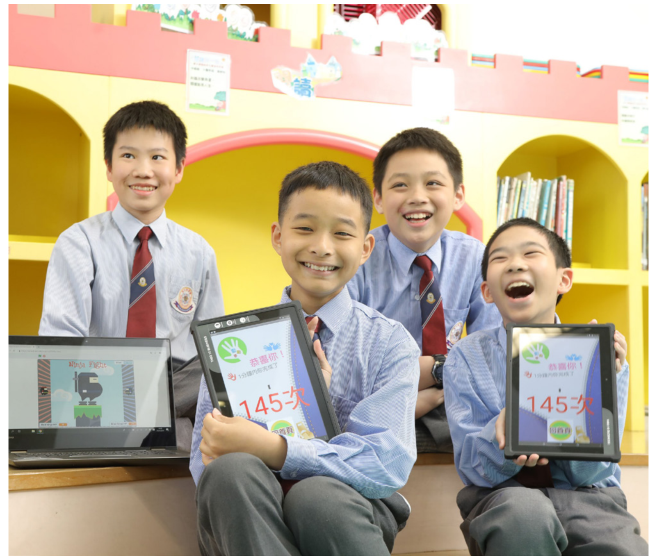
The Network of Excellence was originally funded with only 2 million British pounds. In comparison, the network's successor, the NCCE, benefitted from a larger investment of 84 million pounds. The NCCE awards a nationally recognized teaching certificate to primary teachers who complete a series of online and face-to-face continuing professional development courses, join a Computing at School (CAS) community of practice, document their use of one or more NCCE instructional resources, and participate in an activity to support community in the community (teachcomputing.org/primary-certificate).

The NCCE has been more successful at operating at scale, enrolling 7,600 teachers in continuing professional development and engaging 8,500 primary school teachers in training or use of NCCE curriculum materials in the 2 years after its launch in 2018 (NCCE, 2020). Comparing the inputs and outcomes of the Network of Excellence and NCCE makes it clear that substantial resources and capacity-building are required to build a successful, scalable network of CS professional learning.

Singapore relies on a network of technology vendors to deliver training to primary teachers at scale. Each vendor has developed a 10-hours course with funding from the IMDA; teachers attend these courses, which are offered at their schools, before teaching their adopted program (Seow et. al., 2019). In addition, the CTFest program ("Sharing and Learning about Computational Thinking (CT) in Education"), funded by the Google Data Centre Community Fund, provides teachers with the opportunity to learn about the best practices in teaching computational thinking (NIE, 2021). Other jurisdictions have designed asynchronous, online courses to reach large numbers of teachers.
In 2021, the **Guangzhou** city education bureau launched an online PD series on AI education. The series consisted of 42 class hours of learning modules and was centered on AI content and pedagogy; about 1,500 teachers attended the training (Guangzhou Institute of Educational Research, 2021).

IV.3. Pre-service training in computational thinking education is limited in the benchmark countries, and new initiatives in pre-service training are still in the early stages of development.

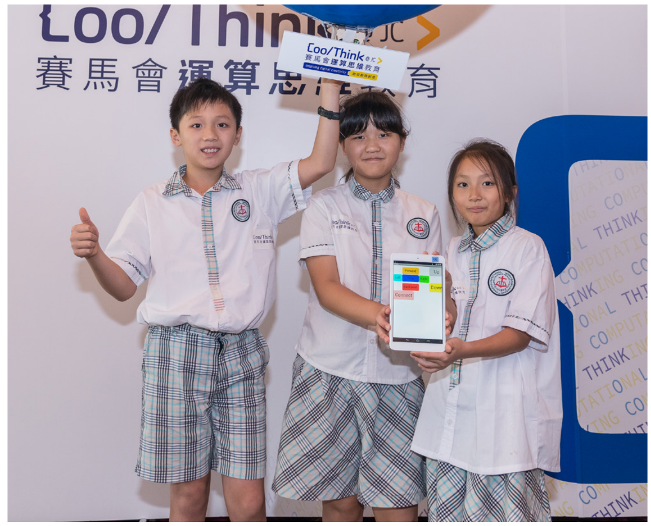
None of the benchmark countries has yet developed a required course of study in CTE for primary grades pre-service teachers. In Hong Kong, two of the largest teacher preparation programs use **CoolThink@JC** curriculum materials in courses for primary pre-service teachers on computational thinking concepts. The courses are currently non-credit bearing but ensure that a large proportion of Hong Kong's primary pre-service teachers have some exposure to CTE concepts and pedagogical strategies. In the **United Kingdom**, pre-service



courses on computing content knowledge are optional and a recent comprehensive review of progress toward the nation's computing education goals raised concerns about the steadily decreasing number of certified computing teachers at the secondary level and the uneven approach to teaching these topics to pre-service teachers at the primary level (The Royal Society, 2017). This national recommended development of an accreditation system to standardize and improve computing coursework for pre-service teachers. In **Singapore**, university faculty have engaged in research to better understand how to train pre-service teachers to teach computational thinking (Looi et al., 2020; NIE, n.d.b). For example, one study has explored how STEM and non-STEM pre-service teachers conceptualize computational thinking (Looi et al., 2020) and its implications for the design of pre-service coursework on integrating computational thinking into teaching practice. However, Singapore's efforts to develop a CTE learning ecosystem have focused on training and upskilling in-service teachers, rather than incorporating CTE concepts and pedagogies into pre-service teacher preparation programs.

V. SPONSORED RESEARCH AND EVIDENCE OF IMPACT

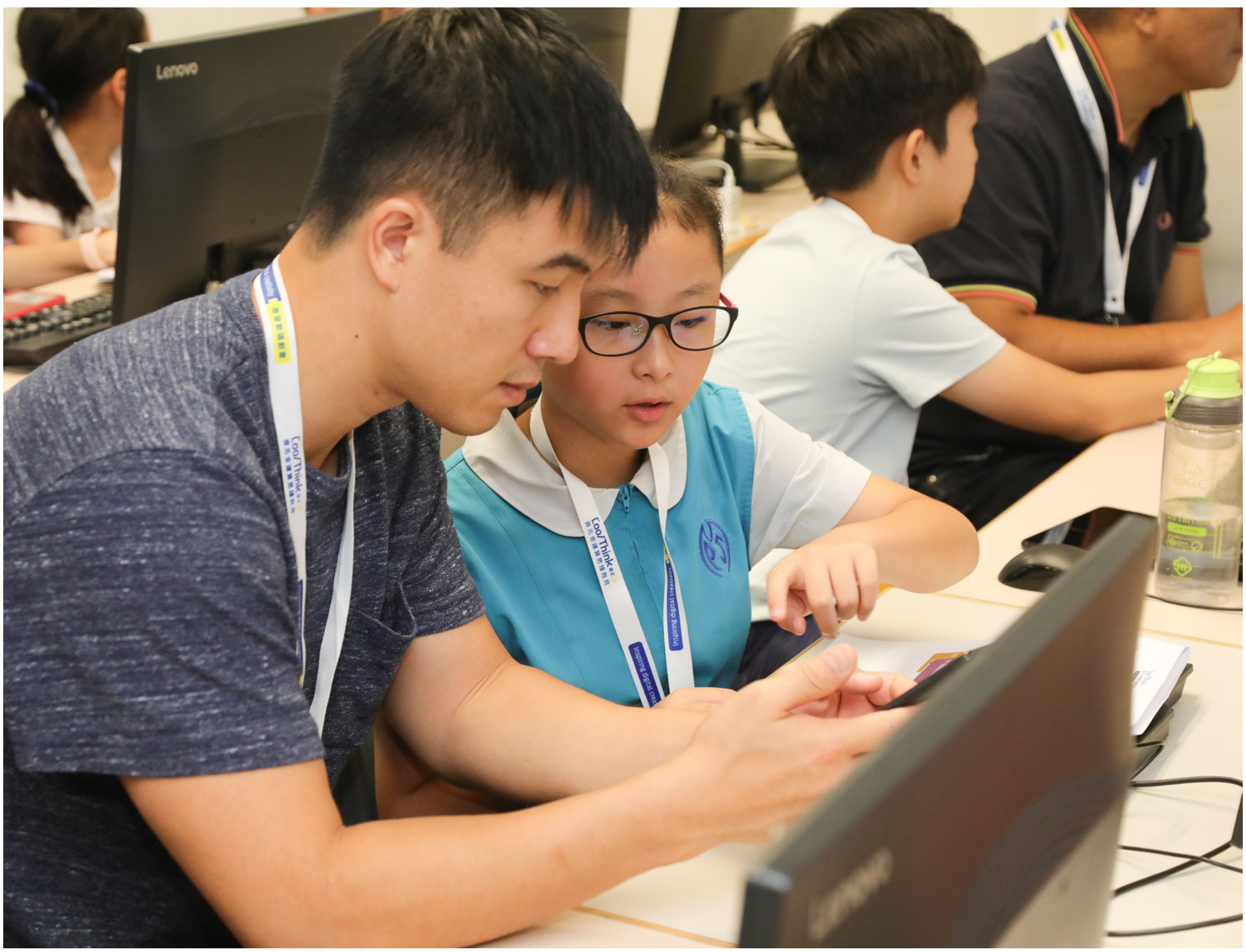
The benchmarking countries included in this report vary in the extent to which they have invested in research and program evaluation to assess the outcomes of CTE initiatives and progress toward scaling goals. Where initiatives are relatively new or still being piloted, published research on outcomes is not available. However, some jurisdictions have carried out comprehensive evaluations of CTE initiatives, and these studies offer helpful lessons for other nations seeking to learn from their experiences.



V.1. Hong Kong and the United Kingdom lead the benchmark jurisdictions with ongoing evaluations of progress toward meeting scaling goals. CoolThink@JC is the only one of the initiatives that has publicly reported on student computational thinking outcomes.

From its inception, **CoolThink@JC** has invested in rigorous evaluation of the program's impact on student learning. Adopting schools administer annual assessments of students' computational thinking concepts, practices, and perspectives to assess the impact of CoolThink instruction on these skills. An evaluation of the CoolThink pilot in 32 schools found that 2 years of CoolThink instruction has a large, positive impact on students' computational thinking practices, logical thinking, and problem-solving skills, compared with students in comparison schools (Shear et al., 2020), as well as recommending opportunities for continued refinement of CoolThink lessons and implementation strategies. CoolThink research partners continue to assess CoolThink@JC's impact on student learning during the scaling phase, as well as the correlation between implementation factors (for example, teacher participation in professional development) and student learning. Among initiatives in the benchmark countries, only CoolThink@JC has reported the results of research on students' computational thinking outcomes.

In the **United Kingdom**, The Royal Society (a scientific association first chartered by the state in 1660) has conducted two comprehensive national reviews of computing education, each of which has had an important impact on CTE policymaking. The first report, *Shut down or restart? The way forward for computing in UK schools* was released in 2012 at the same time that industry leaders had begun calling for an overhaul of the country's ICT curriculum. After its release, the DfE announced reforms to the national computing curriculum, including a new CS-intensive program of study (Brown et al., 2014). Five years later, The Royal Society followed up with *After the reboot: Computing education in UK schools*, which drew on analyses of government datasets and a national survey of primary and secondary teachers to report on the progress of curriculum reforms. Although the 2017 Royal Society report showed a steady increase in the number of students sitting for the GCSE computer science exam in the years following the reform of the national computing curriculum, it also demonstrated that significant gaps in CTE opportunities persisted for students from low-income schools and for girls. In addition, both primary and secondary teachers reported having lower levels of confidence in teaching more advanced computing concepts and limited or having no access to continuing professional development on these topics. *After the reboot* called for better teaching quality in computing classrooms, more ambitious funding, and greater investment in rigorous research on computing education; in response, the government-funded the NCEE to significantly expand teacher PD.



ELEVATING HONG KONG AS A GLOBAL LEADER IN CTE

In some key respects, CoolThink@JC's design and scaling strategies closely resemble those adopted by the benchmark jurisdictions, all of whom are recognized as global leaders in promoting CTE at the primary grades. In other ways, CoolThink@JC offers potentially promising and distinctive strategies for establishing and scaling CTE in primary schools.

- **Student agency, as instantiated in CoolThink@JC, is a strong theme in leading jurisdictions' goals for CTE.** Each of the benchmark jurisdictions has a vision for technology education that positions students as makers and creators—not just users—of technology. Computational thinking is important to the benchmark countries because it supports student agency in the form of digital creativity, "making," and problem-solving. As it scales globally, CoolThink stands well-positioned to contribute to these fundamental goals.
- **Among the benchmark initiatives, CoolThink@JC is unique in its provision of a fully articulated course sequence and set of curriculum materials at the heart of its program.** System-level actors see this as an important feature of the offering. This stands in contrast with jurisdictions that ask schools and teachers to choose their instructional materials from the many offered by commercial vendors or to select and adapt lessons from textbooks or online repositories. Within network schools that adopt it in full, the CoolThink course sequence may help promote standardization of instruction across schools and ensure that all students experience a computational thinking learning experience of similar quality. It also may allow teachers an easier experience in their first year, as they can focus on instruction rather than on lesson curation and design; this is particularly important as many primary teachers do not have a strong CS background.
- **CoolThink@JC provides a comprehensive program of professional learning that is focused on content and aligned with the curriculum.** Research has shown that these are key features of professional development that lead to changes in teacher practice and student learning gains (Desimone et al., 2002). While other benchmark initiatives also offer extensive and ongoing professional learning, the lack of a full standard course sequence implies that these offerings may be more generic across potential curricula or provided to different degrees by commercial designers of the various curriculum offerings. For the in-network CoolThink teachers who have access to the full PD offering, this is an important differentiator.

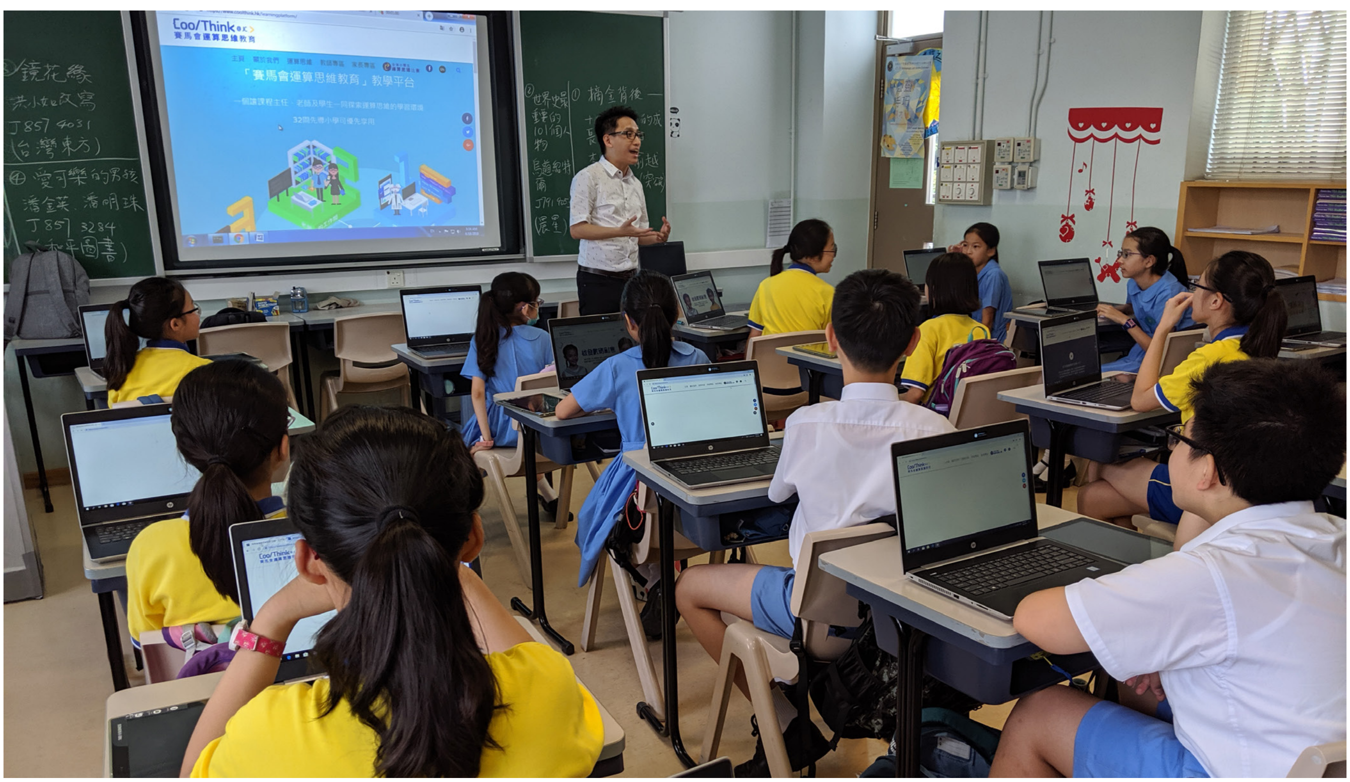
- **CoolThink@JC appears to be unique among the benchmark jurisdictions in its investments in awareness-raising and training that reach beyond in-service educators.** CoolThink@JC offers a robust parent outreach and education campaign as part of its scaling strategy. Coupled with summer camps, coding fairs, and coding competitions, CoolThink's parent engagement campaign is designed to generate support for CTE among the broader community. CoolThink@JC has also made its materials available to teacher preparation programs in Hong Kong to introduce pre-service teachers to CTE concepts and pedagogy. (One CoolThink co-creator, EdUHK, also trains a significant proportion of primary school teachers in the territory.) Over time, CoolThink partners expect that exposure to CoolThink materials and computational thinking concepts during pre-service training will promote teachers' readiness to teach CTE when they reach the classroom.

Over the next several years, CoolThink@JC partners and key stakeholders can take the following steps to ensure that Hong Kong keeps pace with other global CTE leaders:

- **Position CoolThink@JC as part of a vertically aligned CTE progression that covers the full primary and secondary spectrum.** As seen across benchmark jurisdictions, an important driver for wider rollout at the primary level is an integrated CTE strategy across primary and secondary grades. This is particularly important because of the difficulty in all countries of adding a subject to the compulsory primary school curriculum and the need to integrate with outcome measures and accountability mechanisms later in students' educational careers. The benchmark jurisdictions profiled in this report all articulate goals for building students' computational thinking interests that are expected to motivate participation in upper-level concentrations and the later workforce. CoolThink@JC, with its initial offerings specific to primary students, is increasingly looking to build this integration as it scales.
- **Support the development of an AI education plan to highlight the economic importance of CTE.** All of the benchmark jurisdictions have recently released a national AI strategy with the stated goal of becoming—or remaining—a global leader in the quickly evolving field of artificial intelligence. These plans acknowledge the economic imperative of these goals, and the far-reaching potential impact of AI across major sectors of the economy and important aspects of daily life. With the exception of China, the benchmark jurisdictions have not yet released detailed plans for aligning CTE or computing education at the primary and secondary levels with these national AI goals. This is an area where Hong Kong can potentially lead the way for other jurisdictions.
- **Continue to expand teacher networks and leverage teacher professional associations to sustain and advocate for high-quality CTE instruction across the territory.** The case of the Computing at School network in the United Kingdom and of the Computer Science Teachers Association in the United States both offer compelling illustrations of the power of grassroots teacher networks to advocate for and effect changes in the ways that their disciplines are taught. Teachers who are deeply invested in their subjects can be passionate advocates for change and effective ambassadors to colleagues. CoolThink@JC has already

developed strong partnerships with Hong Kong teachers' associations. The experience of other benchmark jurisdictions suggests that these partnerships can play even more key roles in supporting the initiative's continued momentum. The UK's CAS network, in particular, offers models for creating and sustaining teacher-led communities of practice that support teachers as they develop their proficiency in computing instruction.

- **Attend to the trade-offs that benchmark jurisdictions have accepted between standardization, equity, and quality of instruction on the one hand and flexibility to support scaling on the other.** To maximize flexibility in support of broader scaling, CoolThink@JC is making its materials available in a "lite" version that comes with fewer requirements and with professional learning options that are more leveraged and less in-depth. More flexible offerings can lower the bar to entry and allow schools to choose curriculum materials appropriate for their specific contexts: for example, materials that will fill the time available for CTE instruction, that support the integration of CTE with other subjects, or simply that teachers find interesting or compelling. This flexibility supports scaling, although it comes at a cost of consistency across schools and, at times, quality of instruction, as has been demonstrated in the comprehensive evaluations of CTE initiatives that currently exist (The Royal Society, 2017). Continued careful monitoring will help to ensure that designs for scale are achieving the desired results in the classroom, and continued research can help to shed light on the ongoing impact of these strategies on implementation effectiveness and quality of instruction.



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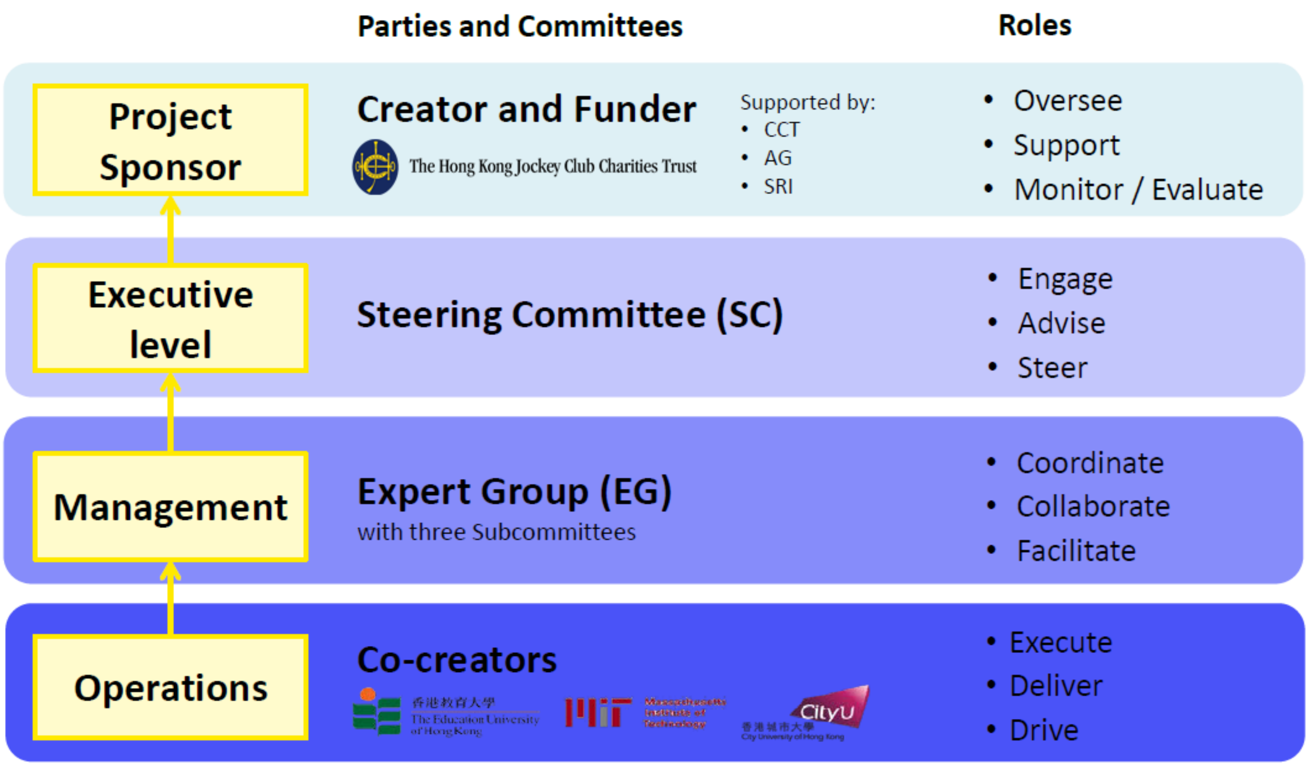
APPENDIX

CoolThink@JC's multi-level governance structure is designed to ensure engagement and sponsorship from key stakeholders throughout the territory. The Steering Committee and Expert Groups shown in the organizational chart below include representatives of each of the co-creator organizations (Education University of Hong Kong, Massachusetts Institute of Technology, and City University of Hong Kong), along with representatives from the Hong Kong Education Bureau, Hong Kong EdCity (a public corporation wholly owned by the government that supports digital and online learning in all Hong Kong schools), the Hong Kong Association for Computer Education, the Association of IT Leaders in Education, school sponsoring body representatives, and other non-governmental organization representatives.

Exhibit A1: CoolThink Governance Structure



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