“Making” Science Relevant for the 21st Century: Early Lessons from a Research-Practice Partnership

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ABSTRACT

The Maker Partnership Program (MPP) is an NSF-supported project that addresses the critical need for models of professional development (PD) and support that help elementary-level science teachers integrate computer science and computational thinking (CS and CT[1]) into their classroom practices. The MPP aims to foster integration of these disciplines through maker pedagogy and curriculum. The MPP was designed as a research-practice partnership that allows researchers and practitioners to collaborate and iteratively design, implement and test the PD and curriculum. This paper describes the key elements of the MPP and early findings from surveys of teachers and students participating in the program.

Our research focuses on learning how to develop teachers’ capacity to integrate CS and CT into elementary-level science instruction; understanding whether and how this integrated instruction promotes deeper student learning of science, CS and CT, as well as interest and engagement in these subjects; and exploring how the model may need to be adapted to fit local contexts.

Participating teachers reported gaining knowledge and confidence for implementing the maker curriculum through the PDs. They anticipated that the greatest implementation challenges would be lack of preparation time, inaccessible computer hardware, lack of administrative support, and a lack of CS knowledge. Student survey results show that most participants were interested in CS and science at the beginning of the program. Student responses to questions about their disposition toward collaboration and persistence suggest some room for growth. Student responses to questions about who does CS are consistent with prevalent gender stereotypes (e.g., boys are naturally better than girls at computer programming), particularly among boys.

KEYWORDS

Maker learning; Computer science integration; Maker research and evaluation; Research-practice partnerships

1. Background Literature and Project Rationale

Since President Obama’s launch of the Computer Science for All (CS for All) initiative in 2016, there has been a surge of activity to bring computer science learning to all students, with a particular focus on students who have been historically underrepresented in the CS field. However, evidence suggests that teachers often lack the capacity to provide students with high-quality learning experiences that integrate CS and CT into their curricula [4,5].

The goal of this project is to build knowledge about how to help teachers successfully integrate CS and CT into elementary grade science classes through maker pedagogy and curriculum and to understand if this instruction deepens student learning. Maker pedagogy emphasizes learning through student-centered inquiry, creating, and innovating. It 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 as necessary [13]. Recent literature indicates a great deal of enthusiasm for the potential of maker pedagogy to transform science education [7,8]. Further, the hands-on, interdisciplinary nature of maker activities makes it an ideal approach to integrating CS and CT into science content.

1.1 Barriers to Integrating CS into Science Instruction

It is widely acknowledged that to develop 21st century skills, students should be exposed to CS and CT throughout their K-12

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[1] For this project, we are using Barr and Stephenson’s definition of computational thinking: “An approach to solving problems in a way that can be implemented with a computer. Students become not merely tool users but tool builders. They use a set of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. CT is a problem solving methodology that can be automated and transferred and applied across subjects” (pg.51) [1].

career, with opportunities to apply CS and CT across subjects [1, 6, 9]. There are significant barriers to accomplishing this, however. First, schools struggle with competing demands and often do not prioritize CS and CT as part of their core programming. According to a national survey of principals and superintendents, a key reason CS is not offered throughout the curriculum is because educators do not feel they can spend class time on instruction that is not directly tied to standardized test preparation [5]. Second, there are few teachers with the background and skillset necessary to teach CS [4,5]. Finally, efforts to offer high-quality CS integrated into other disciplines have been hampered by a dearth of research on exactly *how* to do it, including providing the training and support teachers need to make it happen [12].

1.2 The Potential of Maker Pedagogy as a Strategy for Integrating CS into Science Instruction

The enthusiasm for maker activities and pedagogy as a way to integrate CS and CT with science instruction is grounded in research on effective teaching. Reviews of the emergent literature on integrating making into science education [2,17] suggest that the student-centered, hands-on, iterative nature of maker activities and pedagogy supports student learning and development by:

- *Cultivating student interest and creativity through authentic tasks*. Students and teachers find making activities to be fun and exciting, which sparks student interest in the content and promotes deeper engagement and learning.
- *Promoting equitable, culturally-relevant learning*. Making offers various entry points for students with differing levels of prior CS knowledge. It also leverages student interest and cultural resources, thereby appealing to a wide range of students.
- *Fostering meta-cognitive skills that help students consolidate understanding*. Having students explain their projects and how they solved problems makes thinking visible and helps solidify learning.
- *Engaging students in iterative, improvement-focused cycles*. In making activities, students develop and test their ideas and learn from their mistakes and the feedback they receive. The iterative testing cycle, focused on continuous improvement, promotes deeper learning, persistence, and a growth mindset.

Further, because a maker approach naturally draws on interdisciplinary practices, such as aspects of the engineering design process, scientific inquiry, and technology [10, 14, 16], it is uniquely positioned to integrate CS and science. Making activities can address the goals of K-12 science education as articulated in the Next Generation Science Standards, such as defining problems and solutions, problem solving and sense making [15]. It can also foster core CS practices and 21st century skills, including collaborating around computing; recognizing and defining computational problems; developing and using abstractions; and creating, testing, and refining computational artifacts [9].

Despite the strong promise of the maker approach, there is a need for more evidence about how making fosters student learning and broadens participation, as well as how to prepare teachers to employ this approach. Most research to date has focused primarily on qualitative studies of maker education in informal settings (e.g., afterschool) [2, 7, 17], and has not specifically explored the potential of the maker approach to integrate CS and CT into science instruction.

2. Project Activities

The MPP draws on a research-practice partnership (RPP) model to ensure that research addresses the most critical questions and reflects the realities of practice, leading to more useful findings and more powerful, sustainable program improvements [3]. This project is being conducted as an RPP between three organizations: The Research Alliance for New York City Schools—a research and evaluation organization; Maker State—a curriculum developer, implementer and trainer; and Schools That Can—a school support and network organization. The programmatic key elements of the Maker Partnership include:

- Developing an engaging and culturally relevant maker curriculum for 3rd - 5th graders that integrates CS and CT into science instruction. The curriculum fosters creative collaboration and interactive problem-solving, including addressing social and environmental challenges (such as global warming). For example, in one unit, students use Scratch—a block based programming language—to demonstrate heat transference between objects.
- Building teacher capacity through in-person PD (8 days per year), an online professional learning community, in-person and virtual coaching (e.g., webinars, technical assistance conference calls), and a ‘badging’ process through which students are assessed and recognized for mastery of key skills and concepts. The PD (and accompanying supports) provide hands-on opportunities to learn the CS and CT content and concepts behind the curriculum, as well as the pedagogical content knowledge to effectively facilitate student learning. In many cases, the PD for teachers is structured in the same makerspace format that teachers use with students in their classrooms.
- Supporting and encouraging principals to integrate the maker curriculum and CS instruction into the core work of the school.
- Engaging a Teacher Council and Advisory Board for support with curriculum, research design and to assess progress.

Our theory of action is that the Maker Partnership curriculum, PD, support and assessment will increase teacher and school capacities to implement maker activities, integrate CS and CT into science instruction, and support culturally relevant and equitable learning. As a result, student interest, engagement and learning in CS, CT, and science increases, providing students with a strong foundation to apply across disciplines, ultimately broadening the participation of students historically underrepresented in CS and science.

3. Research Plan

This project is unique in that it will add qualitative and quantitative evidence to inform: 1) how to develop teachers’ capacity to integrate CS and CT into science instruction at the elementary level; 2) whether and how this integrated instruction promotes deeper student learning, interest and engagement; and 3) how the MPP model may need to be adapted to fit local contexts. Because the Maker Partnership seeks to broaden participation of underrepresented students in CS, we will also examine outcomes for different groups of students (e.g., by gender, race/ethnicity, socio-economic status, special needs, English language learner groups).

In spring 2018, we recruited nine elementary schools in a large urban school district, securing a commitment from the principal and up to two 3rd - 5th grade teachers in each school. A total of 16 teachers agreed to participate. During the 2018-19 school year, teachers will participate in the PD and implement the curriculum in an afterschool setting. Throughout the year, we will collect and analyze data on the PD and implementation to inform improvements to the model, with a particular focus on transitioning the curriculum and pedagogical approach from the afterschool setting to the in-school classroom setting.

Implementing in afterschool programs in the first year provides a low-risk setting for short-cycle tests, iterations, and program refinement. In the second year of the project (2019-20), we will work with the same teachers and administrators to implement the model in their in-school classrooms. We will continue to collect and use data to iterate and refine the curriculum, PD and support, and to assess outcomes for teachers and students.

3.1 Data Collection Methods

This project employs qualitative and quantitative methods to address the research areas outlined above, as well as new research questions that emerge as the project evolves. In particular, we use:

Teacher Surveys. Brief online surveys to teachers before the first PD, and end of each in-person PD, as well as at the end of the first and second year of the project's implementation.

Student Pre-Post Surveys. Online student surveys at the beginning and end of each school year. We will use these data to assess growth in important mediating outcomes for students, including attitudes and dispositions toward science, CS and CT, as well as reactions to the pedagogical approach and content taught (e.g., interest in the activities, self-assessed knowledge gained).

Student Assessments. In the second year of the project, we will assess student learning in CS and CT through a classroom-based standardized assessment. The project team will work with the advisory group and teachers' council to identify an existing instrument or develop a new one that is aligned to the CS and CT content taught through the curriculum.

Case studies. In order to learn what works for teachers and students, illustrated by rich descriptions of what the practice looks like on the ground, we will conduct case studies in four participating schools. This will include observations of maker activities and interviews with teacher and principals.

4. Early Findings

This project is in the first year of a two-year implementation plan. Thus far, we have conducted a pre-survey and one post-PD survey with participating teachers as well as pre-program surveys of students enrolled in the afterschool program. Key findings from those surveys are described below.

4.1 MPP Pre-PD Teacher Survey

- Most teachers surveyed had limited or no prior training and experience with CS or maker learning.
- Almost half of teachers reported no knowledge of CT.
- For all three topics—Integrating CS and CT, making CS relevant to students from diverse backgrounds, and assessing mastery—the majority of teachers rated their level of knowledge as "none", "low" or "basic".
- All teachers reported some experience—prior to participating in MPP—with online professional learning communities, although most reported only "occasionally" participating in such a learning community.

These findings highlight the fact that teachers in our study are relatively inexperienced in terms of CS and maker learning, which is typical of many school districts around the country.

4.2 MPP Post-PD Teacher Survey

4.2.1 Teachers rated the quality of the PD positively. All teachers "agree" or "strongly agree" that the training gave them the knowledge to facilitate maker learning at their school, that the objectives of the PD were clearly specified, that it increased their CS knowledge, and that it assisted them in understanding how to implement their learning in the afterschool setting.

4.2.2 Value of MPP supports. When asked which of the MPP project supports they anticipated would be most helpful in implementation, in-person trainings were rated highest (88% said very helpful), followed by in-person coaching (75% said very helpful), and the online supports (75% said very helpful).

4.2.3 Teachers reported gaining knowledge and skills at the PD. After the first PD, almost all teachers reported their understanding of CT, maker learning, and playtesting as "moderate" or "high" (up from "low"). Similarly, teachers' levels of knowledge about most MPP practices (e.g., using non-computer activities to teach CS and CT, using Scratch to teach CS and CT, design cycle, playtesting, etc.) increased as a result of the PD. These findings indicate teachers' low baseline understandings of CT and CS and are consistent with known barriers to integrating CS and science instruction [4].

4.2.4 Teachers reported confidence in their ability to implement the curriculum and use the supports provided. Following the first PD, teachers' confidence in utilizing the online platform was generally high, as the majority of teachers reported that they understood how to complete lessons, collaborate via the site, share assignments, and navigate the platform for support. Additionally, the majority of teachers' reported increased understanding of maker learning strategies as a result of the PD.

4.2.5 Importance of the Maker Approach. In response to an open-ended question, teachers reported that they believed using a maker approach to integrate CS into science was important because it would increase engagement and understanding of CS concepts among students, facilitate collaborative learning, allow for hands-on experiential learning, cultivate problem solving skills, enable students to develop a sense of ownership over their learning, and provide multiple means of engagement. These responses indicate strong teacher buy-in and belief in the potential of maker learning.

4.2.6 Anticipated Implementation Challenges. Teachers were most concerned about lack of preparation time, inaccessible computer hardware, lack of administrative support and lack of CS knowledge. Teachers seemed to anticipate the fewest challenges around classroom management and students' interest in CS. These responses provide the MPP team with information about where to focus supports and assistance to teachers as they implement.

4.3 Student Pre-Program Survey

In addition to the teacher surveys, we conducted a pre-program survey of 197 students in the afterschool activities. The survey explored prior exposure to CS; confidence, interest and engagement in CS and science; interest in making; collaboration and persistence; and gender and race/ethnicity stereotypes about who does CS. Key findings include:

- About half of the students (52%) had taken a computer programming class in or outside of school prior to participating in the MPP
- Most students surveyed had access to a computer and internet access at home.
- Most students agreed or strongly agreed with statements about their confidence in CS and science. For example, 71% agreed/strongly agreed with the statement: "I am good at computer programming," and 83% agreed/strongly agreed with the statement: "I am good at science."
- A majority of students also indicated that they are interested in CS, science, and making. For example:
    - 93% agreed/strongly agreed, "I enjoy creating things with a computer;"
    - 89% agreed/strongly agreed, "I enjoy learning new ideas about science;" and
    - 93% agreed/strongly agreed, "I like to figure out how to make things."
- Student responses to questions about collaboration suggest room for growth. For example, 43% agreed/strongly agreed, "I do not like when people suggest changes to my work"
- Student responses to questions about who does CS suggest prevalent gender stereotypes, particularly among boys (e.g., 72% of girls, but only 57% of boys, strongly agreed with the statement: "Girls can program as well as boys.")

5. Discussion

The MPP represents a unique model for not only developing 21st century science curriculum but also learning about how to best support teachers to use maker pedagogy to integrate CS and CT into elementary level science. Given the dearth of research on these topics, this project will begin to fill the gap. For instance, consistent with literature from the field, we found that teachers' rated their initial understandings of CS and CT as 'low'. However, our early findings also suggest that in-person (as opposed to virtual) teacher PD is critical in the early stages of learning how to use maker learning to integrate CS and CT into science instruction. Findings from the pre-program student survey suggest that the program attracted many participants who had some prior exposure to CS activities, and already showed confidence and interest in CS and science. When the program is integrated into the school-day curriculum with all students, rather than a self-selected group, we expect far fewer students to report prior experience, interest and confidence. The findings also suggest that there is room for growth with respect to collaborating with peers, a key component of maker learning. Additionally, survey findings suggest that students may have internalized gender stereotypes about who does CS. These findings have implications for how the PD and support may be adjusted to include focus on facilitating collaborative problem-solving and dispelling stereotypes and biases prevalent in the CS field.

These findings raise important questions for consideration and study as our project progresses:

1) Can online teacher support—which is more cost efficient and scalable—play a larger role in supporting teachers' PD and implementation of the MPP in across different classrooms?

2) Does the implementation of maker learning improve students' perceptions of working collaboratively with their peers?

3) What classroom and maker learning approaches might mitigate gender stereotypes about who does CS?

We are also eager to use the information from the case studies to illuminate the ways and extent to which teachers were able to integrate CS and CT with science instruction through maker pedagogy, an approach that we believe will help equip students to address today's social and environmental challenges.

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