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Abstract

This paper reports findings from the efforts of a university-based research team as they worked with middle school educators within formal school structures to infuse computer science principles and computational thinking practices. Despite the need to integrate these skills within regular classroom practices to allow all students the opportunity to learn these essential 21st Century skills, prior practice has been to offer these learning experiences outside of mainstream curricula where only a subset of students has access. We have sought to leverage elements of the research-practice partnership framework to achieve our project objectives of integrating computer science and computational thinking within middle science classrooms. Utilizing a qualitative approach to inquiry, we present narratives from three case schools, report on themes across work sites, and share recommendations to guide other practitioners and researchers who are looking to engage in technology-related initiatives to impact the lives of middle grades students.

INTRODUCTION

In the past decade there has been an acute awareness and articulation by researchers and policy makers of the need to infuse computer science (CS) principles and computational thinking (CT) into core K-12 academic areas (Grover & Pea, 2013; International Society for Technology in Education [ISTE], 2011; Mannila et al., 2014; Settle et al., 2012; Wing, 2006). These skills are seen as essential to filling future employment demands, as well as integral to fostering 21st Century skills such as problem-solving and higher order thinking skills across disciplines (Barr & Stephenson, 2011; Wing, 2006). Although both the research and applied definitions of CT continue to evolve (Barr & Stephenson, 2011; Mannila et al., 2014), CT is generally defined as thought processes that are based on CS concepts such as abstraction and composition that allow individuals to formulate and solve problems by leveraging the capabilities of computers (Wing, 2006; Wing, 2011). Thus, computational thinking is a more general set of practices based on CS principles that may or may not involve the use of programming, per se, to solve problems. For the work that we will describe in this paper, CT is inclusive of CS principles and programming skills. Thus, programming may be used as a tool to forward CT, but CT can (and is in this project) be supported through non-programming (i.e., unplugged) classroom activities.

A growing body of research supports the idea that the middle grades have tremendous potential for the integration of CT concepts and practices (e.g., Buffum et al., 2014; Wilkerson-Jerde, Gravel, & Macrander, 2015). In addition, prior research efforts have demonstrated that CT concepts and practices can be effectively integrated into diverse content areas such as English language arts, social studies, mathematics, science, and the arts to foster students' problem-solving capabilities (Rodger et al., 2009; Settle et al., 2012; Wolz, Stone, Pearson, Pulimood, & Switzer, 2011). CT seems particularly well-suited to align with the scientific inquiry approach used in science and other STEM disciplines (Mannila et al., 2014; Repenning, 2012; Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013). A Framework for K-12

Science Education identified computational thinking as an authentic practice of scientists and engineers and considered it an integral component of middle grades science curricula (National Research Council [NRC], 2012), documenting multiple opportunities to use CT as a vehicle for disciplinary content learning. Likewise, the Next Generation Science Standards (NGSS) promoted the practice of CT in K-12 by translating these practices into performance expectations that are embedded throughout the standards (NRC, 2013). The NGSS thus distinguished between the practices of science (including CT) and the content knowledge that has traditionally dominated discussions about science learning. Integrating CT practices into middle grades science standards is in line with the belief that the best way to expose all students to CT concepts and practices is to integrate it within core academic curricula (Repenning, 2012). While this exposure can start at a young age, many argue that middle school is a critical time to capture students' motivations and interests towards future schooling and career options (Lapan et al., 2016).

While standards documents such as the NGSS provide a framework for outcome assessment of CT, there is no consensus pathway for curricular and organizational integration of CT into formal educational contexts; nor is there any prescriptive formula for garnering teacher and school-level buy-in to adopt CT as a practice within core middle grades academic areas. A recognized challenge to this call to integrate these skill-sets into mainstream educational experiences is that CT and CS are both not yet widely embraced and adopted by the K-12 educational community (Grover & Pea, 2013). Historically, CS has been considered a 'niche' subject, only reaching a minute number of students who typically self-select into such curricular activities (Buffum et al., 2016). A majority of CT and CS is addressed in high school as an elective or Advanced Placement courses (Mannila et al., 2014). Similarly, in middle school, CS tends to be isolated to after-school clubs or outreach programs designed for students who already have an interest in it and fail to target students who comprise demographic backgrounds of those traditionally underrepresented in CS (Buffum et al., 2016; Repenning, 2012). In addition, most teachers do not have the training or confidence to pedagogically implement CT and CS activities in their classrooms, let alone the content knowledge of how to integrate it into the subject area content (Cuny, 2012). Furthermore, there is a lack of available curricular resources for middle grades teachers to borrow from for instructional purposes.

Policy Context for Computational Thinking

In North Carolina (NC), state policy regarding curriculum standards and accountability testing presents an additional set of challenges to curricular innovation in core content areas. While there is nominally a high degree of local district autonomy, high stakes testing is tied to a state-level curriculum framework. The result has been a high degree of curricular standardization across classrooms within a district as they follow district-level pacing guides designed to assure content coverage for the end of grade and end of course tests (Au, 2011). These pacing guides and end of grade tests are based on the NC Essential Standards for Science (NCDPI, 2011) which, with the exception of additional language for assessing students with cognitive disabilities, have remained unchanged for over 15 years. Thus, these standards reflect the framing and focus of the national science standards from the 1990's (e.g., inquiry), rather than the NGSS (e.g., science and engineering practices). This document is dominated by content knowledge to be mastered by students and no mention as to how practices utilizing computational tools and techniques might be integrated into the classroom. In addition, as part of the U.S. Department of Education's Race to the Top initiative, the state added a sixth component to the teacher evaluation instrument in 2011. This system now holds all teachers professionally accountable for their students' growth on standardized test scores (Henry & Guthrie, 2015). It is perhaps not surprising that teachers fearing administrative and professional sanctions for low student test scores are reluctant to deviate from the prescribed curriculum. The cumulative effect of this policy environment is a lack of support for innovative practices in the classroom, in general, and the integration of CT practices, in particular.

There is also a diminishing degree of professionalism and morale amongst teachers employed due in part to a political climate within the state that is not supportive of public education. Hallmarks of this climate have been persistent low teacher pay wages and funding for schools, the accountability process noted above, and a plethora of state, district, and school-level initiatives that they are expected to implement with fidelity. The National Education Association (NEA) (2017) reports that NC ranked 48th in per capita expenditures of state and local governments for K-12 public schools in 2016 ($1,298). NC ranked 41st in average teacher salaries in 2016 ($47,941). Though the average salary is due to rise to $50,000 for the 2018-2019 academic year (Hui, 2018), moving NC to an estimated 35th place, this rise was due in part to local supplements that are unevenly distributed across the state. Another source of evidence of increasingly difficult working conditions can be seen through self-reporting by teachers in the NC Teacher Working Conditions (NCTWC) Survey that is administered each year to every teacher employed in the state (2018). Of particular note, results from this survey indicate that only two-thirds of teachers in the state feel they have enough time to plan for adequate student instruction; only 60% of teachers in the state report that their class sizes are reasonable for providing quality instruction to students; and only three-quarters of teachers report they have adequate training on instructional technologies.

Of relevance to this study, many of these percentages are much lower at some of our partner schools. For example, only 29% and 24% of teachers at River Bend and Connolly respectively reported that they are provided with a sufficient amount of time to plan for instruction. Thus, it is evident that in our state teachers are plagued with logistical obstacles such as time to learn new skills and a lack of necessary resources to experiment pedagogically (e.g., small class sizes, professional development, designated school support staff).

Interestingly, in the midst of this very challenging policy and work climate has been a call to develop workforce ready students, particularly through the integration of computationally-rich STEM learning opportunities for students at all grade levels (c.f., SFN, 2018). The following study documents one group's approach to addressing this call through the development of strategies that provide broad exposure to CT practices in science classrooms for middle grades students. Presented is a background on the project goals, a strategy for implementation, cases of three different implementation contexts, and finally emergent informative themes.

The ENGAGE Project

Our research group is currently involved in addressing this need to infuse CT concepts and practices directly into science classrooms through a National Science Foundation (NSF) funded project, ENGAGE, to create curriculum that supports the development of CT practices through a game-based learning environment and in-class activities for middle school students. ENGAGE is designed to foster students' development of CT practices through engagement with computationally rich science problem-solving activities. The first phase, started six years ago, entailed the development of the game-based learning environment focused on developing core CS concepts and programming skills. The gameplay immerses students in a 3-D world where they play the role of a computer scientist who is charged with applying CS principles (e.g., abstraction, algorithmic thinking) to solve programming challenges that enable the protagonist to save an underwater research station that has been taken over by a nemesis. The game uses a custom-built, block-based programming language that is based on the Scratch interface. The second phase, started last year, extended the game-based learning environment through the development of out-of-game activities for students using a variety of block-based programming interfaces all utilizing interfaces based on Scratch (i.e., NetsBlox, Cellular) to model, simulate, and analyze data on scientific phenomena aligned with middle school science content standards. This second phase more fully integrated CT practices with established content knowledge for middle grades life sciences. This development requires a strong partnership between the researchers and science teachers as the team tests and refines these products in formal classroom settings.

The project team recognized that achieving the project objectives would require addressing the specific challenges noted above of integrating CT concepts and practices into classrooms that had essentially no precedent of overtly utilizing this approach. In the absence of a wide embrace by teachers and schools for the infusion of CT concepts and practices into regular course content and pedagogy, there is not a paragon of how to work together to achieve this productive disruption. Furthermore, it is understood that every district, school, and classroom context differs, so implementation strategies will vary with each setting.

Research-Practice Partnerships

Increasingly researchers and practitioners (e.g., district leaders, school administrators, teachers) have begun to value research-practice partnerships (RPPs) as a strategy for school reform (Coburn & Penuel, 2016). RPPs are characterized as long-term collaborations between educators and researchers that are focused on solving problems of practice (Coburn, Penuel, & Geil, 2013). In RPPs, researchers and practitioners engage in joint work that consists of iterative cycles of inquiry that has mutualistic benefits for each partner (Coburn et al., 2013). Increasingly, collaborative efforts between researchers and practicing K-12 teachers have demonstrated promising results as a viable strategy for bringing CT and CS into the mainstream curricula (Settle et al., 2012; Wolz et al., 2011).

The project team saw the research-practice partnerships framework as a promising strategy for our CT integration challenges. In particular, our work aligned with a special type of RPP, design research, in which researchers collaborate with practitioners at every stage of design and development of innovative curriculum materials to support student learning (Coburn et al., 2013). The partnership benefits researchers by allowing them to develop and test instructional activities in real-world contexts, and simultaneously it provides practitioners with the resources to investigate problems of interest to them (Coburn et al., 2013; Penuel, Allen, Coburn, & Farrell, 2015).

In a series of three cases documented below, we use the RPP framework to describe the critical relationships that we have formed with middle grades teachers to engage in joint work that have enabled us to fulfill our project objectives. We include challenges, strategies that we adopted to overcome noted obstacles, and the benefits that our work offered the teachers, students, and researchers involved in the project. We argue that technology initiatives that adopt an RPP framework can be a vehicle for providing strategies and support for overcoming barriers emanating from individual, organizational, and institutional levels to novel, integrative instructional approaches. We believe this work provides guidance to others who may be considering similar endeavors for their research and development work in the field.

The overall research questions guiding this study are: 1) How can researchers and practitioners best work together to integrate CT and CS practices into middle grades students' science learning experiences? 2) What barriers and challenges emerge? 3) What are solutions and strategies for success?

Methodology

We chose to employ a qualitative narrative approach to guide our investigation (Creswell, 2013), given that we sought to elicit the experiences of both the researchers and the teachers who were involved in this collaboration over the past two years. Thus, this study gathered data from a variety of sources over the implementation of the ENGAGE research project to collect multiple stories about all of the participants' experiences (e.g., classroom teachers, members of the research team) throughout the phenomenon.

Data Sources

Data was collected throughout the ENGAGE project for the past two years by members of the research team and include the following:

Project documentation. We consulted records of documentation related to the ENGAGE project from the past two years to establish a chronology of our efforts and elicit important details that had been captured during these experiences. Documents such as formal research reports, team meeting minutes and agendas, and email communication amongst members of the research team and with collaborating teachers were reviewed.

Participant interviews. As part of our ongoing project work we regularly conducted informal and formal interviews and debriefs with teachers during classroom implementations. These interviews were audio-recorded and typically transcribed verbatim for analysis. Additionally, for the purpose of this study, the first author conducted interviews with members of the research team to elicit their personal experiences and reflections of their engagement in this project to-date.

Field notes and classroom observations. Members of the research team regularly conducted classroom observations and took field notes during school implementation of facets of the ENGAGE project. All formal and informal observations and notes were used as data sources for the present study.

Data Analysis

Each of the data sources were analyzed for each of the research questions. To aid analysis, each partner school was treated as a bounded case (Yin, 2014), in which data sources collected from that particular school were analyzed separately to elicit themes within cases. Once a basic thematic analysis had been applied to each case, then a cross-case analysis approach was used to to illuminate common themes across schools (Braun & Clarke, 2006; Miles, Huberman, & Saldana, 2014). The research-practice partnership framework was applied as an evaluative lens to answer the third research question. Reading and memo-ing were used as strategies for helping to make sense of the data, and later served as discussion points amongst members of the research team as we collectively interpreted its meaning (Creswell, 2013; Miles et al., 2014).

Participants

Each of the middle schools that we have worked with serve demographically, racially and ethnically diverse groups of students and are located in medium-sized urban areas. See Table 1 for additional demographics about each school represented by pseudonyms. Collectively across all three schools, we worked with eight teachers who served as the participants in this study. See Table 2 for a composite of these participants who are also represented by pseudonyms.

Table 1

School Demographic Information

School	% Free or reduced-price lunch	% Proficient in Reading	% Proficient in Math	% Proficient in Science	Number of Students
River Bend	48	57	44	80	705
Givers	64	36	29	52	909
Connolly	37	67	59	77	1097

Note. Percent proficient as measured by state end-of-grade test scores in 2015-2016 school year.

Table 2

Teacher Participants

Name	School	Grade Level	# Years in Partnership	Still in Partnership?
Arlene	Connolly	6	4	yes
Isabella	River Bend	7	2	yes
Drake	River Bend	6	1	no
Paul	River Bend	8	1	no
Marie	River Bend	8	2	yes
Annette	Givers	6	1	yes
Kate	Givers	6	1	yes
Joe	Givers	6	1	yes

Case Narratives

Case 1: River Bend Middle School

River Bend is a computational science themed magnet middle school in the county where the researchers work. As a magnet, they can draw from across the county, but still has a majority of students coming from relatively nearby. The school is located in a medium-sized urban area. We have been working with teachers at this school for two years now, beginning with the first year that the school adopted the magnet designation. This school is now in its second year of holding this magnet status and are continuing to explore and evolve their common understanding of how they want to operationalize this theme.

Our initial relationships formed at the school were with the school-level magnet coordinator and technology facilitator who already respected and valued our work. In year one, these members of the administrative team shared with us the science teacher's curriculum pacing guides so that our staff could design activities that aligned with their curricular goals. These administrators were also instrumental in pairing us with teachers that they believed to be particularly innovative and receptive to CT as an instructional goal.

We ended up working with four teachers on three different activities within that first year. All of the teachers varied in their enthusiasm and ability levels with CT practices such as programming and CT conceptual knowledge as we substantiate in the next few paragraphs. The seventh grade teacher that we worked with, Isabella, expressed the high value she placed on CT learning for her students; however, she had no prior programming experience. This manifested in her only being comfortable with a research team member, who was a former classroom teacher himself, leading the instruction in the class. Despite the lack of Isabella's full investment in the implementation of these activities, students effectively learned the scientific principles of force and motion through computer programming and modeling with a block-based programming environment, in part because of the positive messaging the teacher engaged in. The researcher maintained the role of the teacher while the classroom teacher attended to class management and assisted individual students within her comfort zone.

In contrast, we were able to adopt a co-teaching model with a sixth grade teacher, Drake, who was much more familiar and confident with programming tools and CT practices, on an epidemic disease modeling activity. With this activity, students programmed a simulation that modeled elements of the science behind the epidemic spread of disease using a block-based programming environment. A researcher led the students in the CS programming activities while Drake helped to assist students with programming, led the integration of the scientific principles of epidemic disease, and the computational thinking concepts with students. Initially this teacher had agreed to allow one day's worth of activities with only one class that he perceived to be particularly well-behaved. However, by the end of the class period, the implementation had been so successful, he agreed to employ two more days of activities with all of his classes.

The other two science teachers we worked with in year one were eighth grade teachers on the implementation of a programming activity centered around the scientific concepts associated with the periodic table. By the time we were ready to work together, we were approaching the end of the year and near the beginning of the mandated end of grade science test. Despite the impending test, the teachers, Marie and Paul, agreed to a three-day activity, which they hoped could be used as review of the periodic table. From the beginning, we faced technical and logistical difficulties. There were no laptop carts available to bring into the classrooms, so we had to use dated desktop computers in the media center. One of the teachers demonstrated more enthusiasm throughout the lesson than the other, where she took a more active role assisting students and attempted to articulate the scientific and CT principles for students. The other teacher assumed a more passive role, abdicating instruction to the researchers. After the first day of the activity, the two teachers collectively made the decision to terminate the plans for the next two days of implementation. They cited technology challenges and feeling the pressure of not having enough time to devote to focused review of the learning objectives aligned to the state-mandated test.

Now in the second year at River Bend, we set a goal, in consultation with our two key resource staff, to both deepen and broaden our work with teachers in our school. These collaborations with teachers are intended to address the school-wide CT model, which emphasizes the goals of decomposition, pattern recognition, algorithms, and abstraction. After debriefing with our RPP team, we felt like all of the activities would have been more successful if students had some prior foundational programming experience. We received a clear message from the science teachers we had worked with the prior year that they did not feel that learning programming, per se, was a value-added activity for science classrooms as it did not specifically address any of their science learning objectives. As previously noted, the current science standards for the state do not reflect NGSS framing of science and engineering practices such as CT, leaving such instructional activity outside of the accepted material for instruction and assessment.

To address this tension, at the beginning of the school year we met with the technology coordinator to co-plan schoolwide coding activities two days a week for four weeks. Our goal was twofold: to get all teachers at the school exposed to CT curricular content, and to give all students a minimum level of proficiency with CT concepts and block-based programming skills. Because our team committed to supporting these schoolwide activities, there was the added benefit of continuing to build the trust and support of administration and staff. During the sessions we attended, there continued to be a wide degree of engagement by teachers, as some chose to do administrative tasks such as grading papers while the researchers took the lead assisting students with the self-paced activities. While some did express that they valued students learning CT concepts and practices, they noted a lack of time to master instruction of this material themselves. In addition, these activities continued to be perceived as isolated coding activities rather than aligned with more traditional science curricula. It was our original hope that the schoolwide activities would enable students to gain a foundational understanding of CS practices needed for more complex curriculum integration, and would simultaneously benefit the teachers with building their familiarity and confidence with the content. A repeat of the force and motion modeling activities after the school-wide coding intervention did demonstrate that less time was needed in the science classroom to get students to the point that they were able to focus more fully on modeling scientific concepts through coding. However, we believe our impact on teacher interest and preparedness to engage in CT integration activities in the classroom was more modest.

We are continuing our efforts at this school as we work with members of the administrative team to help them operationalize and fully embrace their status as a computational science magnet school. Now in the second year of their magnet designation, there continues to be a dominant culture that students' learning of computer programming skills, in particular, and CT, in general, is the responsibility of designated elective classes and their teachers, and not mainstream academic subject teachers. Our team sees curricular restraints, lack of teacher planning time, and substantive professional development as primary barriers, despite the push from the administration for teachers to embrace their role in the magnet designation. Work continues on designing activities that align with the curriculum goals and be willing to meet teachers at their comfort levels. In addition, we will work to leverage the affordances of the middle school cross-disciplinary model to work with teachers in other subject areas in hopes that science teachers will see the value in our practices. In addition, we continue to provide public relations support for the school by attending open houses to showcase our collaborative work and provide letters of support for their grant writing efforts.

Case 2: Givers Middle School

Givers Middle School is located in a nearby medium-sized urban area that serves a demographically diverse student body. This most recent partnership began with a contact at the district-level who coordinated the K-12 science curriculum. She then connected our research team with the principal at Givers, who then planned a meeting with the science department. After this presentation, three interested sixth grade teachers, Annette, Kate, and Joe, contacted us about collaborating on a new science enrichment course they were designing for sixth grade students. Although Annette and Kate lacked programming experience or exposure to CT concepts, all three teachers recognized the value of this area of study as it contained what they considered essential 21st Century skills for students learning science. Working with the teachers, it was decided that they would begin with the ENGAGE game environment (supporting an introduction to block-based programming and CT concepts), then do a series of supplemental tutorials on block-based programming before starting the block-based programming activities of modeling and simulating physical phenomena. Unlike our work at River Bend, the Givers teachers were willing to devote a reasonable amount of class time in this elective science class to programming and CT activities.

The team used the epidemic activity first taught the previous Spring at River Bend as a template to then refine and expand the modeling and simulation activities to three science topics: epidemics, food webs, and invasive species. We worked with the teachers through meetings and email to create teacher and student guides for the activities. The research team created initial drafts of activities for teachers to provide feedback on. Teacher input was critical to making usable resources for their contexts. For example, the teachers suggested that we create a portal where the students could easily access all of the activities. They also suggested that we give students printed instructions for the activities rather than have them toggle back and forth between electronic versions of the instructions and the programming environment.

Initial instruction with the ENGAGE game provided an opportunity to troubleshoot some of the technical issues at the school. Not surprisingly, inclement weather forcing school cancellations and unfamiliarity with the materials compressed the final modeling and simulation activities into fewer days than originally planned. As was seen at River Bend, there was high enthusiasm for the content area on the part of the teachers and many students, but varied degrees of self-efficacy for leading instruction or engaging with the activities. Regular debriefs with the teachers and use of exit tickets with the students led to both on-the-fly adjustments and a punch list of instructional refinements for the next quarter's implementation. For example, while it was hoped that core programming and CT skills developed in the ENGAGE game would carry over to the Epidemic programmable modeling and simulation activity, we found that many students were unable to effectively transfer this knowledge. We are currently in the process of designing some programming tutorials for the Epidemic activity based on teacher and student feedback. Our determination was that this would be as important for the teachers as for the students.

Case 3: Connolly Middle School

Our longest sustained partnership has been for close to four years with a sixth grade teacher, Arlene, at Connolly Middle School. Connolly is also a magnet school—themed Gifted and Talented—in the county where our university is located. The student population at Connolly is also racially and ethnically diverse. Our ongoing partnership with Arlene was the result of a recommendation from the district-level magnet coordinator. Arlene was part of a group of four teachers that worked on the original ENGAGE game design four years ago. Members of the research team met with these teachers to explore how they could integrate CS and CT into a game-based learning environment. Teachers and researchers met during the summer for a professional development retreat on the co-design of unit and lesson plans. The research team provided the CT objectives, as the teachers furnished the curricular expertise to effectively brainstorm ways to infuse CT-focused lessons with oceanography concepts, with the goal of using the game as part of a revised ocean sciences elective course. Targeting this elective course was a strategic decision since it gave the team the freedom to build their own curriculum without the influence and pressures of state-mandated science testing requirements.

From the beginning Arlene proved to be the most enthusiastic and competent teacher in the group. Two of the teachers moved on to new teaching roles or schools, while the third teacher ended up not having the technological support needed to maintain use of the game. In contrast, Arlene has stayed at a school where she had the freedom to explore the integration of the game into the oceanography elective. For the first semester of the new curriculum, two members of the research team made regular and frequent visits to each school site that was implementing the oceanography elective course. This was not only essential for supporting the initial implementation of the lessons, but also to establish teacher support and buy-in.

From the beginning, conditions at Connolly were favorable for a partnership of research and development work. First, the technology infrastructure and hardware was stable and accessible. Secondly, Arlene quickly embraced the CT instructional goals and was able to pursue lines of instruction more easily than she would have in a regular science classroom. Finally, she was effective at sharing her opinions and curricular expertise with the researchers and maintained stable communication with us. Furthermore, she is a problem solver and learned quickly how to troubleshoot and work through any technology glitches that occurred. We also acknowledge that it was advantageous that Connolly was a Gifted and Talented magnet school as it attracted students who were typically positively oriented toward school and some had likely been previously engaged in programming or other CT or mathematics activities, giving them a head start on our curricular materials. Four years into the partnership, Arlene has successfully developed the capacity to run these activities on her own with little researcher support. We continue to more broadly support Arlene and Connolly with outreach activities like judging science fair competitions and writing letters of support to sustain their magnet status.

Emergent Themes and Recommendations

Based on our retrospections and the data analysis of the work on the ENGAGE project over the past four years, we found that the following themes characterized our efforts across school sites. Subsequently, we have articulated recommendations within those discussions for educators and researchers based on the findings of those themes.

Administrative Buy-In

Through our experiences we have found that initial buy-in from administrators at both the school and district-level has been a critical facilitating condition that has enabled us to establish relationships with teachers. In particular, we found that the school principals sent early signals to staff members that our work was valued and credible, which then motivated teachers to embrace our curricular ideas (Hew & Brush, 2007; Schrum & Levin, 2013).

Arlene credits her principal's "interest in the project" as the impetus for her involvement in what has evolved to be a long-term partnership with this program. Additionally, as Kate explains, she would not have been able to participate without her administrator's support, "The principal was very supportive and allowed each science classroom to have 15 Chromebooks dedicated to the project. We needed our principal's support to obtain technology before we could commit to the program."

We believe that we were less successful at River Bend in our first year because our relationship with their administrative team was more tenuous at that point. Since then, we have solidified a tighter working relationship with the school's magnet coordinator, technology facilitator, and principal as we have gained their trust and support through our willingness to participate in school-wide events such as science fairs, magnet school open houses, and the school-wide coding activities. As a result, at the beginning of this school year we were invited to attend a science department meeting which resulted in future collaborations with two of the science teachers from the previous year and two new additional teachers at the school. At Givers Middle School, the principal not only invited us to meet with the science department and secured the necessary technology for three of her teachers to participate in the program, but she has been so pleased with the results of the collaboration that she has advocated for the seventh grade teachers at her school to partner with us next year.

Thus, to establish ongoing collaborative relationships with teachers, we recommend coordinating with the organizational structure of school systems and with multiple stakeholders on the introduction of novel practices to existing curricular structures. For us, this began with engaging in a dialogue with principals and other members of the school administrative teams to articulate how we believed our ideas around CT and CS addressed key goals at both the district and school level, even though this was not an established curricular subject area. Here, we needed to leverage the larger policy discussions around the centrality of CT to STEM career readiness, and then articulate how we planned to operationalize these goals within science classrooms. It was interesting to see that while principals in NC are held accountable for their school standardized test scores, the larger policy goals around developing "career ready" students (cf., BEST NC, 2015; SFN, 2018), particularly through the integration of computationally-rich STEM learning opportunities for students at all grade levels. Once convinced of the value to the district's goals, school and district administrators were central to identifying schools to situate our work and teachers to collaborate with.

The ongoing relationship with administrative leadership continues to be nurtured by both fulfilling our promised support of classroom instruction through our innovative curricular approaches and professional development opportunities for teachers, as well as participating in other school-wide events. This helps us demonstrate our commitment to both our project and the larger school mission.

Curricular and Testing Restraints

As foreshadowed in the state policy section, we have found that curricular and testing restraints at the state and district level represent significant challenges to our work. For the second phase of the ENGAGE project, our plan was to target eighth grade science, as it was the best alignment for the life science curricular topics we were utilizing in our modeling and simulation activities, based on the state level standard course of study. However, many of our recruitment and collaborative efforts with eighth grade science teachers have ended up being unsuccessful. Our conclusion is that the high stakes testing environment in our state has created acute pressures on eighth grade science teachers, in particular, since this is the designated middle grades testing year for science. The result has been that as this testing window approaches, teachers percieve the need to pursue a reductionist approach that employs a more direct instruction approach focused on memorization and review of subject areas covered in the test and to not engage in exploratory curricular activities that do not have a proven track record of raising test scores. This seems to be exacerbated in the districts where we are situated where avoidance of risk-taking and hewing close to district-developed pacing guides seems to be the cultural norm. This is particularly exemplified in the periodic table activity that we tried to implement with eighth grade teachers at River Bend near the beginning of the testing period. When, after one day, Marie and Paul concluded that they did not see the immediate value for improving performance on standardized end-of-grade test and, amid technical and logistical challenges, decided to abandon our pilot project. One teacher's comment helped us to better understand this paradox, "We have absolutely no time to teach coding in our regular classes. I think that if students already know how to code then the science activities would be awesome in the classroom."

For our project, our curricular model is to have middle school students engage in learning science through the utilization of CT concepts and practices. This inevitably means a dance between developing a core CT knowledge base and programming skill set while not leaving the focus on science behind, since core content teachers are often discouraged from deviating too far from curricular mandates (Orlando, 2014; Uluyol & Sahin, 2013). The result has been a decision to shift to working with sixth and seventh grade science teachers and those teaching elective or enrichment courses. For these contexts, we have witnessed more willingness to experiment with different pedagogical and curricular approaches. However utilizing elective classes creates logistical challenges of exposing all students to CT concepts and practices and fails to address the larger project goal of helping science teachers build deep connections between science and CT. A more promising approach has been our work at Givers Middle School where all sixth grade students are participating in the ENGAGE curricular activities within a specials class taught by the science teachers. This has the benefits of: 1) all sixth-grade students getting exposure to CT content within the context of science activities, 2) science teachers also are engaged in learning and teaching these curricular strategies, but 3) the teachers do not have to do this under the constraints and pressures of their core science class. Joe explained this opportunity from his science team's perspective, "While this program doesn't entirely fit our classroom curriculum it's perfect for our academic enrichment classes which allow us to have focused time to develop other critical learning strategies. This program has been amazing for these students."

Another challenge related to curricular constraints arose from our desire to work across all three grade levels. Adherence to pacing guides which tightly align content areas and grade level meant our material, at times, worked against the strong disciplinary coordination across grade levels that is commonly utilized within middle schools. Recently there were some tensions between teachers in different grade levels at River Bend as to which grade was going to implement which of our modeling and simulation activities. Ironically, as we have made the science content more prominent in our activities, the more this is likely to be an issue. As a result, we have had to carefully work with grade level team leaders to coordinate the appropriate activity for each grade level based on the state curriculum framework and district pacing guides.

Teacher Motivation and Self-Efficacy

Consistent with national norms for K-12 public school teachers, the majority of the teachers we work with do not have prior CS and programming experience (Menekse, 2015). As Kate explained, this can pose a significant barrier, "An obstacle for me was not being hugely confident with coding. If we are able to do it again, I want to be much more familiar with the game and the coding for the activities." The fact teachers often talked about our curricular materials as related to "coding" pointed to the difficulty of getting science teachers to think of CT as being something more general and broadly applicable than computer programming, and not necessarily linked to having to learn syntactically complex programming languages. Therefore, it has been important for us to assess teachers' self-efficacy and motivation to engage with us on these pilot activities. To achieve our research and development goals, it has been crucial that we find innovative teachers that are willing to take instructional risks in their classrooms and are willing to learn new scientific practices. Arlene at Connolly has been an exemplar when it came to independently mastering new content, innovatively integrating it into her elective course, and collaboratively working with the research team on improving content and instructional strategies. Arlene's innovativeness and risk-taking abilities are best characterized in her own words:

> It's been a learning process for myself. The CS side of it, the game. You have to learn the correct terminology, and all that kind of stuff. So, it was kind of intimidating, especially in the beginning… issues popping up and glitches and over the years I've just learned how to fix things or realize that it's fine. It's gotten me more comfortable with technology.

It is thus perhaps not surprising that our relationship has remained a long-term partnership. Arlene not only quickly adapted to the CS and programming concepts, she has also taken the initiative to seek out additional resources as needed by her students. However, Arlene's quote also points up an additional challenge of our materials for teachers. Because many of our activities are computer-based, there is the dual challenge of both mastering CT content and contend with a new computer-based learning environment. As can be seen with many of our collaborative efforts, when plagued with difficulties based in the technology, in addition to the CT content, high motivation and efficacy is necessary to persist and keep the work going forward through problem-solving efforts (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Fullan, 2007).

A contrasting case was at River Bend where Isabella was only willing to work with us if our research team led the class activities. While she saw the value of her students being engaged in CT activities, she did not feel capable of learning and leading the class. Such a relationship limited what we were able to gain from working with her classrooms. While it allowed us to test and refine ideas developed by the research team, it lacked meaningful feedback from the teacher since she was not actively involved in instruction, nor felt qualified to comment on our curricular materials. It also limited our ability to scale our ideas across more classrooms since one of the research team had to be dedicated to teaching. Our lack of ability in getting this teacher to engage in the instruction meant she missed the opportunity to grow professionally. Perhaps not surprisingly though, she enthusiastically invited us back this year—she again wanted us to be the lead instructor. As we move into later stages of the project and we want to demonstrate the scalability of our refined activities, we will need to develop strategies that will help entice and nurture low-efficacy teachers into engaging more fully as a member of the curriculum development team.

The Role of Technological Resources

As with any technology-centric instructional initiative, having adequate and stable technology accessible to students is necessary, but not adequate to its success (Inan & Lowther, 2010; Liu, Ritzhaupt, Dawson, & Barron, 2016). Technology infrastructure shortcomings—from old and underpowered computers, balky wireless networks, to software incompatibility issues—created barriers to implementation. Such technological issues inevitably sapped energy, time, and resources from both the research team and the cooperating teachers. Researchers were further constrained when the technology issues were school- or district-based and, therefore, technical solutions can only be resolved by working through the classroom teachers who had to act as liaison to technology staff members. Weaker partnerships with teachers often used technological challenges as a reason to either end or scale back our collaboration. Again, the eighth grade science teachers at River Bend were a good example of this. These patterns align with the extant literature on teacher technology integration which suggests that technical difficulties often serve as barriers that stymie a teacher's motivations and efforts to innovate within their classrooms (Ertmer et al., 2012; Miranda & Russell, 2012).

Such technological challenges accentuated the importance of a strong partnership with motivated teachers, as strong communication with teachers who did not become discouraged when these roadblocks surfaced was critical. We attribute some of our success at Connolly to the fact that the school already had a strong technological infrastructure in place and Arlene was willing to actively engage with us to solve technology issues as they arose. This is also another reason why establishing relationships and buy-in with school and district-level administrators can be important to ensure that the school infrastructure is in place and well-supported before teachers and researchers engage in partnerships centered around technological innovations. This was reflected at Givers where the support of the principal was critical as she allotted relatively new Chromebooks for the teachers to be a part of the project. Researchers also need to budget resources to be able to make timely site visits when technology troubles arise to ensure the technical difficulties did not hamper both the short-term classroom goals and the long-term relationship with the teachers.

Enhanced Communication

Penuel et al. (2015) cites effective two-way communication as essential for all participants in a RPP to understand the cultural norms of each one's practices and entails both parties listening to each other and asking questions of one another. We credit strong communication with our partner teachers as a critical element to the success of our endeavors. As Annette explained, regular communication has been essential for our partner teachers to feel supported and to allow us to assist them in overcoming technical and logistical problems encountered with the ENGAGE game and modeling activities, "I feel that any time I'm having an obstacle or something like that, I can just send you guys and email and you guys are right on top of it, so it's not like it's I'm waiting forever to get a response." This was particularly important in the initial phases of establishing working relationships with teachers as we strived to build their trust. This can be especially challenging when partner schools are not in close proximity to members of the research team as has been the case with Givers Middle School. However, communication through email and regularly scheduled check-ins has helped to alleviate this obstacle of physical distance if a strong relationship is already in place.

The nature of our communication with these partner teachers typically ranges from technical concerns with hardware or software, logistical questions such as classroom implementation schedules, and to feedback and requests for clarification on resources and interventions. These exchanges require both practitioners and researchers to be committed to administering timely responses to one another's inquiries or concerns, but ultimately help to solidify a stronger relationship between partners.

Joint Work

Likewise, we have found that strong relationships between both partners are developed and sustained through the physical presence of the research team within the school environment. Regular classroom visits during interventions has helped to foster teacher support and buy-in for the research efforts as Arlene explained, "I had a lot of support with members of the team coming by and having that support over the years I've just learned things and realized that it's fine."

Furthermore, when we enter the school sites and engage in the daily practices of the partner teachers, it provides us as the researchers a more comprehensive picture of the realities of the classroom which then informs design processes and our abilities to overcome challenges. Developing and sustaining research practice partnerships involves "boundary crossing" in which both researchers and practitioners are required to transverse "cultural, professional, and organizational differences" encountered in the daily work of each group (Penuel et al., 2015, p. 188). That is another reason why we believe that a co-teaching model for our programming activities can be an important opportunity to not only build teacher confidence with the CS integration, but also offer the researchers an opportunity to gain strong insights into the challenges faced by partner teachers within their unique teaching and learning contexts.

Essential to RPPs is where all members' perspectives are valued and receive equal attention to the design efforts (Penuel et al., 2015). At every juncture possible in the design process, we have also tried to co-plan and co-design ENGAGE activities to ensure that the expertise of the educators informs their design. Because teachers know their students and learning environments best, their insights are critical to our design efforts of student and teacher resources to be used in the classroom. These actions are pivotal so that teachers understand that we respect their professional obligations and are willing to be flexible with the design and implementation of our research. Co-design can also help ensure that we meet teachers' curricular obligations when plagued with testing mandates. Coburn and Penuel (2013) describe this as mutualism, where the expertise from both researchers and practitioners are integrated to co-design the most practical and effective products.

Conclusion and Implications

RPPs are characterized as long-term partnerships between researchers and educators (Coburn & Penuel, 2013). As exemplified by our relationship with Arlene at Connolly, a sustained model has yielded productive results for not only our research efforts and for Arlene professionally, but most importantly for the students. Throughout the past four years, hundreds of students in Arlene's elective course have had the opportunity to learn CS and CT concepts in the middle grades within a motivating and authentic science learning environment. However, to be in a long-term partnership that yields impactful student outcomes, it takes commitment from both researchers and practitioners. Researchers have to be flexible and willing to accommodate for school schedules and curricular needs, as well as meet educators at their comfort levels in the implementation of curricular materials. In addition, researchers need to make frequent visits to classroom research sites to provide support. Both parties need to be committed to initiating and sustaining timely and thoughtful communication with one another. Researchers also need to be prepared to have fruitful conversations with both district- and school-level administrators about how CS and CT can support larger educational objectives. As seen at River Bend, the RPP work becomes more complex as the intervention work scales across multiple classrooms, teachers, and grade levels. We challenge practitioners to consider how the integration of CT content and practices can offer student authentic learning experiences of scientific practices to both interest and prepare them for future STEM careers. In addition, we encourage educators to be willing to work with researchers and share their curricular expertise on the development of materials, and to help keep researchers grounded in the realities and effective practices of everyday instruction to design the most practical and efficacious resources. Our work is dependent upon committed educators who are willing to take innovative risks. This includes the ability to be creative and brainstorm how to situate these goals within institutional structures where these practices are not the norm so that all students can benefit. Similarly, success of the project work is also dependent on the researchers having a high degree of empathy for the organizational and policy constraints under which teachers work. Communication is paramount. For example, at Givers it was the teachers who proposed to utilize a science enrichment period to give all sixth grade students the opportunity to participate in ENGAGE activities that was still within a science learning context. Our team then needed to fully engage with the teacher team to help design what this solution would look like. This approach is shaping up to be a true breakthrough strategy for our project.

Our partnerships over the past several years have afforded us the opportunity to push the boundaries and norms regarding CS and CT as isolated educational opportunities for students into more integrative teaching and learning experiences. We have shared this narrative of our joint work in an attempt to illuminate the barriers that we have encountered and the insights gained. We believe many generalizable lessons have emerged that will inform other researchers and practitioners as they consider RPP as a strategy to collaboratively implement educational innovations. Likewise, we recommend that other educators and researchers leverage elements of the research-practice partnership framework for a more robust and meaningful collaborative experience for a wide range of partnerships.

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