CoolThink@JC
賽馬會運算思維教育
Inspiring digital creativity 啟發數碼創意

CoolThink@JC Pilot

Evaluation Endline Report

May 2020

Created and Funded By

香港賽馬會慈善信託基金
The Hong Kong Jockey Club Charities Trust
同心同步同進 RIDING HIGH TOGETHER

Co-created By

香港教育大學
The Education University of Hong Kong

Massachusetts Institute of Technology

CityU
香港城市大學
City University of Hong Kong

Research Conducted By

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Suggested Citation

Shear, L., Wang, H., Tate, C., Basu, S., Laguarda, K. (May, 2020). *CoolThink@JC Pilot Evaluation: Endline Report.* Menlo Park, CA: SRI International.

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 2016, the *CoolThink@JC Pilot* initiative set an ambitious agenda: to bring computational thinking (CT) education to students in 32 of Hong Kong's primary schools. With a 3-year sequence of lessons and extensive professional development, among other important supports for participating schools and teachers, the initiative envisioned inspiring digital creativity and preparing students to be innovators and active contributors to Hong Kong society in the digital age. The pilot was intended to create a new paradigm for CT at the primary level that would eventually scale to reach many more schools within Hong Kong and provide a model for other nations as they begin to extend computational thinking education to the primary grades.

Four years later, the *CoolThink@JC* Pilot has initiated over 20,000 primary-age students into coding and digital problem solving. This report is a result of a rigorous 3-year evaluation, conducted by SRI International (SRI), of the pilot and the progress made by its students. The report describes outcomes of the initiative for students, as well as the experiences of teachers and other participants, and offers a set of implications for designers and other stakeholders who wish to build on the pilot's successes and lessons as they grow *CoolThink@JC* to a territory-wide offering.

About the *CoolThink@JC Pilot* and this evaluation

Through a global collaboration among The Hong Kong Jockey Club, Education University of Hong Kong (EdUHK), Massachusetts Institute of Technology (MIT), and City University (CityU), the *CoolThink@JC Pilot* initiative produced a 3-year lesson sequence to introduce computational thinking to students in Primary 4–6. Lesson rollout followed a cohort model, with two resource schools (schools that participated in lesson development and initial classroom trials) and 10 Cohort 1 pilot schools beginning the lesson sequence in the 2016–17 school year, and another 20 schools in Cohort 2 beginning the lessons in 2017–18. The pilot also included extensive professional development for each teacher (delivered as a 39-hour session followed by 13 3-hour sessions over the course of the school semester), two graduate student teaching assistants (TAs) who supported each CoolThink class, and subsidies for each school toward the purchase or renovation of computer equipment.

CoolThink@JC Pilot lessons were based on visual programming languages Scratch and MIT App Inventor, but their aim was much broader than teaching programming. Consistent with the goal of promoting digital creativity and problem-solving, lesson design was based on a framework organized around three target outcomes for students:

1. **CT Concepts:** Content knowledge required for developing computational artifacts,

2. **CT Practices:** Problem-solving and logical thinking skills characteristic of computational thinking, and

3. **CT Perspectives:** Interest in and motivation for computational thinking, as well as perceptions of its nature and utility.

The same framework was also the basis of a set of measurement tools developed by SRI in order to assess student outcomes in each CT Concepts, Practices, and Perspectives. Assessments were developed according to world-class design principles to support a rigorous evaluation of student outcomes in relation to students in a comparison group of Hong Kong primary schools that were not participating in the *CoolThink@JC Pilot*. The evaluation also featured an implementation study that used teacher surveys across all pilot schools and interviews/observations at four schools to better understand how *CoolThink@JC* was being used in classrooms and the experiences of teachers, students, and principals.

In addition to the reporting of implementation and outcomes, the evaluation was also designed to play an important formative role for the CoolThink development team, who saw the pilot as an opportunity to learn from initial lesson trials. As such, the evaluation fed an ongoing process of lesson development and refinement that leveraged the experiences of pilot teachers and students to fine-tune lesson design in each successive year of the pilot.

Outcomes of the *CoolThink@JC Pilot*

Data for the *CoolThink@JC Pilot* outcome study were collected over a 3-year period, from early 2017 through the 2018–19 school year. By the end of the study, the first two levels of CoolThink instruction were in use in all 30 pilot schools, with the 10 Cohort 1 schools also offering Level 3 lessons for Primary 6 students. This report focuses on 2-year progress across students in all 30 schools, with 3-year progress based on the 10 Cohort 1 schools described in Appendix C.

In the results that follow, "impact" is defined as the differential performance gain for students in pilot schools as compared with their peers in comparison schools, adjusted for any differences in school and student background (for example, student prior academic achievement or school percentage of special educational needs (SEN) students) that may affect differences in performance. Thus evaluation results answer the question, **How much more did students learn from the *CoolThink@JC Pilot* than they would have if they attended a primary school that did not participate?**

Two-year student outcomes of the *CoolThink@JC Pilot* demonstrate strong learning relative to their peers in other Hong Kong schools, particularly in CT Practices, and substantial potential for the initiative as it moves forward from the pilot stage. Outcomes below are described in terms of "effect size", which is a common measure of the magnitude of an impact; effect sizes above 0.25 are considered "substantively important" in educational research (WWC, 2014). Outcomes after 2 years of CoolThink lessons are as follows:

- **Pilot students exhibited stronger learning of CT Concepts than their peers in comparison schools, with a difference that approaches statistical significance.** The effect size of this impact is 0.21. By 2018–19, many of the comparison schools were also delivering some form of programming instruction. These results suggest that *CoolThink@JC* taught students more CT Concepts than "business-as-usual" programming instruction in Hong Kong primary schools.

- **While boys and girls both benefited from 2 years of CoolThink instruction, relative gains in CT Concepts were stronger for boys than for girls.** No other differences by subgroup were detected.
- The CT Practices assessment captured students' broader computational thinking skills that are required for logical reasoning and problem-solving. **Pilot students achieved particularly strong results in this area as demonstrated by CT Practices scores.** This difference is large, statistically significant, and substantively important, with an effect size of 0.36. These results offer promising evidence that CT Practices is a differentiator for *CoolThink@JC*, in relation to other programming curricula in use in Hong Kong primary schools.
- **For CT Practices, relative gains were similar for boys and for girls, but stronger for students with higher baseline scores on math tests and on CT Practices, and students who had internet at home at the time they entered the *CoolThink@JC Pilot*.** The relationship between CT Practices scores and math proficiency supports the hypothesis that *CoolThink@JC* is helping students to build problem-solving skills that are similar to those required in other subjects such as mathematics. It also raises the concern that this benefit is being realized disproportionately by students who are already advanced academically.
- **Findings on CT Perspectives show no statistically significant difference between pilot and comparison students on an overall measure of students' interest in and motivation for computational thinking,** with scores showing slight downward trends over the 2-year timeframe. These results suggest that the intentions of the CoolThink developers to promote a strong appreciation of the value of computational thinking among Hong Kong primary students is worthy of continued focus as the initiative scales beyond the pilot phase.

Pilot Teacher and Principal Experiences

An important component of this evaluation looked at the implementation of the *CoolThink@JC Pilot* in classrooms and schools. This perspective is essential for understanding how the outcomes cited above were achieved, the benefits experienced by educators, challenges that remain, and paths forward. The findings below are based on a survey across all pilot teachers and interviews/classroom observations in four selected schools in order to add depth to our understanding of *CoolThink@JC Pilot* implementation. The final surveys and site visits were conducted late in the 2018–19 school year, after the 20 Cohort 2 schools had 2 years of experience with CoolThink lessons and the 10 Cohort 1 schools had 3 years of experience.

Reflections from teachers and principals include:

- **80% of teachers reported that teaching *CoolThink@JC* involves adopting new teaching strategies, which some described as a shift toward more student-centered approaches.** While pedagogical approaches varied widely among teachers, some reported that in CoolThink classes students have more autonomy and more opportunity for creativity as they solve problems that do not have a single right answer.

- **The new curriculum revision was seen as a significant improvement, but some still found CoolThink lessons to be too challenging at this point in the ongoing process of lesson refinement.** Simplification of lessons to make them more accessible to a wider range of students is a target of the CoolThink development team's ongoing improvements.
- **Training by MIT and EdUHK played a substantial role, not only in preparing teachers to teach *CoolThink@JC* but also in supporting educators' perceptions of computational thinking and of *CoolThink@JC*.** Teachers who participated in CoolThink training responded with high praise, reported feeling more prepared, and were in better alignment with the initiative's goals than those who joined the initiative later and had access only to school-based training.
- **Most teachers found teaching assistants (TAs) to be essential supports, but for many this need faded as they gained experience with *CoolThink@JC*.** TA support was particularly helpful early in implementation, as teachers were learning lesson content, technology requirements, and teaching approaches that were all new to them and their students.
- **Principals appreciated how *CoolThink@JC* catalyzed teacher community and helped them to advance their schools toward STEM goals.** In principal interviews, a common theme was the alignment of *CoolThink@JC* with the type of STEM instruction encouraged by the Education Bureau, providing a path to operationalize those important and timely objectives within their schools.

Scaling *CoolThink@JC*

The pilot stage has been an essential opportunity for thoughtful iteration in the design of CoolThink lessons and supports, allowing the team to confirm and magnify the value it brings to students and teachers before it is adopted more widely. It also foreshadows a new set of challenges as the CoolThink team turns its attention to the new and equally ambitious goals of scaling the initiative to a much wider, more diverse set of Hong Kong primary schools and addressing system-level supports for sustainability. This report includes a number of design considerations, based on the experience and outcomes of the pilot, to inform this bold new phase:

1. **Maintain effectiveness of the professional development model at scale.** *CoolThink@JC* Phase II brings an important opportunity to explore models that can replicate the value of a proven high-touch professional learning program in a more distributed form that can serve many more teachers. This will require attention to the specific attributes that currently underlie effectiveness, ensuring that they are thoughtfully embedded into the new workshop design, trainer preparation, and ultimately system-level supports for offerings at scale.

2. **Facilitate within-school and across-school communities of practice (CoPs) to reinforce and extend professional learning.** Communities of practice can be important mechanisms for sharing of best practices and for instilling ownership among teachers and schools. This will require deliberate facilitation of CoPs, both within and across schools, to ensure that they reinforce foundational CoolThink principles and help teachers

to resolve both expected and emerging implementation challenges in ways that are consistent with those principles.

3. **Keep problem-solving and logical thinking at the forefront.** Strong pilot student performance in these 21st century competencies as reflected on the CT Practices assessment was a hallmark of the pilot's success, but problem-solving opportunities were not consistently available to students when teachers felt they had to trade them for more efficient instructional methods. Co-developers have an important opportunity to help teachers navigate these tradeoffs and to use *CoolThink@JC* as a catalyst to embed problem-solving and logical thinking more widely throughout the discourse and practice of schools and systems in Hong Kong.

4. **Promote ownership and deep understanding of the rationale for teaching CT.** Both felt readiness for teaching *CoolThink@JC* and buy-in to its goals were much stronger among teachers who attended formal training than those who did not. As professional learning scales, it will be important to support access to CoolThink workshops for all prospective CoolThink teachers, accompanied by staffing models that support release time for them to attend. Ongoing, the goal of sustainability will require continued opportunities for teacher engagement, recognition, and advancement to maintain and grow early enthusiasm over time.

5. **Provide tailored supports within the classroom.** Developing comfort and proficiency with teaching *CoolThink@JC* was often a multi-year process that relied on TAs while teachers were navigating initial learning curves. Classroom teaching support according to need will continue to be important, and can be provided directly by *CoolThink@JC* in the short term. To promote sustainability, the initiative would do well to develop a rubric for ongoing use by school sponsoring bodies to guide the assessment and provision of the technical, organizational, and human resources that must be in place in each new school for the successful adoption of *CoolThink@JC*.

6. **Attend to student diversity.** Equity of computational and problem-solving opportunity is a driving goal of *CoolThink@JC*, but one that many teachers struggled to achieve when faced with a diversity of student abilities within their classroom; girls have also remained somewhat disadvantaged in CT Concepts achievement. Professional learning offerings must provide models and lesson adaptation strategies that give teachers explicit tools for engaging girls in computational thinking and for making problem-solving tasks available and accessible to differently abled students. Attention to equity within *CoolThink@JC* can also be leveraged to catalyze these important discussions and practices at the school and system levels within Hong Kong.

7. **Engage students more completely in computational thinking.** While the *CoolThink@JC Pilot* was successful on average in promoting students' knowledge and competence in computational thinking, it did not move the needle on students' CT Perspectives in a measurable way. An important continued focus of the initiative will be to amplify its explicit encouragement of students' enthusiasm, self-confidence, and appreciation of the value of computational thinking. This mission can most effectively be accomplished by targeting multiple levels of the system: increasing age-appropriate relevance and opportunities for creativity within lesson design; embedding explicit discussions of how to promote positive perspectives in teacher professional learning opportunities and communities of practice; and enlisting the support of principals, parents, and other important stakeholders.

While awareness of the importance of computational thinking for students' futures has gained widespread acceptance around the world, curricula that seed these skills in young children are still in early stages of implementation in many countries, and have typically not yet been substantiated by rigorous research. With the *CoolThink@JC Pilot*, Hong Kong has claimed an important place in the global movement to develop the knowledgebase and resources that can bring computational thinking education to primary school.

This evaluation has demonstrated that the CoolThink lessons can successfully promote students' knowledge and skills related to computational thinking, moving beyond programming concepts to broader 21st century capacities of problem solving and logical thinking skills, while also catalyzing changes in teaching practices, school-based teacher community, and progress on schools' trajectories toward STEM instruction. As it scales in its next phase from 32 primary schools to 168 and beyond, *CoolThink@JC* is poised to offer important new models for the education system in Hong Kong, including professional learning that is both high-quality and scalable; school-based curriculum adaptation and adoption of new initiatives; and communities of practice that can help maintain discourse around student-centered approaches to instruction.

As it begins its next phase, *CoolThink@JC* will offer a comprehensive package that includes instructional materials, capacity building, and a rigorous and validated system of assessments, all built around a framework that promotes computational thinking practices and digital creativity as well as programming concepts. With its connections to the 21st-century competencies that are established goals in many countries, *CoolThink@JC* has the potential to emerge as a strong model not only in Hong Kong but also internationally.

This 4-year pilot, while an important success in its own right, is only the beginning.

INTRODUCTION

The *CoolThink@JC* project is a timely contribution to a growing global movement to make computational thinking (CT) a foundational discipline for all students. A decade ago, the computer science education community was galvanized by a concern over the low numbers of students majoring in computer science (Wilson, Sudol, Stephenson, & Stehik, 2010). What began as an effort to attract more secondary students to college study developed into a recognition that in the modern, technology-infused world, where computing plays an important role in all spheres, all students will need to be conversant in the principles of computing and prepared to apply computational thinking in their schoolwork and their futures.

Education systems around the world are responding to the call for computing and computational thinking to become a core discipline. This movement has resulted in significant curriculum changes in several countries including the United Kingdom (The Royal Society, 2012; Wilson et al., 2010; Seehorn et al., 2011), countries throughout Europe (Joint Informatics Europe and ACM Europe Working Group on Informatics Education, 2013), Australia (ACARA, 2016), and New Zealand (Bell, Andreae, & Robins, 2014). While these initiatives have been most prevalent in secondary school (Bocconi, Chioccariello, Dettori, Ferrari, & Engelhardt, 2016; Yadav, Good, Voogt & Fisser, 2017), recognition is growing that developing CT as a foundational competency must begin in the primary grades. Singapore has introduced CT education from pre-school through the secondary level (Seow, Looi, Wadhwa, Wu, & Lui, 2017). In Korea, the government has organized collaborative efforts among important stakeholders, such as the Korean Information Science Education Federation, to equip students to thrive in an increasingly digital world (Lee, 2017).

Computational thinking has been defined as the thought processes and strategies involved in understanding, formulating, and solving a problem in such a way that a computer can potentially 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.

The last decade has seen the rapid adoption of standards and policies mandating CT education around the world, but policies alone cannot produce the desired student outcomes. For the promise of CT education to be realized, a coherent vision for teacher development, curriculum design, and assessment design is essential. To date, CT assessments have mostly focused on facility with programming constructs more than on problem analysis, digital creativity, and perspectives toward computing (Sentance, Barendsen, & Schulte, 2018). Especially lacking are measures focused on how these abilities develop in the primary grades. More established academic disciplines have evolved over hundreds of years. While computing education has a long history in post-secondary education, its relative newness in lower grades, as well as the rapid development of the field—for example, the growing prominence of artificial intelligence and machine learning—make this work especially challenging. There is a tremendous global need for guidance on what to teach, how to teach it, and how to assess progress in computational thinking education (Sentence et al., 2018).

The *CoolThink@JC Pilot* makes important contributions in each of these areas. The initiative provides a comprehensive package of carefully designed lessons and related professional learning for participating teachers in primary grades. The computational thinking framework that drives design includes CT Concepts (the concepts designers engage with as they program), CT Practices (the practices designers develop as they engage with the concepts), and CT Perspectives (the perspectives designers form about the world around them and about themselves). This framework is also the foundation of a system of assessments that this research uses to measure the progression in students' computational thinking as they move through the upper primary grades. After a 4-year, 32-school pilot, *CoolThink@JC* is poised to bring this model to scale in Hong Kong.

This endline report is the third in a series of reports from an independent evaluation research study, conducted by SRI International, of the pilot phase of Hong Kong's *CoolThink@JC* initiative. This report summarizes students' computational thinking outcomes over the course of the first 3 years of the pilot. It focuses on students' 2-year learning progression in 30 pilot schools, exploring whether early outcome trends from prior reports have persisted, and whether (and for whom) student learning has deepened with more exposure to the CoolThink lessons. The report goes on to describe teacher and school leader experiences after another year of pilot activities, reflect on implications for scaling, and offer recommendations to inform *CoolThink@JC*'s next steps as it extends the promise of computational thinking education to primary age students across Hong Kong.

CoolThink@JC: Inspiring Digital Creativity

Launched in 2016, the *CoolThink@JC* initiative is a 4-year pilot program (*CoolThink@JC Pilot*) to teach computer programming and computational thinking to upper primary students in Hong Kong. The program was created by The Hong Kong Jockey Club Charities Trust (HKJC), and co-created by Education University of Hong Kong (EdUHK), Massachusetts Institute of Technology (MIT), and City University of Hong Kong (CityU).

One of the hallmarks of *CoolThink@JC* is its focus on a well-rounded vision of computational thinking, going beyond typical programming instruction to prepare students as digital problem-solvers with an appreciation of the value of programming to their futures and to the world. Based on the work of Brennan and Resnick (2012), the framework grounding program design (Appendix A is organized around the following three target outcomes for students:

1. **CT Concepts:** Content knowledge required for developing computational artifacts,

2. **CT Practices:** Problem-solving and logical thinking skills characteristic of computational thinking, and

3. **CT Perspectives:** Interest in and motivation for computational thinking as well as perceptions of its nature and utility.

In *CoolThink@JC*, these goals are embedded into a progressive 3-year lesson sequence for students in Primary 4, 5, and 6, based in the visual programming languages Scratch and MIT App Inventor. Each of the three levels of instruction includes increasingly complex opportunities for students to explore the instructed topics and ultimately to create their own projects.

In the *CoolThink@JC Pilot*, lessons were offered alongside a substantial package of support for teachers and for instruction. Participating teachers were offered a sequence of two 39-hour teacher development courses, including an intensive week-long workshop delivered by MIT and a series of 13 3-hour lessons, approximately one per week, delivered by EdUHK. Together these offerings introduced the lessons, computing environments (Scratch and MIT App Inventor), and pedagogical considerations essential to *CoolThink@JC*, and provided teachers with sustained support for reflection on practice and for collaborative lesson planning. In addition, two graduate student teaching assistants (TAs) were assigned to each CoolThink class for technical support and student assistance, and participating schools received subsidies toward the purchase or renovation of computer equipment.

The *CoolThink@JC Pilot* included 32 Hong Kong primary schools that had been successful in an application process that selected schools based on their commitment and readiness, with the additional goal of creating a portfolio of schools whose characteristics are representative of Hong Kong overall. Lesson rollout began with the first level for Primary 4–6 students in 10 pilot schools in the 2016–17 school year (Cohort 1), and in another 20 schools in 2017–18 (Cohort 2). In addition, two resource schools participated in lesson development and initial trials, as well as teaching the lessons to their own students.

By the end of the 2018–19 school year, Primary 6 students in 10 Cohort 1 and 2 resource schools had completed the full 3-year lesson sequence, while students in all 32 schools (Primary 5 in Cohort 1 and resource schools; Primary 5 and 6 in Cohort 2 schools) had completed 2 years of lessons. This report focuses on the students who had completed 2 years of lessons in the 30 Cohort 1 and Cohort 2 schools. Results for the smaller number of Cohort 1 students who had completed all 3 years are presented in Appendix C, but they do not show substantially different trends.

The extended timeline of the pilot and cyclical nature of implementation (with the Level 1 sequence of lessons beginning again for each new cohort of Primary 4 students within a school) offered the CoolThink codevelopers an opportunity for iterative refinement of lessons. As a result, extensive input from teachers as well as intermediate observations and results from the ongoing study contributed to lesson improvement in each successive year of the pilot, with the goal of optimizing the design by the end of the pilot phase.

Research Methods for the Pilot Evaluation Study

The external evaluation of the *CoolThink@JC Pilot,* designed and executed by SRI International (SRI), consists of two important and complementary components:

1. An **outcome study** that uses rigorous analytic techniques to measure the impact of the CoolThink lessons on student computational thinking outcomes, and

2. An **implementation study** that describes the experiences of participants (teachers, students, and principals) over the course of the *CoolThink@JC Pilot* and characterizes the enactment of lessons in classrooms.

Together, these complementary views of the pilot are intended to inform stakeholders' decisions about the readiness of *CoolThink@JC* for scaling to a larger number of schools in Hong Kong, and how best to enact and support the program for success at scale.

Specific methods used in this study are introduced briefly here. For a more complete description of these techniques and instruments, please reference the study's Midline Report (Shear et al., 2019).

1. Outcome Study

The outcome study is designed to measure, with as much rigor as possible, student progress in each of the three target outcome areas defined in the CoolThink computational thinking framework: CT Concepts, CT Practices, and CT Perspectives (Shear et al., 2019). Primary outcome study research questions are as follows:

1. What is the impact of the pilot lessons on students' computational thinking concepts, practices, and perspectives?

2. How do gender, grade level, dosage, baseline performance, and other factors impact primary outcomes?

3. How does students' progression of CT learning vary across levels of the lesson sequence?

The pilot outcome study uses a comparative design, looking at the differences in outcomes between students who participate in the *CoolThink@JC Pilot* and their peers who are not enrolled in pilot schools. The comparison design helps answer the question, **How much more** do students learn from *CoolThink@JC* than they might have learned without the program?

The study includes a total of 30 pilot schools across the two cohorts, and 24 matched comparison schools. Comparison schools were chosen from schools that had applied to participate in *CoolThink@JC* but were not selected for the pilot. SRI researchers matched participating schools with comparisons taking into account several factors that were reported on schools' applications, including prior experience with coding instruction, percentage of students receiving financial aid, and percentage of students with special education needs, as well as a "paper vetting score" that was assigned by the CoolThink team during the selection process based on willingness and capacity to participate in the program as described in the applications each school submitted to enter the pilot. Please see Snow et al. (2017) for a description of the matching process and its outcomes in terms of pilot and comparison samples.

An important contribution of this research is the suite of instruments it developed for the measurement of hard-to-assess constructs that make up the dimensions of CT Concepts, Practices, and Perspectives (Table 1), slightly adapted for purposes of measurement. The suite includes two assessments (CT Concepts and CT Practices) and one student survey (CT Perspectives) that operationalize these complex ideas in ways that are appropriate for primary grade students.

Two important design approaches were used in the development of these assessments:

- **Evidence-Centered Design (ECD)**[1] ensures alignment between the learning goals of the CoolThink framework and the ultimate items that students respond to in the assessment. ECD entails a process of design and iterative review that defines assessment goals in terms of the focal knowledge, skills, and abilities (FKSAs) to be measured, and uses those as a basis for the development of assessment tasks.
- **Partial matrix sampling** minimizes testing burden for each student while achieving coverage of the large number of complex constructs that make up the CoolThink framework. In partial matrix sampling, a complete set of test items is distributed across multiple forms, with questions that are common across each form. Forms are randomly assigned to individual students so that each student only has to answer a subset of questions, while a comprehensive picture of performance across a cohort of students can be developed in analysis.[2]

Table 1: Constructs Measured Through *CoolThink@JC Pilot* Evaluation Instruments

CT Concepts	CT Practices	CT Perspectives
Repetition	Algorithmic Thinking	Interest in Programming
Conditionals	Reusing and Remixing	Digital Self-efficacy
Parallelism and Sequencing	Testing and Debugging	Utility Motivation
Data Structures	Abstracting and Modularizing	Motivation to Help the World
Procedures[2]		Creativity
		Engagement
		Belonging

1 For more information on ECD, please see Mislevy, 2007; Mislevy & Haertel, 2006; and Mislevy & Riconscente, 2006.

2 Beginning in 2018, partial matrix sampling was only used for the CT Practices assessment. For CT Concepts, to match the change in focus of the CoolThink lesson content as part of ongoing lesson refinement, the 2018 assessment did not include Procedures. This allowed the CT Concepts assessment to be streamlined to just one form for each level of the curriculum, so partial matrix sampling was no longer needed.

Figure 1. Outcome Study Data Collection

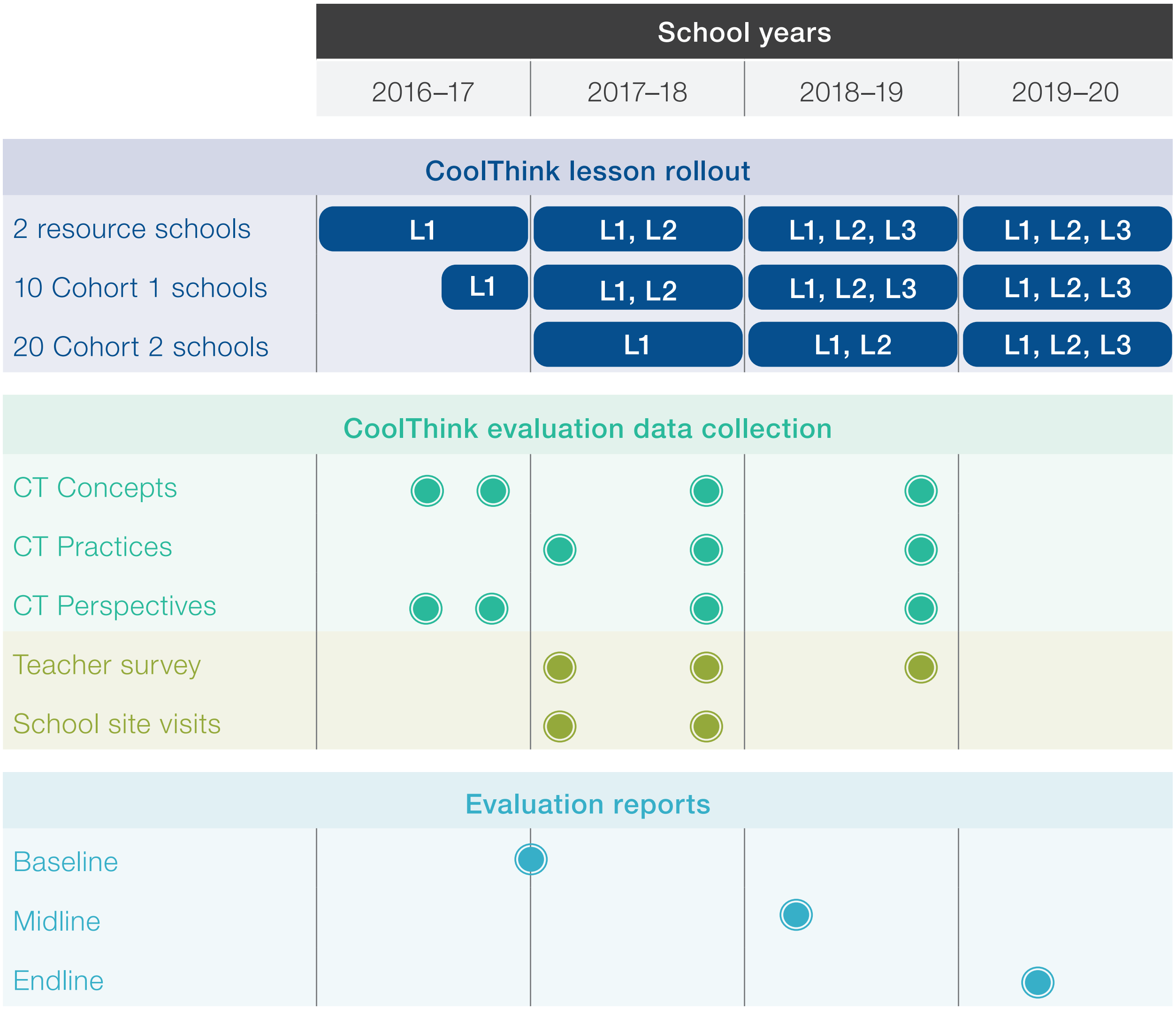


Figure 1 describes the timing of CoolThink lesson rollout and evaluation data collection across both the outcome and implementation studies. For the outcome study, each of the three instruments was administered to students in Primary 4, 5 and 6 annually in both pilot and comparison schools for the first 3 years of the 4-year *CoolThink@JC Pilot*. For CT Concepts and Perspectives, baseline data were collected in February 2017, at the start of Level 1 instruction in Cohort 1 schools, and outcome data were collected at the end of the 2016–17, 2017–18, and 2019 school years. For CT Practices, baseline data were collected at the beginning of the 2017–18 school year (when Cohort 2 schools started Level 1 instruction), and outcome data were collected at the end of the 2017–18 and 2018–19 school years.[3] Annual data collection also included forms completed by administrators of all pilot

3 In addition, students in Primary 3 were included in end of school year data collections for CT Concepts and Perspectives in 2017 and 2018, and for CT Perspectives in 2018, to serve as a baseline for the following year when these students would be in Primary 4.

and comparison schools that included additional school-, teacher-, classroom-, and student-level data to support further analysis (for example, school percentages of Special Education Needs (SEN) students and other programming instruction taking place at the school).

At the time of endline data collection, analysts had access to 2 years of outcome data for all 30 pilot schools, and 3 years of outcome data in the 10 pilot schools in Cohort 1. Primary analytic methods that were used for outcome study analysis included the following:

1. **Hierarchical linear modeling (HLM)** accounts for the nesting of students within classrooms within schools, as variation at each of these levels contributes to student outcomes. For the 2- and 3-year analyses included in this report and its appendix, covering a time period in which students changed classrooms, we used a two-level model (nesting students within schools) that also controlled for differences in student and school background characteristics and student baseline scores on the CoolThink assessments.

2. **Item response theory (IRT)** is a modeling method that is often used in large-scale standardized assessments to track student learning over time. IRT uses scores from individual assessment items to create a single continuum of both student ability and item difficulty for a given construct. Resulting estimates of overall computational thinking ability can be tracked over time for both individual students and cohorts of students, accounting for the variation of items and item difficulties that a given student receive across multiple years of assessment administration. For CT Concepts—the only one of the assessments that had different versions to align with each level of the curriculum—some items were common to all three levels of the assessment in order to allow for growth measurement using IRT.

Please see this study's Midline Report (Shear et al., 2019) for a more complete description of assessment design and instruments used in this outcome study. The appendices in this report include more detailed discussion of analytic models used in the endline analysis.

2. Implementation Study

While the outcome study focused on measuring what students learned, the implementation study sought to describe how this learning took place in classrooms. The pilot implementation study was designed to inform scale up by helping stakeholders understand how schools and teachers adopt, adapt, and implement the *CoolThink@JC* program.

The implementation study was guided by the following research questions:

1. To what extent are the CoolThink lessons implemented as intended?

2. In what ways do the enacted lessons deviate from the expected models of implementation?

3. What supports and barriers do teachers encounter as they take on the *CoolThink@JC* pilot?

4. What implementation factors seem to be associated with success?

The implementation study employed qualitative methods (site visits that include classroom observations and interviews/ focus groups) to look deeply into the experience of teachers and students in four CoolThink pilot schools. Data collection instruments were designed by SRI, in consultation with project partners, and data were collected by Ipsos, a global research organization with an office in Hong Kong. In addition to this in-depth inquiry at the four selected schools, a survey of all pilot teachers, designed and administered by Ipsos in consultation with SRI, provided a broader view of teacher characteristics (e.g., years of experience, primary subject area), teacher attitudes, and perceptions of *CoolThink@JC* as they evolved over time. The survey also gathered information about adaptations teachers made to the lessons, including how, why, and how much teachers modified the materials and activities. In 2019 data collection, the survey focused in particular on how teachers' approaches to teaching *CoolThink@JC* had changed with experience.

Implementation study data were collected in three waves (Table 2). The sample of case study schools was designed to be representative of the wide range of Hong Kong primary school contexts. In choosing schools, we sought variation in funding sources, student backgrounds, medium of instruction (Chinese and English), and religious affiliation. Two of the four case study schools had an affiliated secondary school.

Table 2. Implementation Study Data Collection

Method	Sample	Timing
Classroom Observations	12 (3 per school)	Wave 1: November–December 2017 Wave 2: May–July 2018 Wave 3: March–June 2019
Teacher Interviews	12 (3 per school)	
Student Focus Groups	8 (2 per school)	
Principal Interviews	4 (1 per school)	
Educator Survey	All CoolThink teachers	

ABOUT THE SCHOOLS IN THIS PILOT STUDY

Thirty-two schools and more than 20,000 students in Primary 4–6 have participated in the *CoolThink@JC Pilot*; of these, 30 schools and 16,054 students were included in the pilot research. According to data submitted at baseline, the pilot schools represent a broad cross-section of the school types in Hong Kong, with a distribution of characteristics that is in many ways similar to the diversity of Hong Kong primary schools at large (Table 3).

The majority of pilot schools (serving 87% of the total pilot student population) are aided schools that conduct instruction in Chinese, and half of them are located in the New Territories. The schools serve students with a variety of religious backgrounds, including just over half that are either Catholic or other Christian schools. On average, the pilot schools enroll 11% students with special needs and 37% students who receive financial aid.

Two other characteristics of schools and teachers in this study are important for understanding the results that follow:

- At baseline, approximately 50% of pilot students reported on the CT Perspectives survey some level of programming experience prior to CoolThink. This is one area in which school characteristics have changed over the 3 years of this study: according to school-level data collection in 2019, all comparison schools reported some level of ongoing instruction in programming languages in Primary 4–6, suggesting that access to programming instruction is generally on the rise in Hong Kong's primary schools. For purposes of this research, it is important to understand that the outcome study is comparing outcomes from CoolThink to business as usual in Hong Kong primary schools that in many cases includes alternative programming instruction for comparison students.
- A total of 191 teachers taught *CoolThink@JC* during the pilot, and 169 of those teachers remained with the program for all 3 years. Based on a survey administered by the Hong Kong Jockey Club,[4] 94% are teachers of other subjects in addition to computer science, and only 25% hold a bachelor's degree or above in information and communication technologies (ICT) or a related subject. Based on this evaluation's teacher survey, teachers had an average of 7 years of experience teaching ICT. However, there were a significant number of teachers that had little or no prior experience teaching ICT, and many others that had limited ICT education prior to their entry into the *CoolThink@JC* program.

4 These numbers are based on responses from the 143 (of 169) teachers who participated to the survey.

Table 3. Characteristics of *CoolThink@JC Pilot* Schools and Students

	Number of Schools	Student Enrollment	% Students
Total	**30**	**10,513**	**100%**
By school type			
Government	2	802	8%
Aided	26	8,894	85%
Direct subsidy scheme	2	817	8%
By region			
Hong Kong Island	4	1,243	12%
Kowloon	11	4,133	39%
New Territories	15	5,137	49%
By religious affiliation			
No affiliation	11	3,707	35%
Catholicism	9	3,212	31%
Christianity, Non-Catholic	7	2,759	26%
Other	3	835	8%
By instructional language			
Chinese instruction	26	9,160	87%
English instruction	4	1,353	13%
Overall student characteristics			
With financial aid	-	3,851	37%
With special education needs	-	1,207	11%
Non-Chinese speaking	-	205	2%

Data source: 2016-17 school rosters and data templates completed by school principals.

COOLTHINK@JC PILOT STUDENT OUTCOMES

This study's midline report (Shear et al., 2019) described student learning in the first year of CoolThink lessons and presented preliminary 2-year results for just the 10 Cohort 1 schools that had begun instruction in the first year of the pilot. With another year of CoolThink lessons, we are now in a position to look at learning over multiple years for students at all 30 schools.

This section describes the learning over 2 years of instruction achieved by *CoolThink@JC Pilot* students across 30 pilot schools in CT Concepts, Practices, and Perspectives. We look at pilot student outcomes relative to the gains of students from 22 comparison schools[5] on the same measures, keeping in mind that comparison students either did not have programming instruction or participated in a different curriculum that their school may have offered during these 2 years. In this way, we compare pilot student learning in CoolThink classrooms to what they might have achieved had they not participated in this program. We also report on whether and how student learning varied for key subgroups, and use findings from the implementation study to better explain the results.

The findings below are based on gains in overall measures of computational thinking across two years, defined as the difference between scores at baseline and at the end of the second year of CoolThink lessons. This report focuses on 2-year gains because these data are available for students in all 30 Cohort 1 and Cohort 2 schools, providing a large dataset that can support robust conclusions.[6] Data on 3-year gains are also available for Primary 6 students in the 10 Cohort 1 schools that began the lessons a semester earlier; these preliminary findings are presented in Appendix C.

We report on the **impact** of *CoolThink@JC*, or relative gains for pilot students in relation to their peers in the comparison schools. Using hierarchical linear modeling (HLM), we compared student gains in pilot and comparison schools taking into account a number of factors that help us to make a fair comparison of similar students in similar circumstances, including the nesting of students within schools, and important characteristics at the student and school levels. We then present the estimated gains from these impact models for pilot and comparison groups

5 Of the 24 comparison schools, two schools do not have student baseline scores and are therefore excluded from the analysis.

6 The study's midline report (Shear et al., 2019) included a preview of 2-year outcomes, but at midline second-year data were available only from the 10 Cohort 1 schools, which was too small a sample to draw conclusive results or enable claims across the pilot initiative.

separately to show what students in each condition learned in the first 2 years, and the difference in learning between the two conditions. In the graphs that follow, the overall IRT-generated score for students' CT Concepts or Practices is converted to a Normal Curve Equivalent (NCE) score. This allows for easier comparison of relative gains between pilot and comparison students.

The Normal Curve Equivalent (NCE) scale is a standardized score that uses students' position relative to the mean of a distribution to offer a comparable view of results across measures. NCE scores range from 0-100, with an average of 50, and more than 60% of students scoring between 30 and 70. Details on this measure are described in Appendix B.

Summary of key takeaways

- **After 2 years of CoolThink lessons, the pilot had a positive impact on students' understanding of CT Concepts that approaches statistical significance.** This result suggests that in relation to comparison schools, the vast majority of which are using another form of programming instruction, students in pilot schools learned more of the fundamental coding concepts included in the CT Concepts measure.
- **Importantly, pilot students showed strong results in relation to their peers in comparison schools on improving problem-solving skills, as demonstrated in CT Practices assessment scores.** The CT Practices assessment captured students' broader computational thinking skills that are required for logical reasoning and problem-solving. These results offer promising evidence that CT Practices is a differentiator for *CoolThink@JC* in relation to other programming curricula in use in Hong Kong primary schools.
- **While boys and girls both benefited from 2 years of instruction in CoolThink, relative gains in CT Concepts were stronger for boys than for girls**. No other differences by subgroup were detected.
- **For CT Practices, relative gains were similar for boys and for girls, but stronger for students with higher baseline scores on math tests and on CT Practices.** This supports the hypothesis that *CoolThink@JC* is helping students to reinforce problem-solving skills that can be applied in other subjects such as mathematics, at least for students who are stronger academically. Relative gains were also stronger for students who had internet at home at the time they entered *CoolThink@JC*.
- **Findings on CT Perspectives show no statistically significant difference between pilot and comparison students on the overall CT Perspectives score,** with scores showing slight downward trends over the 2-year timeframe.

Student Outcomes: CT Concepts

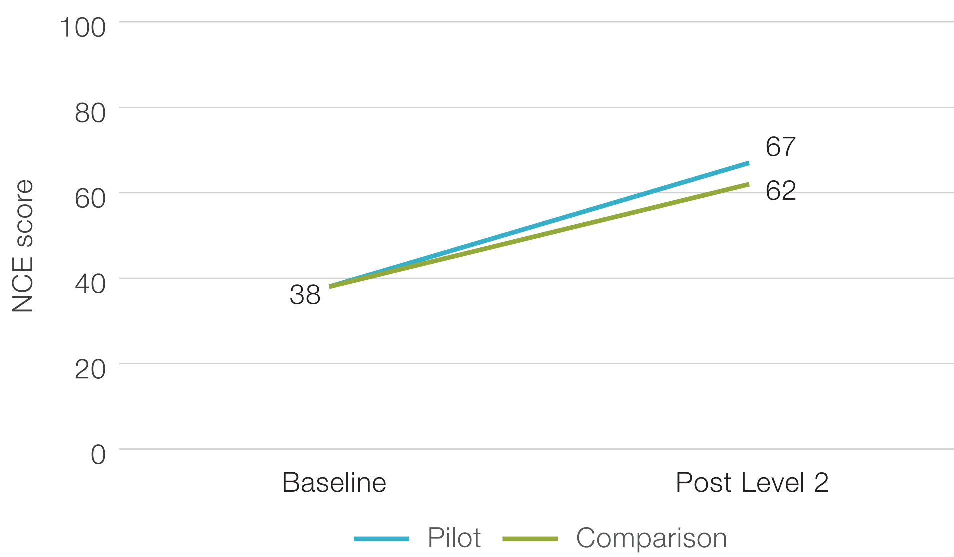
CT Concepts	
Repetition	Data Structures
Conditionals	Procedures
Parallelism and Sequencing	

In the CoolThink computational thinking framework, CT Concepts represent the programming concepts that are a focus of the program. For example, Repetition is the understanding of how loops work in programming, while Conditionals is the understanding of how to branch code. The concepts identified are fundamental to students for building an understanding of how programs work, and underlie students' abilities to design and execute code that matches a goal.[7]

After the first 2 years of CoolThink lessons, students in pilot schools demonstrated more learning in CT Concepts than similar students in comparison schools (Figure 2). The difference is marginally significant statistically. It is important to keep in mind that many of the comparison schools were offering some kind of programming instruction that may target CT Concepts, so this result shows that **CoolThink students learned more than students who were receiving business-as-usual programming instruction in Hong Kong.**

Figure 2 shows the predicted trajectory in CT Concepts scores for an average student who started at an NCE score of 38 at baseline. Both pilot and comparison students demonstrated strong gains in CT Concepts, which is consistent with the understanding that programming instruction was

Figure 2. Trajectory of CT Concepts Scores for Pilot and Comparison Students, Baseline to End of Year 2



Note: This analysis includes students in 30 pilot schools who had received 2 years of CoolThink lessons, along with their counterparts in 22 comparison schools.

7 In parallel with ongoing refinement of lesson coverage, Procedures was removed from the CT Concepts assessment beginning in 2018.

offered in many Hong Kong primary schools. This student's score would be predicted to rise five points higher after 2 years of CoolThink lessons than in a comparison school that was offering non-CoolThink programming instruction.

In the most recent educator survey, over three quarters (76%) of teachers agreed that *CoolThink@JC* **"equips my students with basic programming capabilities,"** and two-thirds agreed that it **"helps students learn to think step by step."** One teacher we interviewed said he understands that *CoolThink@JC* is about more than programming, and he appreciates how the program provides a framework for teaching the CT concepts that he finds hard to translate into solid ideas.

When we adjust for differences in student and school characteristics,

- Pilot students gained an estimated **5 NCE points more in CT Concepts** than comparison students, with a p value of 0.08. This difference is marginally significant.
- The estimated impact translates to an **effect size of 0.21.** Effect size is a common measure of the magnitude of an impact, and an effect size of 0.25 or larger is considered a substantively important effect size in education research by the What Works Clearinghouse (WWC, 2014), a U.S. federal repository of "gold-standard" evidence on education programs.
- In percentile terms, looking at the change in ranking of an average student in relation to other students, a 0.21 effect size is equivalent to an **increase from the 50th percentile to the 58th percentile,** or a "percentile improvement index" of 8.
- On average **pilot students gained 21% more** than students in comparison schools.

Student Outcomes: CT Practices

CT Practices	
Algorithmic Thinking	Testing and Debugging
Reusing and Remixing	Abstracting and Modularizing

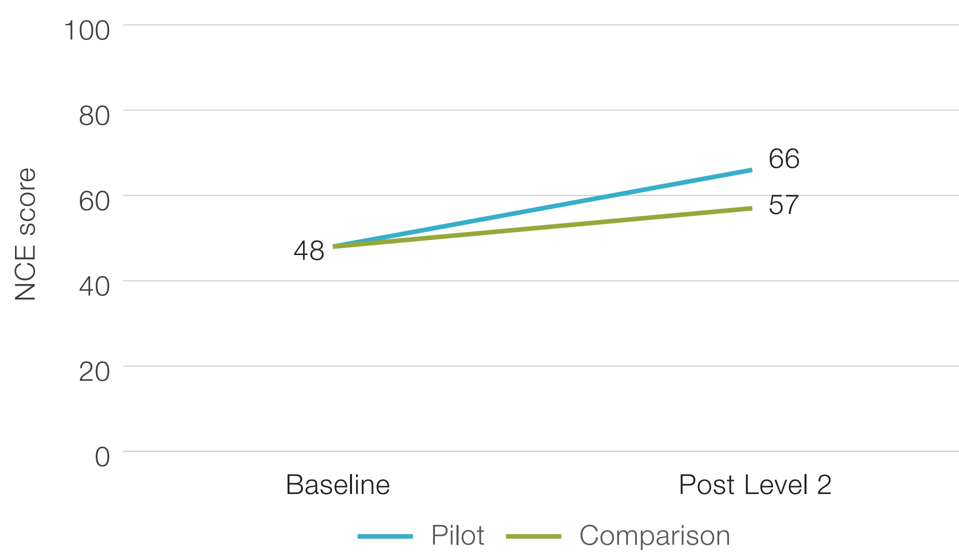
In the CoolThink computational thinking framework, CT Practices represents a student's understanding of a number of more general skills and orientations that are fundamental to computational problem-solving. Algorithmic thinking, for example, is a conceptual orientation fundamental to the task of converting a problem into computational terms. An important design principle of the *CoolThink@JC* program is that it is not limited to programming instruction; instead, it is tuned to emphasize this broader definition of computational thinking.

Consistent with the framework, the design of the CT Practices assessment requires students to engage in the practices, without requiring the specific programming structures and computer science content knowledge that reside in the CT Concepts domain. While CT Practices tasks are presented in the context of computational thinking, the underlying abilities they test are more general to problem solving and logical thinking. As such, there is strong overlap between tested skills in CT Practices and more generally applicable "21st Century skills", such as problem solving and critical thinking.

After the first 2 years of CoolThink lessons, students in pilot schools demonstrated more learning in CT Practices than similar students in comparison schools (Figure 3). The difference is large, substantively important, and statistically significant.

Figure 3 shows the predicted trajectory in CT Practices scores for an average student who started at an NCE score of 48 at baseline. In a pilot school, this student's score is predicted to increase to 66; in a comparison school, it would only rise to 57.

Figure 3. Trajectory of CT Practices Scores for Pilot and Comparison Students, Baseline to End of Year 2



Note: Because Cohort 1 students were not assessed in CT Practices at baseline, this analysis only includes students in the 20 Cohort 2 Pilot schools and their 20 comparison schools. Within those schools, we include students who had received 2 years of CoolThink lessons and their counterparts in comparison schools.

This strong result is particularly notable in light of the fact that many of the comparison schools are offering some kind of programming instruction. **The fact that CoolThink students significantly outperformed their peers in other schools suggests that students' learning of problem solving and logical thinking is an important differentiator for the CoolThink lessons in comparison to business-as -usual programming instruction in Hong Kong.**

In addition, the more general problem-solving and logical thinking focus of the CT Practices assessment that was described above can also be relevant to other disciplines that demand these types of thought processes, such as mathematics and engineering. While this research does not test transfer of computational thinking practices learning beyond the computer science classroom, the strong impact of *CoolThink@JC* on students' CT Practices scores may indicate that the initiative is helping students to build more fundamental problem-solving skills that they can apply in other subjects.

Based on evidence from the educator survey and student focus groups, students and teachers appreciated the opportunities for creative problem solving that CoolThink classes offered, and some found the intellectual challenge compelling. These results are consistent with student gains on CT Practices measures, indicating that **CoolThink lessons in some schools were fostering the dispositions needed to succeed in creative problem solving.**

> "Coding is like playing with puzzles, which I quite enjoy. I will spend time to think of solutions and when I could solve the problems, I often gain a huge sense of accomplishment, which other lessons seldom offer." (P4 student)

When we adjust for differences in student and school characteristics,

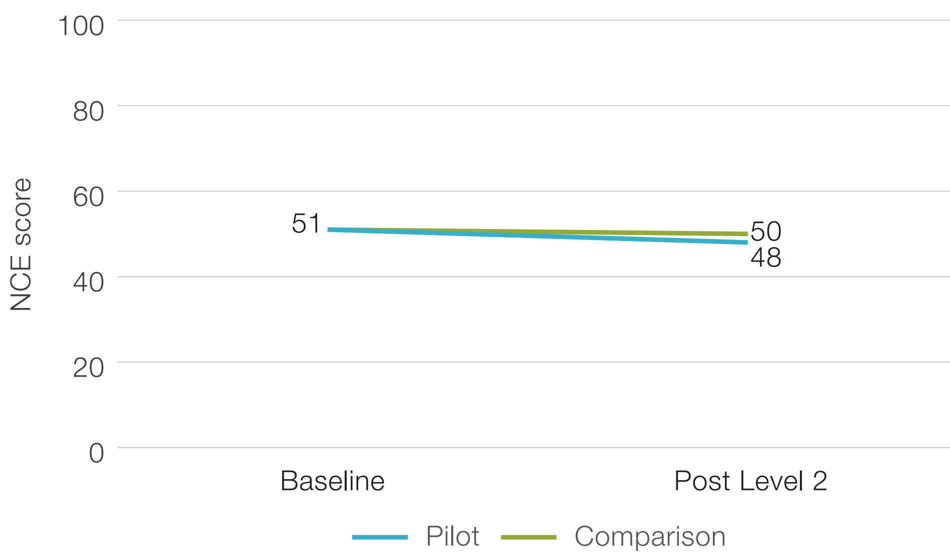
- Pilot students gained an estimated **9.3 points more in CT Practices score** than comparison students, with a p-value of 0.001. This is a statistically significant difference.
- The estimated impact translates to **an effect size of 0.36, which is considered a substantively important effect size** in education research by the What Works Clearinghouse.
- In percentile terms, looking at the change in ranking of an average student in relation to other students, a 0.36 effect size is equivalent to an **increase from the 50th percentile to the 64th percentile**, or a "percentile improvement index" of 14.
- On average **pilot students gained 2.1 times as much** as students in comparison schools.

Student Outcomes: CT Perspectives

CT Perspectives is a survey of students' opinions about, and relationship to, computational thinking. According to the CoolThink CT framework, CT Perspectives includes seven distinct but interrelated constructs: for example, Digital Self-efficacy is a student's confidence in his or her abilities related to programming, and Utility Motivation relates to meaningfulness, or the degree to which a student feels that programming is personally important. Because *CoolThink@JC* places a primacy on building not only skills but also motivation toward digital creativity, CT Perspectives measures an important set of outcomes for the initiative.[8]

CT Perspectives	
Interest in Programming	Creativity
Digital Self-efficacy	Engagement
Utility Motivation	Belonging
Motivation to Help the World	

Figure 4. Estimated CT Perspectives Scores for Pilot and Comparison Schools, Baseline to End of Year 2



Note: This analysis includes students in 30 pilot schools who had received 2 years of CoolThink lessons, along with their counterparts in 22 comparison schools.

8 As described in Appendix C, the composite measure of CT Perspectives reported here does not include the construct of Belonging. Rather than focusing on students' opinions of programming, the Belonging subscale relates to students' opinions of working with others while they are programming. For this reason Belonging showed low correlation with the other subscales and was eliminated from the overall measure.

When we adjust for differences in student and school characteristics,

- Pilot students lost an estimated **2 points more in CT Perspectives score** than comparison students, with a p-value of 0.13. This difference was not statistically significant.

After the first 2 years of CoolThink lessons, pilot students exhibited slightly less progress in CT Perspectives than comparison students (Figure 4), but this difference was not statistically significant. Among subconstructs including Interest, Digital Self-efficacy, Utility Motivation, Motivation to Help the World, Creativity, Engagement, and Belonging, only the difference in Self Efficacy (a measure of students' confidence in their own programming abilities) was robust enough to be considered a statistically significant disadvantage for CoolThink students.

In educational initiatives, it is not uncommon for students' confidence and enthusiasm to go down at first. One hypothesis is that this is because they begin to experience how difficult the topic is (for example, they learn that programming is harder than they may have thought at first, and there is more to learn than they initially thought). This could also explain the fact that pilot students' scores drop more in self efficacy, particularly if the CoolThink lessons are more rigorous than some other programming curricula. However, a continued (though slight) downward trend over multiple years warrants consideration in designs for the *CoolThink@JC* Phase II curriculum.

This slight downward trend is consistent with results on the educator survey. In 2019, 78% of teachers agreed that "Students actively participate in the learning activities" and 71% reported that "Students demonstrate enthusiasm and effort in completing assigned tasks." While these numbers are encouraging, it is notable that both of these measures are down more than 10% from the first survey in 2017. Teachers report that ongoing improvements by the curriculum team have boosted student engagement by making the content more understandable. In interviews, teachers cited the freedom to choose projects and to exercise initiative in researching information and resources as contributing to engagement. One teacher said, "Students are more motivated when they understand the concepts and make their own app with their own ideas. They show better engagement as they own the work." However, another teacher reported that motivation is low in his classroom as students struggle to understand the concepts. Making challenging content more accessible to younger students continues to be a target of ongoing lesson refinement.

> "It gives a lot of autonomy to the students. The students gain a great sense of achievement when they finish."
> (teacher)

> "Level 2 is more difficult than Level 1, so the less competent students have lower interest."
> (teacher)

Learning across subgroups

A very important goal of *CoolThink@JC* is the support of equity: providing opportunities for computational thinking that are accessible to all students, including those with special needs or who are otherwise educationally disadvantaged. This evaluation looks at student outcomes for various subgroups on CT Concepts and Perspectives, where we found that students benefit from *CoolThink@JC*, to inform the question of who benefits the most.

CT Concepts across subgroups

One area of uneven outcomes that emerged in earlier years was gender. After 2 years of CoolThink participation, although there is evidence that both boys and girls benefited from taking CoolThink lessons as measured by CT Concepts assessments (meaning that they learned more CT Concepts than their comparison peers), **boys continued to benefit more from the pilot lessons than did girls**. This trend has persisted since it was first reported after 1 year of lessons. The difference in the impact of the pilot on boys versus girls is 2.3 points, with a p-value of 0.02.

The midline report also suggested that after 1 year of lessons, several other subgroups were disadvantaged in CT Concepts learning, including less academically advanced students, students with less knowledge of CT Concepts at baseline, and students in classes with more special education needs (SEN) students. **After 2 years of lessons, however, these differences are no longer in evidence.**

Other than gender, analyses of CT Concepts scores after 2 years of CoolThink lessons did not detect any statistically significantly differential impacts on students by these factors:

- Baseline math achievement or concept score
- Grade level
- Baseline computer use at home
- Baseline internet access at home
- Student prior programming experience
- School percentage of students with special education needs
- School percentage of students receiving financial aid
- School baseline coding experience

Nevertheless, interviews suggest that some SEN and less advanced students were receiving a different CoolThink experience than their peers. For example, some teachers told us that these students were more likely to be led through the tasks step by step, filling in templates rather than engaging in creative construction and problem solving. Attention to equity and to strategies to engage diverse students successfully in CoolThink activities should remain a focus as *CoolThink@JC* goes to scale.

CT Practices across subgroups

Subgroup performance in CT Concepts and CT Practices showed markedly different patterns. On measures of CT Practices, the advantage that was seen for boys in CT Concepts was not statistically significant. Instead, **there was a strong and significant relationship between relative gains and baseline math test scores:** students who were stronger in math benefitted more from CoolThink as reflected in CT Practices. In addition, students with higher baseline CT Practices scores, and students who had internet at home at the time they entered CoolThink, benefitted more from CoolThink on measures of CT Practices.

To interpret this different pattern of results, it is important to keep in mind that the knowledge tested in CT Concepts is firmly rooted in the field of computer science: it represents the specific knowledge required to perform programming tasks. In contrast, the skills tested in CT Practices are more general: while the questions are presented in the context of computational thinking and block programming, the underlying problem solving and logical thinking skills they demand are separate from any computer science knowledge or specific computer concepts. As such, they have much in common with students' problem-solving abilities in mathematics.

The strong positive correlation between students' baseline mathematics scores and their relative gains in CT Practices as a result of engaging in CoolThink lessons adds strength to the hypothesis that CoolThink students may be building transferrable skills in problem solving and logical thinking. However, together with the positive findings on students with higher baseline CT Practices scores and with home internet access, it also suggests that more academically advanced students and students with better home resources are experiencing this benefit to a greater degree than their peers. This may be an important consideration as the co-developers continue to tune their designs for equity in the new scaling phase of *CoolThink@JC*.

Other than baseline CT Practices and math scores and baseline internet access, analyses of CT Practices scores after 2 years of CoolThink lessons do not detect any significantly differential impacts on students by the following:

- Gender
- Grade level
- Baseline computer use at home
- Student prior programming experience
- School percentage of students with special education needs
- School percentage of students receiving financial aid
- School baseline coding experience

PILOT TEACHER AND PRINCIPAL EXPERIENCES

The overall student outcomes reported in the previous section mask a great deal of diversity of *CoolThink@JC* implementation across schools and classrooms. Previous reports described differences in pedagogy across teachers, with some supporting learning through exploration and others using more teacher-centered approaches. School-level contexts and capacities can also vary in ways that are impactful to the success of teaching and learning in a CoolThink classroom.

This section uses data from the survey of all CoolThink teachers, and from site visits to four schools, to portray the implementation of CoolThink instruction in pilot classrooms, focusing in particular on how teacher perspectives and practices have evolved with experience teaching *CoolThink@JC*.

The overall implementation trajectories of teachers and schools over time hold important lessons as the CoolThink team prepares to build a self-sustaining ecosystem to support ongoing opportunities for computational thinking in a much larger set of primary schools in Hong Kong.

Summary of key takeaways

- Teachers reported that teaching *CoolThink@JC* involves adopting new teaching strategies, which some described as a shift toward more student-centered approaches.
- The new curriculum revision was seen as a significant improvement, but some still found CoolThink lessons to be too challenging at this point in the ongoing process of lesson refinement.
- Training by MIT and EdUHK played a substantial role, not only in preparing teachers to teach *CoolThink@JC*, but also in supporting educators' perceptions of computational thinking and of *CoolThink@JC*.
- Most teachers found teaching assistants (TAs) to be essential supports.
- For many this need faded as they gained experience with *CoolThink@JC*.
- Principals appreciated how *CoolThink@JC* catalyzed teacher community and helped them to advance their schools toward STEM goals.

Teaching *CoolThink@JC*

Teachers consistently reported that teaching CoolThink lessons presented a significant departure from business-as-usual instruction.

Adopting student-centered pedagogies

Pilot teachers exhibited a range of pedagogical styles. This comes as no surprise, as the pilot contained schools that varied widely in their teaching approaches. For some, active learning and student collaboration were already the norm, but for the majority, the exploratory nature of CoolThink lessons represented a significant departure from their customary practice. On the educator survey 80% of respondents indicated that teaching CoolThink is different than teaching their other classes. When asked to elaborate on these differences, several teachers cited the emphasis on collaborative learning and student-directed exploration as distinguishing factors. Others said that they spend much less class time speaking to the whole group than they do in other classes. One teacher said that in *CoolThink@JC* it is important that students not merely practice but also understand the concept and the rationale in the lesson.

80% Teachers who agreed that "the way to teach CoolThink@JC is different from what I usually do in other classes"

> "The lessons are led by students. There are lots of discussion opportunities to the students. Teachers only guide the students." (teacher)

> "It gives a lot of autonomy to the students. The students gain a great sense of achievement when they finish." (teacher)

> "There is no model answer, so students could develop their creativity." (teacher)

In some focus groups, students expressed appreciation for the differences between *CoolThink@JC* classes and their other subjects.

> "I always look forward to CoolThink lessons. I have much fun during class time. I get to work on my tasks and it's very satisfying when I can overcome the errors on my own." (P4 student)

The majority of teachers interviewed in early 2019 said that their approach to teaching *CoolThink@JC* had changed over the course of the pilot. Two teachers described their increased efforts to relate new CT concepts to practical, real-life examples. Two other teachers said that their focus shifted from getting students to accomplish tasks toward building their understanding. On the educator survey, teacher comments described how experience can guide pedagogy:

> "I know more about students' difficulties so that I could focus on the key points." (teacher)

> "I have more confidence to handle the students' problems and questions." (teacher)

Some teacher comments point to shifts in their pedagogy toward a more student-centered approach.

> "Less talking from me, more time for students to try." (teacher)

Although both the survey and the site visits showed evidence that some teachers were changing their practice over time as they became accustomed to the CoolThink lessons, these sources also revealed that many pilot teachers had not fully embraced the pedagogy inherent in the program. In nearly a third of the classrooms we visited over the course of the pilot, the observer characterized the teacher as a "transmitter of information" rather than as a "coach" or "facilitator." On the most recent educator survey, 41% of respondents disagreed with the statement that *CoolThink@JC* "gives students opportunities to be creative in class."

A challenging assignment

Teachers and principals agreed that teaching *CoolThink@JC* presented challenges. **Throughout the pilot, "too much content for the allotted time" was a consistent theme across all data collection activities.** As described earlier, computational thinking is a novel subject for primary school, and this pilot offered an invaluable opportunity for designers to determine how much content coverage is realistic at this level of students' development. In response to this issue, the co-developers adjusted lessons iteratively before each academic year, and teachers and principals expressed appreciation for the lesson revisions. For example, one major change made in response to pilot feedback was to take MIT App Inventor—a more advanced computing environment than Scratch—out of the P4 level and reserve it for P5 and P6 students.

In the last wave of data collection, teachers commented that parts of the Level 3 curriculum, which was in its first iteration, were too difficult. The difficulty of the lessons may account for a six-percentage point drop in teachers' overall perception of the benefits of participating in CoolThink, as reported on the educator survey. These perceptions were highest for teachers of Level 1 lessons and declined with each successive level. Co-developers are addressing this feedback in ongoing lesson refinement activities.

Another important challenge was adapting lessons to different student ability levels. In interviews, teachers expressed concern that the adaptations they made to help struggling students keep up, such as providing templates for them to fill in rather than letting them figure out approaches on their own, may have been sacrificing opportunities for learning and creativity for the sake of keeping the class moving together.

Teaching assistants

An important element of in-class support provided by *CoolThink@JC* was the presence of two TAs in each CoolThink class. Depending on the needs of the teacher and the class, the TAs played a variety of roles, ranging from tech support for the students to occasional instructional support for teachers who were not yet confident about teaching the lessons.

In the third year of the initiative, TAs remained valued assets for teachers. On the 2019 survey, fewer than 10% of teachers surveyed agreed with the statement "The TA is not essential for teaching CoolThink." Over a third chose, "I could not teach CoolThink without the help of the TA," while the majority (55%) felt that the TA becomes less important as they gain experience with the program. In interviews, several of the teachers we spoke with called TAs a "nice to have" support, but most considered them "essential" or "important." All 11

> "[Students] always have so many questions and I only have 35 minutes. Some students would even get stuck on logging onto the platform. So without the TAs, classes would be chaotic."
> (teacher)

teachers described the role of the TA as offering individual one-on-one help to students. Several said something like, “It’s like having three additional teachers in the classroom.”

Professional Development

In past reports (Shear et al., 2019), we reported on the value of the training by MIT and EdUHK in preparing teachers to teach *CoolThink@JC*. In the final year, comparison with teachers who had not had the opportunity to attend this training shed light on the role it played in supporting educators’ perceptions of computational thinking and *CoolThink@JC*. On the survey, over three quarters of teachers who had benefitted from the full professional development were likely to recommend *CoolThink@JC* to colleagues. But of the 28% of teachers who received only school-based preparation, fewer than half said they would recommend the program. Teachers we spoke with who did not benefit from the full training were more likely to describe a narrower vision for computational thinking education, emphasizing coding skills rather than creative problem solving. **This finding suggests the need to find ways to provide deliberate CoolThink training experiences for all teachers as the initiative goes to scale, based on the highly effective models for training that have been demonstrated through this pilot.** Developers are also responding to teachers’ requests for more pedagogical tips and real-life examples to help explain concepts to the students.

98% CoolThink teachers who report having collaborated with colleagues on lesson planning

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> “We have always wanted to see more knowledge exchange between teachers. It is a sustainable yet healthy way for teachers’ development. It also brings benefit to students too. I am very glad that teachers are taking the initiative to share and learn.” (principal)

> “More interactions and brainstorming are seen among the four CoolThink teachers. They are more actively working on the planning and preparation as it is a more challenging curriculum than before. They also take more initiative in coming up ideas or new ways to teach the lessons.” (principal)

> “*[CoolThink@JC]* influenced the teachers’ learning and teaching, which was beneficial to the growing of the whole community.” (principal)

School–Level Effects

Although principals and teachers agree that teaching *CoolThink@JC* entails an increased workload, **principals note that it had a positive effect on their school communities by catalyzing the development of an active teacher professional community to address STEM goals.**

Case study schools varied in terms of how much computing was present in their program prior to *CoolThink@JC,* but all four principals remarked that the *CoolThink@JC Pilot* helped them to advance toward their goals for computing education. A few said that it was especially timely as it helped them to meet the expectations of the Education Bureau regarding school development in STEM education. Before *CoolThink@JC,* it appears that the will to teach computational thinking was there, but a framework was lacking.

> "The CoolThink program is like a beacon for us. We didn't have any concrete plan on the syllabus or directions we were going to take for the STEM initiatives." (principal)

> "CoolThink came in the right time for the school as we were looking for directions to develop computational thinking. As the EDB was pushing STEM education, we know that our school could work better in this area and therefore we looked for suitable programs for input." (principal)

> "It was a good experience for our school. It introduced us to computational thinking and education, and in many ways it enlightened our staff and myself on what the next steps should be." (principal)

Principals also noted that the supports provided by the program are key to its success, and that it would be much harder to implement without them.

> "Systematic and resourceful supports help the school speed up and expand CT learning to more students." (principal)

SCALING *COOLTHINK@JC*

This evaluation has painted a comprehensive picture of the successes and challenges of the *CoolThink@JC Pilot*, which can offer many lessons to inform the broader next phase. In this section we offer specific considerations for the design of the expanded initiative and the process of going to scale, based on teachers' and students' experiences to date.

Research provides ample evidence that school reform is difficult to sustain and scale (Datnow, 2002; Friend, Flattum, Simpson, Nederhoff, & Neumark-Sztainer, 2014). As an initiative scales, it is important to attend to specific steps that can support adoption and fidelity. For example, fostering greater ownership and understanding of the reform among stakeholders can bolster fidelity of implementation and guard against shifts in focus (Bryk and Gomez, 2008). Additionally, instituting ways to build social ties and peer support among teachers and principals is crucial to maintaining engagement (Coburn, Russell, Kaufman, & Stein, 2012).

After a successful 32-school pilot, the *CoolThink@JC* team is poised to bring computational thinking opportunities to a much larger group of primary schools and students within Hong Kong. As the team is well aware, success at scale requires a lot more than high-quality lesson materials. As the initiative rolls out to many more schools, the co-developers must consider how to generate buy-in among a much larger assortment of stakeholders; how to promote success across a wider variation of school contexts; and how to continue to provide sufficiently high-quality professional learning opportunities affordably at scale, among many other questions.

Most categories of scaling issues can be conceived at multiple levels. Here we focus on two:

- **The micro:** What are the implications for the classroom and for instructional and professional learning supports offered to teachers?
- **The macro:** What are the implications for schools and systems, which may provide more programmatic supports and attend to system-level capacities?

1 **Maintain effectiveness of the professional development model at scale.** High-intensity, ongoing training, including 78 hours of workshops led by university researchers, was key to the success of many of the pilot CoolThink teachers. Because this is not a feasible model at scale, and to provide increased flexibility for teachers and schools, Phase II will leverage a range of instructors, including trained mentor teachers, to support professional learning. This new distributed model for teachers' professional development brings with it the risk of inconsistent quality across offerings.

Micro implications: Designers should refine and codify the successful elements of pilot training offerings into foundational principles of a comprehensive professional learning program that promotes deep understanding, pedagogical content knowledge, and the practical toolkit needed to enact CoolThink lessons. Specifying the foundational principles that should always be present through any form of CoolThink professional development will provide a basis for design of train-the-trainer activities and promote consistency across offerings on dimensions that matter.

Macro implications: Schools need strategies for release time and classroom coverage to make CoolThink teachers available to participate in professional learning. This requirement also has implications for system-level consideration of capacity. Partnerships with and among system-level actors (e.g., Education Bureau, school sponsoring bodies, teacher education programs) must maintain a focus on foundational principles in the design of professional learning opportunities for enactment beyond the CoolThink network.

2 **Facilitate within-school and across-school communities of practice to reinforce and extend professional learning.** The implementation study showed that many teachers have begun some degree of collaboration with their colleagues to support each other as they take on the ambitious goal of CoolThink adoption. This suggests an opportunity to create planful CoPs within schools and among CoolThink teachers in Hong Kong.

Micro implications: While communities of practice will have their own organization and character across schools, active coaching for school leadership teams can provide models for effective CoP leadership and ways to make sure the time is used effectively in support of core principles related to CoolThink and computational thinking. Recommendations for the designs of school-based communities of practice are also included in many of the issues below; while an active CoP does not on its own solve these issues, it can be an important means to reinforce and share strategies on a range of priority topics among staff within the school community.

Macro implications: In a similar way, CoolThink-facilitated communities of practice across schools in the network can amplify ongoing learning and share promising models for teaching *CoolThink@JC* across schools. They can also communicate the importance of CT education within the Hong Kong primary grades curriculum and publicly recognize teachers' efforts to innovate by adopting CoolThink lessons and new pedagogies in their classrooms. With ownership from the Education Bureau and other system-level agencies, communities of practice can extend enthusiasm and strategies for promoting these opportunities to students across Hong Kong.

3 **Keep problem-solving and logical thinking at the forefront.** These broader skills are an overriding goal for *CoolThink@JC*, and strong measured impact on CT Practices during the pilot phase is promising. An important risk worthy of consideration is that when teachers are faced with the common challenges of time pressures and diverse student needs, some respond by giving students code snippets and other strategies that increase efficiency at the expense of opportunities for problem solving.

Micro implications: In addition to reinforcing problem solving and logical thinking within lessons and professional development, designers must provide strategies for making materials more accessible to a wide range of students and limiting content coverage without reducing problem-solving challenges and opportunities for creative exploration.

Macro implications: Ongoing coaching of principals and other school-level instructional leaders, and facilitation of professional community among them, can ensure that the focus on broader 21st century skills is promoted at all levels within schools. More formal partnerships with the Education Bureau and participation in territory-wide conversation about standards and curricula are important to promote messaging about these ideas beyond *CoolThink@JC* and engender system support for their inclusion more widely in educational programming in Hong Kong.

4 **Promote ownership and deep understanding of the rationale for teaching CT.** In the pilot, teachers who hadn't participated in official CoolThink training held a narrower view of the nature and purposes of CT education than those who benefitted from the full training. Enthusiasm for the program waned, to some degree, over time and among teachers of the newer and more challenging Level 3 lesson sequence.

Micro implications: Offerings for professional learning workshops at scale must be designed to provide participation opportunities for all CoolThink teachers, rather than including some teachers in formal professional development and leaving others to find their own ways to learn. In addition, an important design principle for communities of practice is to include a focus on computing as a creative medium.

Macro implications: It is important for schools and system-level actors to build in incentives and ongoing professional opportunities to keep teachers engaged over time, and to put structures in place to recognize teachers as they gain more experience and responsibility. Engagement throughout the system is required to support CT education so that school-level resources and incentives are aligned with system-wide goals.

5 **Provide tailored supports within the classroom.** Many teachers found TAs to be essential supports as they learned to teach CoolThink, and often felt the most need for their help early in the teacher's path of CoolThink adoption. As described in earlier reporting (Shear et al., 2019), some schools also have technology access or configuration issues that inhibit students' participation in the learning opportunities.

Micro implications: For adoption at scale, develop a strategy for TA support that is available to all CoolThink teachers at a level tailored to need.

Macro implications: Engage system-level partners to attend to longer term capacity issues by providing needed technical support, upgrading technology infrastructure, and institutionalizing a system for providing classroom support as teachers take on new complex classroom responsibilities. Offer a rubric that school sponsoring bodies could use to assess the relevant resources (technical, organizational, and human) in place at a school prior to CoolThink adoption, and to guide thinking about what steps might be necessary to remediate any gaps.

6 **Attend to student diversity.** While 2-year student gains showed no significant differences on SEN status and receipt of financial aid, it is important to recognize that data on these important equity-related factors were available only at the school level, masking individual inequities within classrooms that the implementation study helps to illuminate. The need to support students who struggled to complete CoolThink lessons often had the effect of reducing opportunities for creative exploration and problem solving. In their efforts to promote teamwork during CoolThink lessons, teachers sometimes adopted grouping strategies that limited learning opportunities for stronger students. Overall CT Concepts outcomes of *CoolThink@JC* have remained somewhat biased in favor of boys over girls.

Micro implications: Ensure that strategies to support equitable access to problem solving are topics of focus in teacher professional development and communities of practice. Offer teachers a range of models for grouping students of different abilities, for making materials more accessible without sacrificing opportunities for student exploration and problem solving, and for engaging girls in computational activities. Continue to refine the accessibility of materials, particularly the newer Level 3 lessons.

Macro implications: At a system level, including teacher and principal preparation within Hong Kong, elevate the priority of discussions of equity issues within education and specific strategies for supporting diverse students in the classroom. While these are important issues across subjects in the current curriculum, CoolThink foreshadows the need to implement strategies that promote equitable access to problem solving and other 21st century skills as these new educational ideas become increasingly embedded in curricula across subjects in Hong Kong.

7 **Engage students more completely in computational thinking.** Of the measured outcomes of this evaluation, CT Perspectives was the only dimension in which students did not show gains over time. This means that although *CoolThink@JC* is promoting students' understanding and skills in computational thinking, it is not—on average—promoting their enthusiasm, self-confidence, and perceptions of the value of computational thinking.

Micro implications: Through all levels of the CoolThink lessons, increase the provision of exercises and examples that relate CT concepts to students' experiences and emphasize how computational thinking can be employed to solve problems relevant to students' own lives. Increase opportunities for students to exercise creativity in CoolThink projects by tackling novel problems that they have helped to define. Continue to adjust lesson objectives for age-appropriateness. Gather information from teachers about what they have done to make CoolThink lessons more fun and engaging for students, and consider as input in ongoing lesson improvement. In teacher professional development, emphasize the importance of student agency to ensure that all students experience success applying CT and coding skills in creative ways to solve problems.

Macro implications: Continue to promote inspiring and engaging activities and events such as coding fairs and competitions. Share examples of creative projects within communities of practice so that teachers across schools develop a shared understanding of students' CT abilities and creative potential. Make visible a wide variety of career opportunities that leverage computational thinking beyond "being a programmer." Explicitly enroll principals to promote a holistic approach to communication about the value and relevance of computational thinking throughout the school, and make CT perspectives a topic of public and parent discourse as well.

CONCLUSIONS

This report demonstrates the substantial contribution that the *CoolThink@JC* pilot has made to the relatively new field of computational thinking education at the primary level. In comparison with other similar students in Hong Kong, some of whom have access to other varieties of programming instruction at their schools, CoolThink students showed stronger gains in knowledge and skills of computational thinking. These advantages were particularly notable in CT Practices, which suggests that CoolThink is promoting broader problem-solving and logical thinking skills: important building blocks toward the digital creativity that is a core goal of the initiative and of the education system.

These outcomes are based on several more tangible contributions of the CT education package that was created under this pilot initiative. The CoolThink lessons themselves offer an important model and instructional resources for embedding computational thinking into students' academic experiences from an early age. The CoolThink program of professional development demonstrates the value of ongoing facilitated support for the adoption of a complex new addition to teaching and learning in Hong Kong's schools and provides a model of effective professional development that can inform supports for other educational initiatives. In addition, the evaluation of the pilot initiative generated rigorous validated assessments that can help track the progress of students' CT learning as the initiative scales. This complete package positions *CoolThink@JC* to be an important contribution to computational thinking education at the primary level both within and beyond Hong Kong, with the potential to provide a strong model for system-level initiatives.

While the pilot's multiple years offered a platform for continuous refinement of the CoolThink materials, it would be a mistake to think of this process as complete. At secondary levels, and particularly in post-secondary, programming curricula have benefitted from having many years to mature. Scaling the initiative to a wider variety of schools will bring new opportunities to continue to refine age-appropriate learning goals, to make materials and activities increasingly friendly and engaging to younger students, to embed emerging technologies such as artificial intelligence, and to develop strategies that help teachers maintain opportunities for exploration and problem solving even as they adapt for diverse student abilities and limited available time.

Moving forward from a successful pilot stage, *CoolThink@JC* is poised to offer important opportunities for computational thinking and creative problem solving to a much larger proportion of Hong

Kong's upper primary students. As it scales, one of the core challenges will be to maintain the quality of implementation and of professional development that were demonstrated during the pilot phase, which carried the opportunity for more intensive interactions with schools and teachers. Taking professional learning opportunities and support to scale, and continuing to study the resulting implementation and outcomes to learn which methods best meet standards of both quality and affordability, will produce important models that can inform broader programming both within Hong Kong and beyond.

An additional challenge for the *CoolThink@JC* team will be to shift reform ownership from the project collaborators to schools and systems (Coburn, 2003). This is supported by the team's decision to promote school-based curriculum decisions, encouraging teachers to experiment and take ownership of the strategies that best suit the needs of their own students. Planned partnerships for professional development offerings are another very promising step that is already being realized. Additional roles for system partners that will advance widespread adoption in important ways might include facilitating inter-school communities of practice, screening and remediating conditions for school readiness, and ongoing communication of the importance of CTE in the primary curriculum.

Four years ago, the Hong Kong Jockey Club and its partners took on a tremendously ambitious goal: to develop a 3-year sequence of lessons that brings computational thinking education to a new age group of students, and roll it out to 32 schools—an unusually wide scale for a pilot initiative. This evaluation has shown that the effort was successful in promoting strong student learning, particularly in terms of building skills like problem solving and logical thinking that are key to students' successful and productive futures. The initiative also demonstrated strong models for the facilitation of professional learning, and helped to catalyze school-based responses to EDB calls for stronger STEM education within Hong Kong schools. In addition, this evaluation produced state-of-the-art assessments to measure student learning in this novel domain.

The *CoolThink@JC Pilot* initiated an iterative and ongoing process of development and refinement for an important new instructional program contributing substantially to nascent global efforts to introduce computational thinking to students at an earlier age. The stage is set for continued leadership as *CoolThink@JC* scales, empowering a much larger number of students to move beyond technology consumption and into problem solving, creation and innovation: skills needed to prepare Hong Kong's students for a complex and fast-changing future.

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