

COMPUTATIONAL THINKING READINESS FOR ALL: REFLECTIONS ON STUDYING A FRAMEWORK FOR SUPPORTING SCHOOLWIDE CT INTEGRATION IN ELEMENTARY CURRICULA

H. Sherwood,¹ B. Moeller,¹ C. Fancsali,² A. Kaiser¹

¹*Education Development Center (UNITED STATES)*

²*New York University (UNITED STATES)*

Abstract

This paper describes efforts to develop and study a framework for schoolwide integration of computational thinking (CT). The *CT Integration Framework (CT Framework)* is a self-assessment and planning tool for educators that serves three essential goals: (1) to identify and describe core elements that will affect CT integration across school curricula; (2) to help determine a school's readiness, diagnosing strengths and challenges to integrate CT across multiple grades and subjects; and (3) to guide schools in setting goals for CT integration and determine indicators of progress toward those goals. We describe the results of two successive mixed-methods research studies that field-tested the *CT Framework* and its companion self-assessment tool, documenting the pathways toward schoolwide CT integration and professional development (PD) experiences of eight elementary schools located in both rural and urban school districts in four states in the United States of America. Based on the studies' findings, we reflect on the ways in which the *CT Framework* proved to be a useful tool for the researchers and practitioners who participated in the projects. Specifically, we found it helped researchers to understand the different elements each school prioritized as their initial areas of focus and how each school expanded their efforts over time. When triangulated with additional survey and interview data, the information collected by using the *CT Framework* provided the project team with a structure for learning about the approaches each school took and understanding the similarities and differences that emerged among the schools in their approaches toward schoolwide CT integration. The *CT Framework* also proved to be very useful in guiding schools' implementation efforts, as it helped school leaders clearly define the vision for schoolwide CT integration and identify and prioritize goals to ensure progress toward the school's vision for CT integration.

Keywords: *Computational thinking, education, professional development, equality in education*

1 INTRODUCTION

Computational thinking (CT) is broadly defined as a set of concepts and practices that draws on computer science (CS) principles for problem framing and solving, involves computational devices, and is applicable to many different disciplines ([1], [2]). It is also described as a creative activity, with the ability "to use abstraction, automation, and analysis to create original products" using technology ([3]). Currently, computing education and CT are globally recognized as being critical in helping to narrow education and workforce gaps. Having a foundational knowledge of how computers work will benefit the daily life of all 21st century learners ([4]). Furthermore, preparing underrepresented young people to use CT to work through problems and generate solutions in multiple domains is likely to have significant benefits for cultivating a diverse future-ready STEM workforce. There is growing recognition for the need to expand CS and CT learning opportunities for students in grades pre-K–12, which include not just access to digital devices, but also providing students with repeated opportunities to engage in activities that require the reasoning and problem-solving skills needed for creatively using computer programs or for engaging in the critical-thinking purposes that are foundational to CT, such as self-expression, analysis, and problem-solving ([5]). For these reasons, students must be presented with opportunities to learn and practice CT regularly throughout pre-K–12 education ([6], [7]).

The goal of CT integration generally is to help students extend the problem-solving practices and creative activities associated with computing into other subjects. It promotes the transfer of learning via authentic experiences, with the result being that CT and CS are not learned in isolation from other subjects. Current research indicates that the application of CT improves students' facility with problem-solving and understanding concepts in math and science ([8], [9]). Integration is also a way to make CT

more accessible to a wider range of youth because it enables them to connect it with other personally meaningful topics and disciplines.

Despite the rapid global expansion of CS- and CT-focused initiatives, there is relatively little evidence-based practical guidance and there are few actionable tools to support schools and individual teachers in effectively integrating CT into multi-subject teaching and learning. Schoolwide CT integration entails a coordinated effort to develop students' CT competencies beyond stand-alone technology or computer science classes, and it also involves a sustained and intentional effort to develop learners' CT competencies across subject areas. Integration occurs through the ongoing coordination among school leaders, teachers, and other stakeholders and includes the alignment of curriculum programming, teacher professional development (PD) opportunities, teacher practices, and assessment routines. In addition, integration implies that students have repeated opportunities to apply CT across multiple content areas.

To address the need for schoolwide CT integration, the *CT Framework* ([10]) was developed across two successive research studies. Study 1 was conducted between 2019 and 2021; Study 2 began in 2022 and is currently in its final year (2024). Study 1 utilized an iterative and collaborative process with school administrators and staff, CS/CT PD providers, and experts in CS education to define key determinants for schoolwide CT integration and to study the way in which the *CT Framework* supports educators in developing and implementing pathways for achieving schoolwide integration. Study 1 aimed to answer the following research questions:

1. What resources do school administrators and teachers in schools with large populations of underserved students say they need to help determine whether they are prepared to integrate CT into the curriculum?
2. What features of a framework, self-diagnostic tool, and rubric will be most useful for helping school administrators, teachers, and evaluators identify strengths, weaknesses, and areas for improvement with respect to CT integration? How do those features differ among user groups? What formats of the resources are most useful for each user group?
3. Which "indicators of CT readiness" are most recognizable, germane, and valued by each user group (administrators, teachers, and evaluators), and why? What differences exist, if any, in terms of how each user group defines the indicators and judges their importance?
4. Is there preliminary evidence that the use of the refined framework, self-diagnostic tool, and rubric is associated with the successful integration of CT across elementary curricula, based on self-assessments and observations of implementation?

Analysis from data in Study 1 resulted in the final version of the *CT Framework*, which postulates six focus areas: (1) teacher knowledge and pedagogical knowledge, (2) teacher supports, (3) curriculum features and lesson/unit planning, (4) CT assessment, (5) student outcomes, and (6) families and the school community. Each focus area is further defined by specific elements (indicators) that have been found to influence effective CT integration efforts and to focus on the larger ecosystem within the school, reaching all teachers in all grades and content areas, increasing access for all students, and reducing the disparities that can be caused by students opting in or out of CS ([11], [12]). The companion self-assessment tool specifies indicators for each element within a focus area (Fig. 1); provides examples of what the indicator might look like when implemented; and includes reflection questions to guide educators in assessing their school's priorities, strengths, and challenges, along with a four-point rubric (ranging from "not a priority" to "achieving") for users to indicate the extent to which they meet each indicator.

Element A1. Teacher definition of CT and CT integration across the curriculum					
Description	Examples of what it might look like when implemented effectively in your classroom	This is not a priority at the moment (1)	Beginning (2)	Approaching (3)	Achieving (4)
Teachers conceptualize CT integration across the curriculum as the teaching and learning of computational thinking within the scope and sequence of major elementary content areas such that learners have repeated opportunities within and across grades to use CT for problem solving with or alongside other subject-specific practices to achieve standards or common objectives.	<ul style="list-style-type: none">I have my own well-articulated definition for CT integration across the curriculum that is aligned with my school and district's definition and I can articulate it clearly and consistently when asked about it.When my vision or definition of CT integration diverges from those of the administration or my school district, I am able to explain why.There is a definition I can refer to for guidance on affecting or modifying CT-integrated instruction and for analyzing student progress and learning outcomes.				

Figure 1. Excerpt from the CT Framework. The CT Framework is composed of six categories; each category has correlating elements and a self-assessment rubric that help to guide the prioritization of goals.

Study 2 field-tested the *CT Framework* with the goal of investigating its promise for helping schools create schoolwide CT integration plans and provide equitable access to CT education for students from traditionally underrepresented groups in CS. The research questions investigated in Study 2 are as follows:

1. How does the *CT Integration Framework* and self-assessment tool facilitate the CT integration planning process?
2. What additional tools and resources are needed in order to help schools with the CT integration planning process and in enacting their plan?
3. How do teachers implement their school's CT integration plan across different grades and subjects and for diverse students, and what structures does the school put in place to support scalability and sustainability within the school?
4. What is the impact of the CT planning process and PD on school leaders' and teachers' understanding of schoolwide CT integration and strategies for providing equitable access to CT education to all students (including girls, those from low-income families and those from underrepresented racial and ethnic groups, ELLs, and students with disabilities)?
5. To what extent does the implementation of the CT integration planning process result in students' increased access to and participation in high-quality CT instruction, especially for girls, those from low-income families, those from underrepresented racial and ethnic minority groups, ELLs, and students with disabilities?
6. To what extent does the implementation of the CT integration planning process result in the development of students' CT knowledge, skills, and interests? How are the schools measuring the impact of CT integration on students' CT knowledge and skills, and what are the results?

The purpose of this paper is to present a synthesis of our findings to date—including the impacts and potential challenges to schoolwide CT integration—and to discuss the similarities and differences in pathways in which schools utilized the *CT Integration Framework*.

2 METHODOLOGY

2.1 Study 1 overview

During the first year, the project team enlisted 16 experts in CS and CT education, including researchers, school leaders, PD providers, and teachers, to conduct reviews of the *CT Framework*. These expert reviews helped to establish the construct validity of our framework. The project team then conducted a small pilot study in collaboration with three elementary schools, one located in New York City, New York, and two located in Chicago, Illinois, to explore educators' use of the self-assessment tool. Teams of educators from participating schools found the self-assessment tool to be useful and were able to utilize it successfully to guide their schoolwide CT integration planning and implementation efforts ([10]). The pilot study helped us to establish the feasibility of using the self-assessment tool in school settings. Feedback from the participants in the expert reviews and from educators participating in the pilot study was used to refine the *CT Framework* and the self-assessment tool.

2.1.2 Study 1 Professional Development Model and Sample

Due to the ongoing cycle of school closures and shifts among in-person, hybrid, and virtual instruction as a result of the COVID-19 pandemic, the project team conducted the pilot study in two phases. Phase 1 began in 2020 with planning conversations with two principals from two schools in Chicago, followed by the implementation of a full-day joint CT integration planning workshop for both schools. During this workshop, the project team led the two schools through the process of introducing CT concepts; unpacking elements within the *CT Framework*; completing the self-assessment; and identifying each school's short-, mid-, and long-term goals. The workshop was attended by two teams of teachers (one team from each school), which included a total of two administrators, eight teachers, and one K–8 curriculum and bilingual coordinator. In fall 2020, the project team recruited one additional school in New York City, to participate in the pilot study. Research with this school commenced by hosting two planning workshops with seven science teachers from the school. However, the continued disruptions to school instruction due to fluctuations in the COVID-19 cases prohibited the research team from conducting any research activities before the end of the 2020–2021 school year, thus the project team extended the pilot study to the fall of 2021 (Phase 2). The project team hosted a *CT Framework* refresher

workshop in fall 2021 with the New York City school, which included three of the seven participating teachers from the prior year and one administrator.

Table 1. Study 1 included a total of 18 educators from three schools.

State	School	Grade Levels	Number of Participants	Number of PD Sessions	Duration of PD Session
NY	School A	2–5	7	2	1 hour
Illinois	School B	Pre-K–8	5	1	6 hours
	School C	Pre-K–8	6	1	6 hours

2.1.2 Study 1 Data Collection Methods

Data collection activities in Phase 1 were conducted with a total of 12 teachers and four administrators, whereas data collection activities in Phase 2 were conducted with a total of six teachers and four administrators. During Phase 1 and Phase 2 of the pilot study, teachers completed lesson logs and participated in an interview where they described the content focus of lessons, the manner in which they implemented lessons, and any specific pedagogical strategies they used during implementation. The interview also elicited feedback on how they used the self-assessment tool throughout the study period. Participating teachers also completed a pre- and post-survey, which asked about the perceived challenges and supports in relation to their efforts toward schoolwide integration, their level of comfort with integrating CT into their classroom, and their understanding of CT.

2.2 Study 2 overview

Building on the prior study ([13]), this project field-tested the *CT Framework* and self-assessment tool as a way to understand how the use of this tool can support schools in creating pathways for sustained schoolwide CT integration. Analysis of data in this study focused on the usage of the *CT Framework* and on the specific elements that were identified as more pressing short-term goals that were necessary for building the foundation for integration efforts.

2.2.1 Study 2 Professional Development Model and Sample

Study 2 was designed to engage participants in a series of PD sessions. These sessions focused more methodically on the process of completing the self-assessment and on identifying the elements that were priority areas for starting integration efforts. To do this, the PD team (an external CS/CT PD provider and one project member) hosted a kick-off meeting with an administrator from each school, during which a cycle of PD workshops was scheduled and the administrations' vision for what schoolwide integration looked like was established. The PD team developed a timeline and process for addressing each of the six categories in the framework and met with the teacher teams from each school multiple times over the course of an academic year. Each PD session was structured to achieve the following goals: (1) introduce, define, and deepen pedagogical content knowledge of CT concepts; (2) introduce and elaborate on one category in the *CT Framework* and do a deep-dive into each of its corresponding elements; (3) lead participants through the self-assessment process of the focal category and identify the elements that they believed were key to address in order to achieve their vision for integration; and finally, (4) focus specifically on providing examples of the critical aspects within each of the element(s) the school identified. In addition, the team curated a set of resources, including lesson plan examples, content-specific plugged and unplugged CT-integrated activities, and informal assessment tools that were relevant to a number of the different elements in the framework.

Study 2 recruited participants from five schools located across three states, for a total of 23 participants. School A was located in New York City and participated in Years 1 and 2 of the study. School A participants in Year 1 included the school's specials' team (i.e., art, music, and technology teachers), who all taught multiple classes and grade levels, thus interacting with all students (including English language learners [ELLs] and students with special needs). In Year 2, this school extended their efforts by delegating a second cohort of educators to attend the PD sessions, which consisted of four instructional coaches and one science teacher from Year 1. The PD team also met with school administrators three times over the course of Year 1 to review progress, receive their input, and revise future plans.

School B was located in rural Georgia and participated in Year 2 only. School B participants included all of the school's social studies and science teachers and one K–8 media teacher. Finally, schools C, D, and E were located within the same district in eastern Maryland. Each school had the media teacher/librarian participate, who was responsible for teaching all students in all grade levels.

Table 2. Study 2 included 24 teachers from five schools.

State	School	Grade Levels	Number of Participants	Number of PD Sessions	Duration of PD Sessions
NY	School A	K–5	Year 1: 6 Year 2: 5	Year 1: 14 Year 2: 7	40 minutes
Georgia	School B	K–5	9	6	1 hour
Maryland	School C	Pre-K–5	1	9	1 hour
	School D	Pre-K–5	1	9	1 hour
	School E	Pre-K–5	1	9	1 hour

2.2.1 Study 2 Data Collection Methods

Participating teachers were asked to complete baseline and year-end surveys to gauge frequency of CT integration; related knowledge, beliefs, and confidence; and the barriers and supports to implementing CT across grades and subjects. Participating teachers also engaged in an end-of-year focus group to share their experiences using the self-assessment tool, implementation successes and challenges, and additional resources needed to support CT integration efforts to ensure equitable access to all students. Finally, the science and technology teachers distributed a student assessment to their classes, which measured students' interest, engagement, and self-efficacy in CT.

3 RESULTS

Below we synthesize findings that emerged from both studies, focusing on four themes (1) the ways in which schools used the *CT Framework* as a planning tool (2), the pathways that schools chose to schoolwide CT-integration, (3) key factors that influenced the CT integration efforts, and (4) emergent student outcomes.

3.1 Usage analysis of the *CT Framework* as a planning tool for developing pathways toward schoolwide integration

A primary focus of both studies was to gain an understanding as to how schools were utilizing the *CT Framework* as a planning tool to help determine their vision and for setting goals intended to support their efforts toward schoolwide integration. To do this, both projects led schools in unpacking each of the elements in the *CT Framework* and through the self-assessment process. However, the studies differed in their approach for studying the ways in which educators utilized the framework. Study 1 focused on analyzing the frequency that educators utilized the framework and for what purpose, whereas Study 2 focused on analyzing which elements were identified as immediate-, mid-, and long-term goals necessary for determining their pathway toward integration efforts.

3.2.1 Study 1: Frequency and Purpose for Using the CT Framework

In Study 1, the research team documented how often and in what ways participants utilized the *CT Framework* and self-assessment tool to help guide their efforts. The research team specifically sought to learn the frequency in which educators referenced the framework on their own during the project period and for what purpose. In interviews, five out of six teachers and three out of four administrators said that they referenced the self-assessment tool at least twice over the three-month pilot period, whereas one teacher and one administrator said that they did not use the tool at all. The most common purpose for using the self-assessment tool was to check on their progress in relation to the goals that

were set at the initial planning workshop. When asked which specific categories within the self-assessment tool were used most often, participants reported using *Section A: Teacher Knowledge, Pedagogical Content Knowledge, and Facility with Tools to Support Student learning* most frequently, followed by *Section C: Curriculum Features and Lesson Planning*, and *Section E: Student Outcomes*.

Teachers described using the self-assessment tool as a means to help with planning lessons and as a reflective tool to think about the areas in which they could continue to grow their and their students' knowledge of CT. One administrator also described referencing the self-assessment tool throughout the project period to make sure that students were being made aware of why they were learning about CT and how this knowledge will affect them in the long run.

3.2.2 *Study 2: Identifying Key Elements within the CT Framework Necessary for Initiating Integration Efforts*

In Study 2, the project focused on documenting each school's process and pathway. Each school developed a plan for their integration efforts by completing the self-assessment and identifying one or two elements that they felt (1) they lacked expertise in or had necessary support in place and (2) were most critical in terms of making progress early on as a way for setting the foundation for sustaining long-term efforts.

As described above, Schools C, D, and E initiated their efforts by focusing on element *A1 (Teacher definition of CT and CT integration across the curriculum)* and developing a shared definition of CT that would be used as the foundation for district-wide integration efforts in the future. Once the definition was solidified, they were then able to move swiftly through addressing subsequent elements. Conversely, Schools A and B struggled early on to make progress in their integration efforts. School A teachers rated themselves as *Approaching* during the initial self-assessment for element *A1 (Teacher definition of CT and CT integration across the curriculum)*; however, there was inconsistency in how the participants were defining CT concepts. Participating teachers in School A stated that it was necessary for them to develop a shared understanding of the role CT will play in their curriculum, and that in order to successfully integrate CT systematically across all classes, they needed to agree upon the specific CT concepts and approaches that will be the foundation for their work. In early PD sessions, teachers expressed frustration around not having a shared definition of CT and that they did not focus on the same CT concepts and practices. They shared that this led to them feeling as if they were working independently and not toward the same goal. They also felt that while there might be teachers who introduced CT as a part of their curriculum before participating in the project, it was sporadic and not in a coordinated way. Due to this challenge, PD focused largely on element *A1 (Teacher definition of CT and CT integration across the curriculum)*. The PD sessions exposed teachers to a variety of resources that operationalized CT concepts and led them through the process of creating CT anchor charts that included different examples of each CT concept. Through this work, participants in School A agreed upon four specific concepts that they would focus on integrating into their lessons by the end of the year: decomposition, abstraction, pattern recognition, and algorithm/debugging.

In the end-of-year reflection interviews, teachers expressed that a successful outcome of their work was that they solidified a definition of CT that was to be used schoolwide, and all teachers applied CT vocabulary consistently across their classes. *"I do computational thinking, but it was always just like here and once we moved on, the kids were not practicing or hearing it in other places. Most of them don't always carry that over, so for me, I was happy to see that at least this year within us we're using that vocabulary and that they're hearing it more across all the other classes and not just with me."* — Teacher

By contrast, when teachers at School B began their integration efforts, they rated themselves as *Beginning* during the initial self-assessment for element *A1 (Teacher definition of CT and CT integration across the curriculum)*. Yet, during PD sessions, they expressed that they felt as though they had a clear definition of CT that was jointly agreed upon, which resulted in them wanting to move quickly through sections A and B of the *CT Framework* and prioritize developing CT-integrated lesson plans as their primary focus. However, the teachers became frustrated during CT-integrated lesson planning exercises because their definition of CT was inconsistent with their understanding of how to operationalize CT concepts in lessons. While the teachers were able to define CT as a vocabulary term, they were challenged with how to lead students through opportunities to utilize CT as a metacognitive strategy that can extend from unplugged to plugged work. Additionally, they had limited exposure with integrating CT into content-area lessons using plugged or technology-driven activities, which increased their hesitation in making the transition from using unplugged, paper-based coding activities to developing plugged lessons. This situation delayed their implementation of CT-integrated lessons, and

PD sessions shifted to focus on elements A2 (*Teacher content knowledge of CT concepts, practices, and perspectives*) and A4 (*Teacher pedagogical content knowledge for integrating CT in multiple subjects (ELA, math, etc.)*).

3.2 Documenting the unique pathways to schoolwide integration

Each school that participated in either Study 1 or Study 2 were treated as a distinct case, meaning that while the PD structure was consistent for all schools within each study, individual schools had autonomy in determining a small team of teachers, the specific grade levels, and the content areas in which the integration efforts would begin. During the self-assessment process in both studies, each school identified the elements that they would prioritize as key starting points for undertaking their integration efforts. When comparing the starting places across all eight schools in both studies, element A1 (*Teacher definition of CT and CT integration across the curriculum*) was consistently selected as a key starting task. While many of the participants might have had prior exposure to CT, teachers expressed that it was necessary for them to develop a shared understanding of how CT concepts were to be operationalized within their curriculum in order to successfully integrate CT systematically across all classes.

Table 3. Each school focused on specific elements during their first year of integration efforts to help create a foundation for sustaining their efforts long term.

	School	Grade Levels	Starting Content Areas	CT Element(s) Prioritized as Immediate Goals
Study 1	School A	2–5	Science	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>
	School B	Pre-K–8	CS/All subjects	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>
	School C	Pre-K–8	CS/All subjects	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>
Study 2	School A	K–5	Art, gym, social studies (School included instructional coaches in Year 2.)	<i>Element A1 Definition of CT</i> <i>Element B2 Schoolwide vision of CT integration</i> <i>Element A4 Teacher PCK in multiple content areas</i>
	School B	K–5	Science, social studies, media	<i>Element A1 Definition of CT</i> <i>Element A4 Teacher PCK in multiple content areas</i> <i>Element C1 Developing CT lesson plans</i>
	School C	Pre-K–5	Media, library	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>
	School D	Pre-K–5	Media, library	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>
	School E	Pre-K–5	Media, library	<i>Element A1 Definition of CT</i> <i>Element C1 Developing CT lesson plans</i>

Furthermore, schools varied as to how they planned to achieve schoolwide integration. School A in Study 1 and all schools in Study 2 initiated efforts by focusing on one content area across all grade levels, whereas schools B and C from Study 1 included teachers that represented a variety of grade levels and content areas. This analysis shows that most schools approached achieving schoolwide integration by not explicitly focusing on the school as a whole, but instead on building the capacity of teachers within one or two content areas that touched all students within the school.

3.3 Key factors that impacted integration efforts

Interviews and surveys with participants in both studies provided insight into key factors that hindered or supported integration efforts. Participants completed pre- and post-surveys to rate a range of items as to whether they presented no challenges, challenges to a small extent, challenges to a moderate extent, or challenges to a great extent. The items included examples of common barriers to integration efforts, such as lack of materials, lack of instructional time, lack of administrator support, competing priorities, lack of student interest, lack of teacher content expertise, lack of pedagogical expertise, lack of hardware or software, and lack of Internet access. Participants were further asked to elaborate on those challenges during interviews and focus groups.

3.3.1 Lack of Time during the School Day

Teachers in both Studies 1 and 2 identified lack of time within the school day as a major challenge when undertaking CT integration. In a survey, 11 out of 18 participants from Study 1 and 19 out of 23 participants from Study 2 stated that lack of time during the school day presented a some challenge to engaging in integration efforts, which was further explained by a teacher in the focus group: *“I think a lot of it has to do with we only see the kids once or twice a week, you’re trying to squeeze everything in a 45 minute block and you’re running out of time, you have to pick and choose which pieces are the most important and you still have to get through your own curriculum that’s already been planned out, so it’s just very difficult to squeeze it in.”*—Teacher

3.3.2 Administrators Need to Take an Active Role Setting the Vision and Definition of CT to Support Schoolwide CT Efforts.

In both studies, we also found that the level of support from administrators was a key factor in initiating and supporting schools’ CT integration efforts. In Study 1, all participating teachers indicated in survey responses that they felt their administrator(s) would support CT integration efforts to a great extent. This point was further accentuated throughout the project period by the amount of PD and planning sessions attended by administrators. During PD and planning sessions, administrators were present and took an active role in working through the self-assessment, collaborating with the participating teachers in setting the definition and the vision, and determining the specific elements of the CT framework to focus their immediate efforts on. Additionally, during post-interviews, administrators indicated that they referred to the *CT Framework* at least twice during the project period to monitor their progress. However, in Study 2, administrators took less of a hands-on approach. In the pre-survey from Study 2, 14 out of 20 responding teachers indicated that the lack of administrator support would present some challenge in integration efforts. While administrators were explicitly supportive of efforts and provided teachers with time to attend PD, none of the administrators from the five schools attended PD sessions. Additionally, School A participants stated in the focus group that they felt as though they made significant progress in the beginning of the school year, but then got to a place where they were unable to move forward because they needed administrative input as to the administration’s definition of CT, as well as the main CT concepts and practices the administration wanted to see embedded into lesson plans to be able to move forward. *“We were...kind of stuck in a certain spot where we needed the administration’s collaboration to open the door to the next stage and that never happened... It seemed like we did a lot of the front loading of it and then we’re kind of continuing to kind of chug with that certain approach, but we were just kind of spinning wheels towards the end where we were supposed to figure out a bigger picture for the building to continue.”*—Teacher

3.4 Emergent student outcomes in cross-curricular work in Study 2

The potential impact on students of utilizing the *CT Framework* and integrating CT was not measured in Study 1. In Study 2, the project team asked participants during the focus groups to reflect on any successes or positive impacts from utilizing the framework. The participating teachers from School A in Study 2 noted that after engaging with the framework as a structure for developing a cohesive definition of CT and identifying the specific CT concepts and practices the school will focus on, they heard students in different content-area classes make cross-curricular references to how they were applying CT as a problem-solving strategy in their other classes. *“We noticed there were moments within the specialist group that students would actually go, ‘Oh I remember this in art. I remember this in technology,’ and the terms are starting to become more organic and understood. So, I feel like that was a really great approach to introduce this as a tool you use anywhere; it’s problem-solving”*—Teacher. As described above, a large part of School A’s PD focused on supporting the teachers in developing a shared definition of CT, including solidifying the specific CT concepts and practices they would jointly

focus on integrating within their curriculum. Because CT was utilized as a problem-solving process in a unified way across multiple classes, students were able to make connections across different content-area work. These teachers stated that introducing CT as a problem-solving process to their students in each of their own classes laid the foundation for students to appropriately make cross-curricular connections by referencing instances of using CT in work they did in another class.

4 CONCLUSION

This synthesis of findings from two studies describes how eight elementary schools utilized the *CT Framework* and its companion self-assessment tool to create and implement schoolwide CT integration plans for the purpose of broadening the participation of traditionally underrepresented groups in CS education. The findings of these two studies demonstrate a systematic look at the planning processes elementary schools engage in to support their efforts to integrate CT across multiple subjects and grade levels. Each study presented a lens into the different pathways schools took when engaging in CT integration efforts, and brought to the surface key elements identified in the *CT Framework* that were needed to be addressed to initiate their work. During Study 1, teachers and administrators utilized the framework and companion self-assessment tool as a structure for collaboratively setting their vision and goals, and then referred to the document several times individually over the remaining project period. In study two, teachers also utilize the framework and companion self-assessment tool collaboratively to help set their goals, but referred to the framework jointly during PD sessions to review progress. In both studies, schools initiated the work by either developing a shared definition of CT or solidifying their understanding of CT concepts operationalized within a specific content area. This finding points to the need for schools to ground the work in a common understanding of CT. Additionally, all participating schools in both studies developed an approach for integrating CT that did not exclude any individual type of learner from participating in a CT and CS learning experience. Schools opted to develop integration plans that included either integrating CT within all contents in an entire grade level or integrating CT across one or two content areas within the entire school. Finally, in both studies we found that schools ran into common barriers in their efforts to integrate CT schoolwide, including a lack of time to integrate CT into the curriculum, and a lack of administrator support to guide the work. These studies provide an initial understanding of the potential use of the *CT Framework* as a tool to support schools in providing greater access to CT education for all students. Future work should further explore the conditions that support and hinder efforts to integrate CT schoolwide, and its impact on students' learning.

ACKNOWLEDGEMENTS

The *CT Integration Framework* has been developed through generous funding by the National Science Foundation, awards #1838523 and #2219314. Any opinions, findings, and conclusions or recommendations expressed in these materials are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

- [1] J. Wing, "Computational thinking," *Communications of the ACM*, vol. 49, no. 3, pp. 33–35, 2006.
- [2] A. Yadav, H. Hong, and C. Stephenson, "Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K–12 classrooms," *TechTrends* vol. 60, no. 6, pp 565–568, 2016.
- [3] I. Lee, F. Martin, J. Denner, B. Coulter, W. Allan, J. Erickson, J. Malyn-Smith, and L. Werner, "Computational thinking for youth in practice," *ACM Inroads*, vol. 2, no. 1, pp. 32–37, 2011.
- [4] E. Vegas, M. Hansen, & B. Fowler, "Building skills for life" *How to expand and improve computer science education around the world*. 2021.
- [5] K. Mills, M. Coenraad, P. Ruiz, Q. Burke, and J. Weisgrau, *Computational thinking for an inclusive world: A resource for educators to learn and lead*, Washington, D.C.: Digital Promise, 2021.

- [6] V. Barr, and C. Stephenson, "Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community?," *ACM Inroads*, vol. 2, no. 1, pp. 48–54, 2011.
- [7] J. Malyn-Smith, D. Blustein, S. Pillai, C. E. Parker, E. Gutowski, and A. J. Diamanti, *Building the foundational skills needed for success in work at the human-technology frontier*, Waltham, MA: Education Development Center, 2017.
- [8] L. A. Calao, J. Moreno-León, H. E. Correa, and G. Robles, "Developing mathematical thinking with Scratch" in *Design for teaching and learning in a networked world* (C. Gráinne, K. Tomaz, R. Christoph, K. Johannes, & E. Lavoué, eds.), pp. 17–27, Switzerland: Springer, Cham, 2015.
- [9] S. Grover, and R. Pea, "Computational thinking in K–12: A review of the state of the field," *Educational Researcher*, vol. 42, no. 1, pp. 38–43, 2013.
- [10] H. Sherwood, C. Fancsali, M. Israel, J. Diamond, and B. Moeller. *Framework for effective computational thinking integration in elementary (K–5) schools*. New York, NY: Education Development Center, EDC Center for Children and Technology, 2020.
- [11] K. Jona, U. Wilensky, L. Trouille, M.S. Horn, K. Orton, D. Weintrop, and E. Beheshti, "Embedding computational thinking in science, technology, engineering, and math (CT-STEM)," in *Future directions in computer science education summit meeting*, Orlando, FL: 2014.
- [12] K. Orton, D. Weintrop, E. Beheshti, M. Horn, K. Jona, and U. Wilensky, "Bringing computational thinking into high school mathematics and science classrooms" Singapore: International Society of the Learning Sciences, 2016.
- [13] H. Sherwood, W. Yan, R. Liu, W. Martin, A. Adair, C. Fancsali, E. Rivera-Cash, M. Pierce, and M. Israel, "Diverse approaches to school-wide computational thinking integration at the elementary grades: A cross-case analysis," in *Proceedings of the 52nd ACM technical symposium on computer science education (SIGCSE '21)*, New York, NY: ACM, 2021.