Executive Summary

Integrating Computer Science and Computational Thinking into Elementary Science: Lessons Learned from the Maker Partnership

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The perspective that computing and computational thinking (CT) are necessary competencies for the 21st century is increasingly pervasive (NASEM, 2021). Computational concepts and methods—problem solving, designing systems, refining the steps in a process, and tinkering toward creative solutions—are relevant in nearly every discipline, profession, and industry (Grover & Pea, 2018). As a result, there has been a push to increase access to and participation in computer science (CS) instruction throughout the K-12 curriculum, with widespread efforts to integrate CS/CT across subject areas (Barr & Stephenson, 2011; Grover & Pea, 2018). However, evidence suggests that teachers often lack the capacity to provide students with high-quality learning experiences that integrate CS and CT into their courses (Goode, Margolis, & Chapman, 2014; Gallup, 2015). Further, there is a lack of research on the training and support that teachers need to play this role effectively (Cooper et. al., 2016; NASEM, 2011; Yadav, Stephenson & Hong, 2017).

To address these problems, the Research Alliance for New York City Schools, MakerState, and Schools That Can established a research-practice partnership called the Maker Partnership Program (MPP). Beginning in 2016, MPP developed and tested a model for building individual teacher capacity to integrate CS/CT into elementary science classes using Maker pedagogy. The Maker approach is based on the principles and practices of the engineering design process—an iterative cycle consisting of defining a problem; researching, planning, prototyping and testing solutions; and refining the solution (NRC, 2012). The hands-on, interdisciplinary nature of Maker activities makes them promising for integrating CS/CT into science content and broadening CS participation of those who have historically been underrepresented (Bevan, 2017; Castek et al. 2019; Halverson & Sheridan, 2014).

The following pages highlight key findings from MPP. Drawing on multiple data sources, our study produced lessons about building teachers' capacity to integrate CS/CT into science through Maker pedagogy, the facilitators and challenges to integrating CS/CT into science instruction, and students' experiences in such learning environments. Below, we briefly describe these lessons and share related recommendations for professional development (PD) providers, school leaders, and teachers who are interested in engaging in similar work. The insights and recommendations we highlight emerged from the collective sense-making of the research findings that we engaged in through our research-practice partnership.
What We Learned About Building Teachers’ Capacity to Integrate CS/CT into Science

Developing the Capacity of Novice Teachers to Integrate CS/CT

Most MPP teachers integrated lessons by asking students to use Scratch—a block-based programming language—to create a simulation or model of a natural phenomenon (such as the water cycle, energy conversions, or the movement of the earth and sun), which demonstrated students’ understanding of the phenomena they were studying. Teachers may need additional PD and support to make use of more sophisticated CS skills and tools. (This might include, for example, modeling complex phenomena, or using CS to analyze, organize, and display data.)

Nonetheless, teachers with little or no prior experience in CS were able to learn CT concepts and basic to intermediate Scratch programming, and feel comfortable implementing what they learned into their instructional practices, within a fairly short period of time (i.e., over the course of two school years). Notably, we found that teachers needed some facility, but not advanced Scratch skills, to use it as a tool for integrating CS/CT into their science lessons. This bodes well for efforts that are attempting to integrate CS/CT for elementary students at a large scale.

Types of PD and Support That Were Most Helpful

Teachers benefited from sustained engagement in PD, with sessions spread throughout the year. This allowed them to learn new concepts, approaches, and skills in a session, try them out with their students, and then come together again to review their successes and challenges and get more feedback and support. It also allowed teachers to provide formative feedback to our practice partners, which helped improve the PD and support being provided.

Teachers found a number of characteristics of the in-person PD to be particularly effective. These included hands-on learning (e.g., teachers learned CS/CT concepts and skills by creating their own Scratch programs), modeling of lessons and pedagogical approaches, experiencing the lessons as students would, guided practice in using new CS/CT skills, and time for planning and collaboration with other teachers.

MPP coaches provided “wraparound” supports (such as site visits to conduct classroom observations, provide feedback, and meet with teachers and school leaders; emails; and conference calls), which supplemented the knowledge and skills that teachers learned during PD sessions. We found that these activities enhanced coaches’ understanding of the contexts in which teachers were working, making it possible to provide better, more customized support.
What We Learned About Integrating CS/CT into Science Through Maker Pedagogy

Factors That Affected Implementation

There is no “one size fits all” model for who should be responsible for integrating CS/CT into elementary level science (core teachers, science teachers, CS/tech teachers), or where it should occur (in a science class or in a CS/tech class). Rather, integration can occur in a variety of ways and must reflect the specific context, resources, and needs of the school.

Providing resources and materials (e.g., lesson plans and units, model projects and skill-building videos for students, student assessment rubrics) helped teachers integrate CS/CT into science instruction and saved them time and effort. However, even with access to high-quality resources, teachers needed to modify or adapt most lessons to differentiate supports and align activities with the specific science topics they planned to teach.

Teachers benefited from structured time for this work during MPP PD sessions—as well as the guidance and support of MPP coaches and teacher colleagues.

Significant logistical issues related to schools’ technology infrastructures (e.g., hardware and internet access, setting up Scratch accounts and getting students logged in, etc.) had to be addressed for successful integration of CS/CT into science. Teachers benefitted from specific support and assistance troubleshooting and establishing routines and procedures to mitigate these issues.

Teachers valued opportunities to collaborate with peers to design lessons, share pedagogical and instructional practices, provide and receive feedback, troubleshoot, and share materials and resources. Working in a school that has an overall vision for CS/CT and concurrent CS/CT efforts (e.g., the districtwide CS4All initiative) seemed to support implementation of MPP by creating an environment where teachers have a community of peers with whom they can share resources and collaborate.

Non-science teachers in particular (e.g., CS or technology cluster teachers) benefitted from collaborating with science teachers to support integration. MPP’s PD and supports focused on building skills and knowledge about CS/CT, Maker pedagogy, and integration across disciplines. It presumed that teachers had science content expertise and experience teaching science. However, this was not always the case. Non-science teachers addressed this gap by working closely with colleagues who could provide guidance on the science content.

Engaging school leaders in MPP was challenging and time consuming, but proved to be an essential element in successful implementation and sustainability. School leaders are in a position to support teachers in overcoming common barriers, such as facilitating class scheduling to allow for integration of CS/CT, carving out planning time with other teachers integrating CS/CT, allowing teachers release time so they can attend PD, and ensuring that teachers have access to adequate internet, hardware, software, and other needed resources.

The Value-Add of a Maker Approach

Using a Maker approach provided teachers with a common language and consistent framework for planning and delivering instruction that facilitated student engagement,
creativity, collaboration, persistence, reflection, and independence. This framework helped teachers’ shift their pedagogical approach from instructors transferring knowledge and skill to facilitators of learning. Structuring lessons around the Design Cycle (described below) allowed students to practice the steps that scientists take in exploring natural phenomena (e.g., gathering information and brainstorming solutions, creating prototypes or models of the solution, testing out and improving the design), and in doing so, facilitated the use of computational thinking. Finally, teachers found Maker pedagogy to be an effective approach for integrating CS/CT into science because it allows multiple entry points for students with a wide range of CS/CT skill levels.

Student Experiences

**Building CS/CT competencies.** Integrating CS/CT into science creates opportunities for students to build fundamental CS skills (e.g., how to create simple programs using motion, control, and event blocks). Similar to teachers, students were able to fairly quickly learn block-based programming, such as Scratch, through scaffolded and guided instruction. Peer collaboration (a key Maker pedagogy practice) seemed to facilitate students’ rapid uptake of coding skills and helped teachers address a wide range of CS abilities in their classes.

At the same time, MPP students spanned the spectrum in terms of CS skills, with many having little or no prior CS experience. This raises important questions about when and how to provide students with the support they need to learn the foundational CS skills that will allow them to use CS/CT to explore scientific phenomena. Science teachers may find it difficult to carve out time from already limited periods of instruction to build these core CS skills. Possible alternatives include collaborating with computer science or technology teachers to provide CS instruction to students, or making basic CS skills a prerequisite to an integrated class.

**Outcomes for students.** Teachers observed that MPP activities were engaging, encouraged and provided multiple opportunities for peer collaboration and feedback, and improved problem-solving skills, suggesting promising outcomes for students. Our ability to directly measure student learning and attitudes was hampered by the abrupt transition to remote learning as a result of the COVID-19 pandemic. Additional research is needed to fully understand if and how CS/CT integrated into science instruction through a Maker approach improves student learning in either content area.

Recommendations

Emerging from our research and the experience and insight of the MPP partners, we offer several recommendations for PD providers, school leaders and teachers interested in engaging in similar work.

**For PD Providers:**

- Collect quick turn-around data on teachers’ development of CS/CT skills and pedagogical practices so that PD sessions can better meet their needs.
• Supplement in-person PD with support between PD sessions (e.g., phone calls, emails) to address teachers’ specific needs and questions as they attempt to implement what they have learned.

• Provide teachers with high-quality lesson plans and resources that are aligned with the school’s science curriculum (and that they can easily modify); this is especially important when teachers have little or no prior experience with CS.

• Prepare teachers to address logistical challenges, such as getting students set up on equipment, logging into computers and Scratch, and storing and maintaining the equipment.

• To the extent possible, work with school leaders and teachers to schedule all PD sessions for the year before the school year starts. This helps leaders and teachers avoid conflicts and preserve the time needed to attend. In addition, consider a mix of shorter, more frequent sessions and online sessions that may be less burdensome for teachers to attend.

• Provide school leaders with guidance about how to support teachers’ development of integration and Maker practices. For example, coaches could conduct observations with school leaders and provide a rubric they can use to offer feedback to teachers.

For School Leaders:

• Facilitate scheduling, common planning time, and collaboration with other teachers, and address the infrastructure needs that are common barriers to integrating CS/CT into science. Teachers need these resources before and during the school year.

• Integration is inherently multidisciplinary. Consider including both science and CS/technology teachers from the start, in a collaborative effort to help make the best use of staff knowledge and resources and create a foundation for scaling within the school.

• Consider implementing efforts such as MPP with multiple teachers to facilitate collaboration and sharing of resources. Align and collaborate with other CS-related efforts in the building to foster a community of practice.

• Provide teachers with ample time to revise and adapt lessons and activities to address their specific contexts (e.g., to differentiate supports for students, accommodate special needs, and meet students where they are in terms of prior CS experience, and to align lessons with the school/district science curriculum).

• Provide teachers with opportunities to try out new pedagogical approaches and lessons in a lower-stakes environment (e.g., absent of high-stakes teacher evaluations), such as afterschool programs.

For Teachers:

• Use existing MPP lessons and lesson templates (available in the Resources section of this report) as a launch pad for adapting and developing your own integrated
lessons that take into consideration the needs, skills, and interests of your students and alignment to the classroom science curriculum.

- Anticipate and try to address logistical and technical issues (such as having equipment in the classroom, charged and ready to use; providing students laminated login instruction cards to assist with logging into computers and Scratch; testing internet connections and software). Avoid cutting into instructional time by tackling these issues before students arrive for class.

- Work with school leaders to schedule common planning periods or times to collaborate with other teachers to share support, information, and resources.

- Build in “unstructured” coding time to allow students who are ready to go farther in their explorations to do so, and to allow students to express their creativity. This also provides opportunities for teachers to work individually with students who need extra support.

- Use peer collaboration so that students can help each other learn (particularly programming skills). Peer collaboration helps students iterate and improve their own work and develop independence from the teacher, and allows the teacher more time to work one-on-one with students who can benefit from additional support.

**Next Steps**

Building on the lessons from MPP presented in this report, we aim to expand our research-practice partnership to address new problems of practice. Specifically, we are planning to design and test a schoolwide approach to sustainably integrating CS/CT. This work will address the pressing need for models that effectively engage underrepresented students in CS and will continue to inform efforts at CS/CT integration more broadly.

**MPP Publications and Resources**

In addition to this report, we have published two other papers on MPP. The first paper, “Making Science Relevant for the 21st Century: Early Lessons from a Research-Practice Partnership,” published as part of the FabLearn conference proceedings, describes early findings from Year 1 of project implementation. In a second paper, *Making Research Practice Partnerships Work: An Assessment of The Maker Partnership*, published as part of the Research in Equity and Sustained Participation in Engineering, Computing, and Technology (RESPECT) conference proceedings, we describe our assessment of the health of our RPP, and lessons learned.

Resources created for this project can be found on the MakerState website. We encourage others engaged in similar work to use these resources and adapt them as needed to support their practice.
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