The Pack: Using Game-based Learning to Infuse Computational Thinking into Science Teaching and Learning

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INTRODUCTION

The New York Hall of Science (**NYSCI**), a nationally recognized leader in creative approaches to STEM learning, along with ***Participate***, an online professional development provider, the American Institutes for Research (**AIR**), and **13 Title 1 community school districts in New York City**, propose an **early-phase study** to build and test ***The Pack intervention*** for 6th–8th grade students who live in low-income communities and are from backgrounds under-represented in STEM career pathways. *The Pack* intervention offers a novel approach to supporting the development of computational thinking (CT) skills by engaging students in solving problems that are anchored in the NGSS Crosscutting Concepts for 6th–8th grade. It consists of an open world digital **game**, a supplemental **CT curriculum** for integration into 6th–8th grade science courses, **professional development** activities, and online **communities of practice** (**CoPs**). The intervention will be used by **226 teachers** in **54 schools**, and will reach approximately **27,000 students**. The digital game at the heart of the intervention, *The Pack*, has been fully developed with over $2.8 million in funding from the National Science Foundation (Award #1543144) and the JPB Foundation. It supports students' discovery of core CT skills including problem decomposition, algorithmic naming and sequencing, debugging, parallel programming, and design pattern identification.

This early-phase study responds to **Absolute Priorities 1 and 3** with a special focus on CT. We define CT as *cultivating the habits of mind that support the use of computational tools and practices to define and solve problems*. CT is critical to scientific inquiry across a wide range of fields. It expands our capacity for iterative problem solving, algorithmic thinking (Grover & Pea, 2013; Lee, 2015; Weintrop, et al., 2016; Wing, 2008), and inventing and testing solutions to complex scientific problems (Aho, 2012; Futschek, 2006; Katai, 2014; Lockwood, Apps, Valton, Viding, & Roiser, 2016; Shute, Sun, & Asbell-Clarke, 2017).

A. SIGNIFICANCE

A.1. National Significance. Over the past ten years, both private and public funders have invested heavily in establishing computer science (CS) and computational thinking (CT) as fundamental components of U.S. K-12 STEM education (Code Advocacy Coalition/CSTA, 2018; Office of Science and Technology [OSTP], 2018; White House, 2016). Many of these efforts have supported the creation of curricular and professional development resources that build teachers' and students' understanding of foundational CT concepts and practices. These investments, as well as a range of policy initiatives, have sought to increase students' access to stand-alone computer science courses, or to integrate core disciplinary practices of CS into existing STEM courses. For example, the CS Blueprint from Computer Science for All (CS4All) (NYC DoE, 2019), the NGSS Science and Engineering Practices, and other learning standards all call for the integration of CT concepts and practices into science teaching across the K-12 spectrum (College Board, 2016; Council of Chief State Officers [CCSSO], 2010; National Research Council, 2013; Villavicenco, Fancsali, Martin, Mark, & Cole, 2018; Weintrop et al., 2016). These standards documents include broadly-defined science and engineering practices, crosscutting concepts, and discipline-specific skills and concepts (e.g., analyzing data, programming, modeling). They emphasize practices and ways of thinking that are central to CS and CT, and are increasingly driving new discoveries and ways of working in the STEM professions (Grover & Pea, 2013).

These investments have led to major strides in the provision of stand-alone computer science courses (Code.org, 2018), but have had much less impact on the integration of CT concepts and practices into science instruction more broadly in K-12 classrooms (Rich, Strickland, Moran, &

Franklin, 2017). Integrating CT into science classrooms requires providing teachers with high-quality instructional materials that build appropriate connections between CT and core academic science content, and professional development that integrates CT practices and concepts with the content teachers are already required to teach (Basu et al., 2016; van Driel, Beijaard, & Verloop, 2001; Weintrop et al., 2016). Accomplishing these goals requires a different approach to curricular design than freestanding courses; and also requires sustained investments in professional development and support.

The Pack intervention will respond to this need by supporting the integration of CT into the science courses of high-need 6^{th}-8^{th} grade students. It will prepare and support their teachers and help students learn specific computational thinking skills: decomposition, creation of algorithms, sequencing, naming, debugging, parallel programming, and identifying design patterns. The intervention will use the NGSS crosscutting concepts of *stability and change*, *cause and effect relationships*, and *patterns* as pathways to articulate these CT skills with content that is already present in 6^{th}-8^{th} grade science courses and is familiar to the teachers who teach those courses. Formative and summative evaluation of the intervention will inform efforts to refine the intervention and deploy and support its use by 6^{th}-8^{th} teachers and students in New York City.

A.2. Rationale addressing Absolute Priority 1. *The Pack* intervention offers a distinct approach to Absolute Priority 1—**Demonstrate Rationale**—because it integrates CT into 6^{th}-8^{th} grade science teaching and learning in ways that build teachers' capacity and support for engaged, ambitious, and connected science learning for students. *The Pack*'s approach is grounded in and builds upon extensive evidence as follows.

A.2.1. Situating CT in the context of science learning and NGSS crosscutting concepts. Professional scientific practice is becoming increasingly complex, data-driven, and interdisciplinary (Liu et al., 2007; National Academies of Sciences, Engineering, and Medicine, 2017). Preparing students to pursue contemporary scientific careers requires exposing them to the use of advanced computational tools and computational thinking skills that enable them to: decompose problems into component parts and understand the effect these parts have on one another; create sequential steps (algorithms) to solve complex problems; identify patterns that emerge; use systematic debugging to understand how a design pattern can be fixed or optimized; and engage in parallel programming to address multiple tasks or issues simultaneously and monitor how they affect one another (National Research Council, 2011; Weintrop et al., 2016). These practices are potentially relevant to a range of scientific content areas, and 6th-8th grade students often receive separate units of instruction in physical, biological, social and geoscience domains within a single academic year. But despite these potentially broad opportunities for intersection, few teachers working in these grade levels are prepared to integrate computational thinking tools and into the science content they cover (Lockwood & Mooney, 2017).

The NGSS Crosscutting Concepts (National Research Council, 2013) can provide anchors for teachers seeking to integrate CT into their coverage of existing middle grade science content. As the National Research Council notes, the crosscutting concepts are a valuable part of the NGSS because "they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas" (2012, p 233; Wertheim, et al 2016). *The Pack* intervention will leverage the crosscutting concepts to unite CT with scientific problem solving in ways that tightly align with the New York City Science Scope and Sequence (which are themselves based on the NGSS) (WeTeachNYC, 2018). Recently developed CS frameworks highlight the particular value of the NGSS crosscutting concepts as a pathway into CT (Parker & DeLyser, 2017). In particular, we will support teachers and build students' understanding of CT using three crosscutting concepts that run through the diverse science content covered in the 6th-8th grade science curriculum: 1) Stability and Change, 2) Cause and Effect Relationships, and 3) Patterns. These crosscutting concepts align well with the advanced CT skills described above, are relevant to multiple topics addressed in grade 6-8 New York City Science Scope and Sequence, and are well supported and realized in *The Pack's* gameplay.

A.2.2. Using games to support CT. *The Pack* uses affordances of gaming and simulations that have been shown to be effective in supporting students' understanding of complex scientific concepts and engagement in computational thinking (Ainsworth, 2008; Dede, 2009; Fleer, 2009; Gaber, 2007; Gee, 2007; Hennessy, Deaney, & Ruthven, 2006; Kazimoglu, Kiernan, Bacon, & Mackinnon, 2012; Maloney, Peppler, Kafai, Resnick, & Rusk, 2008; Niess, 2005; Steinkuehler & Chmiel, 2006; Steinkuehler & Duncan, 2008; Turkay, Hoffman, Kinzer, Chantes, & Vicari, 2014; Varma & Linn, 2012). *The Pack* is an open world, single-player digital game that can be played on PCs, Macs or the iPad. The game invites players to rehearse the targeted CT skills as they solve problems they encounter as they navigate a virtual world. A player embarks on a quest via their avatar, who must remain near a water source to survive (see Appendix I1). Keeping the avatar close to water becomes increasingly difficult as players advance through game levels. A player cannot effect change in its environment on his/her own. Instead, the player must befriend creatures he/she encounters in the game world, who can work together to help the player navigate the environment, face challenges and attain the goal of each level. The creatures the player collects (their "pack") each perform critical **functions** such as "hold," "move," "dig," and "repeat" and can work together to combine their actions to accomplish more complex goals. Players **decompose** problems they confront into component parts and combine their creatures into specific **sequences** to solve them. For example, lining up a digger, a mover and a repeater and setting them into action results in an algorithm that can be used to dig a trench. These activity sequences, or enacted **algorithms**, can also be **named** and saved for future re-use and modification. Over time, players are able to identify useful **design patterns** and create libraries of modular algorithmic pieces that can be applied to future problems their pack might confront. As they advance, players may also engage in **parallel programming**, employing several separate packs at once to perform tasks in different places simultaneously. Players have access to diagnostics and a running record of their achievements and actions that provide opportunities for students' self-assessment and teachers' formative assessment. These game mechanics lead students to directly enact foundational CT practices (discussed above) as they explore core crosscutting concepts (discussed above) by using their pack to manage *stability and change* in environmental conditions, track the *causes and effects* of their actions, and identify and react to *patterns* in behaviors and impacts.

A.2.3. Supporting teachers' integration of CT into science. While there is limited research on professional development about CT (Skaza, Crippen, & Carroll, 2013), preliminary studies do identify promising strategies, which include: modelling integration into the curriculum and alignment with standards; developing CT pedagogical content knowledge through targeted examples that feature relevant skills; and providing opportunities to collaborate and reflect with other professionals (Hestness et al., 2018; Pollock, et al., 2017).

A.3. An Exceptional Approach to Absolute Priority 3 building on Promising Strategies. This project represents an exceptional approach to Absolute Priority 3—**Promoting STEM Education** and Competitive Preference Priority—**Computer Science**—by offering engaging CT supplementary materials, professional development activities, and online CoPs to support 6th-8th grade science teachers serving high-need students from groups traditionally underrepresented in STEM careers, another area of **critical national need** (Powers, 2017; Tanenbaum, 2016).

***A.3.1. Key instructional and support strategies*.** Despite national and state-level emphasis on both NGSS adoption and CT, there are significant gaps in the instructional resources and professional development available to educators to prepare them for the shifts required to teach to these new standards (Hagg and Megowan, 2015; Harris, Sithole, & Kibirige, 2017; Yadav, Mayfield, Zhou, Hambrusch, & Korb 2014). The proposed project will develop and rigorously test an intervention that includes *The Pack* game, supplemental curricular activities, professional development, and CoP support mechanisms to help teachers effectively engage their students in CT skills and practices in the context of the crosscutting concepts. In Year 1, project staff will work intensively with a Design Team of ten teachers to co-develop the curricular activities and resources. In Year 2, we will engage 24 teachers to pilot test the resources, professional development experiences, and CoP structure (Cohort 1). In Years 3 and 4, we will engage an additional 192 teachers and conduct a randomized controlled trial (RCT) to gather evidence of the potential impact of the intervention on student outcomes (Cohorts 2 and 3).

Results from prior design-based research, teacher studies, and small-scale evaluation studies conducted with *The Pack* game indicate that teachers who use the game with their students make connections between fundamental CT and science ideas, and 6^{th}-8^{th} grade students who play the game are deeply engaged with it and are able to use algorithms within the game to solve problems (Rockman et al., 2019). While *The Pack* game has shown promise in small-scale studies with teachers and students, it has not yet been studied in the context of an associated supplementary curriculum, professional development, and CoP support, or tested through rigorous experimental design research methods.

A.3.2. The Pack: The Game. *The Pack* is differentiated from other coding tools and platforms by its emphasis on affective relationships and analogical supports for computational reasoning. *The Pack*'s core game mechanic requires players to collect and manage evolving "packs" of appealing, non-threatening creatures and guide them into appropriate sequences to cooperate with one another and achieve a desired goal. This mechanic provides a low-barrier invitation into CT for young people, and particularly girls, who may not be intrinsically interested in the procedural grammar of coding for its own sake (Brady et al., 2017; Buechley, Peppler, Eisenberg, & Kafai, 2013; Harteveld, Smith, Carmichael, Gee, & Stewart-Gardiner, 2014; Kafai & Burke, 2013). The game mechanic puts players in direct control of their computational grammar (the creatures), allowing them to attach meaning and affect to their emerging mastery of computational procedures and the complex causal relationships they are managing in the game world.

A.3.3. CT and Science Crosscutting Concepts and Supplemental Curriculum Resources. To support teachers' use of *The Pack* in the classroom, NYSCI, Participate, and a **Design Team of ten teachers** will co-design supplemental curriculum resources that will include an **introduction to the game**; **twelve game challenges** designed for use at different grade levels and in different disciplinary areas spread across the 6^{th}-8^{th} grade science scope and sequence; concept maps illustrating how *The Pack* and CT can be **integrated across the science curriculum**; and **formative assessment** tools and **discussion prompts** to help teachers leverage gameplay to support students' development of CT concepts and skills. A curriculum guide will provide background information about core CT core skills and help teachers recognize the crosscutting concepts that *The Pack* supports across living environment, physical science, and earth and space science areas. Table 1 demonstrates how the targeted crosscutting concepts are science disciplines covered in the 6th-8th grade scope and sequence, specific game challenges and targeted computational thinking skills all align with one another.

Table 1: Crosscutting Concepts in Science Disciplines, Game Play and CT Skills

Crosscutting Concepts	Situated in Science Disciplines	Game Challenges	Computational Thinking Skills
Stability and Change: Change in one part of a system can produce change in another part of the system.	**Living Environments:** Ecosystems are not static, but include dynamic interactions between living and non-living things.	Create different ways for a pack to gather food sources in different environments.	**Decomposition:** Modularize an outcome into concrete steps to be carried out by different members of the pack. **Sequencing/Algorithms**: Assemble the order in which pack functions have to be carried out to achieve the goal. **Naming:** Describe the purpose of the algorithm by naming it. **Debugging:** Exploring unintended results of running a pack algorithm to identify errors in function or sequence. **Parallel Programming:** Creating multiple autonomous packs running simultaneously to do things in different places **Design Pattern Identification:** Reuse and remix previous pack algorithms to solve similar or analogous problems.
Cause and Effect: Cause and effect relationships may be used to predict phenomena in natural or designed systems.	**Physical Sciences:** Causes and effects may be separated by time and distance.	Find the farthest distance from a water source where plants can still grow.	
Patterns: Patterns in rates of change in numerical relationships can provide useful information about systems.	**Earth Science**: Patterns found in the fossil record can provide information about past life on Earth.	Find patterns in the location of seeds throughout the game world and use that information to build algorithms that efficiently find seeds.	

A.3.4. Professional development activities. The approach to professional development described here draws on the Scale Immersion Model for Professional Learning (SIMPL) (Weiss, Heck, Pasley, Gordon, & Kannapel, 2010). It employs an iterative learning process in which teachers first **experience the game**, **CT concepts**, and **science content as learners** and then **reflect as educators** (Mundry & Stiles, 2009). In a two-day professional development workshop, teachers will learn how to use the game and explore the targeted crosscutting concepts through a CT lens by completing game challenges and supplemental activities. They will learn about CT and its role in their everyday lives, and reflect together on the value of using a CT approach to problem solving in the science classroom and how to realistically use *The Pack* to support integrated CT and science activities.

A.3.5. Online CoPs. A proven way to increase the efficacy of professional development programs is to embed them within a Community of Practice in which support is **continuous**, **job-embedded**, **data driven**, and targeted to the **specific needs of students and staff** (Wiener & Pimentel, 2017). The three essential components of *The Pack* CoP will be: **the targeted** CT practices and NGSS crosscutting concepts that are discussed and explored; **the asynchronous and synchronous learning experiences** that scaffold teachers' work as they use *The Pack*; and the **community** that supports teachers through close collaboration.

The CoP will use Participate's platform to host time-bound online learning experiences, including a design clinic (for the Design Team) and two integration clinics (for teachers in Cohorts 1-3). The **design clinic** will be a three-week virtual workshop in Year 1 and will provide the Design Team with an online space for collaboration and mentorship. In Years 2-4, the online CoP will include two, three-week virtual **integration clinics** for Cohorts 1-3. Each week, teachers will be provided with a new activity to try and asked to post their reflections online for discussion. The integration clinics will address a variety of topics through themes including Game On: Using Games to Build CT Skills; Crosscutting Concepts across the Science Curriculum; and Play with Algorithms: Algorithms in The Real World.

Between clinics, the CoP will provide ongoing access to curated activities and discussion spaces to further support classroom implementation. Participants will upload student work samples and their own reflections to a digital portfolio for at least three activities over the course of the year (one for each targeted crosscutting concept).

A.3.6. Logic Model. We hypothesize that teachers' participation in the intervention's professional development and ongoing CoPs, and their implementation of *The Pack* supplemental curriculum resources and game with fidelity, will lead to greater engagement in CT for students (short-term outcome). We expect this engagement to have a direct, unmediated relationship with increased development of learners' CT skills (long-term outcome). These include improved problem decomposition, algorithmic naming and sequencing, debugging, parallel programming, and design pattern identification skills (see Appendix G1).

B. PROJECT DESIGN

B.1. Clearly Specified and Measurable Objectives, Outcomes, and Indicators. The goal of this project is to build and test a strategy for implementing *The Pack* in 54 Title 1 schools in New York City with 6th-8th grade students and their teachers. Table 2 presents the intervention's objectives and strategies to be developed and implemented, the outcomes and indicators to be achieved, and how we will measure each of those objectives.

Table 2: Summary of Project Objectives, Strategies, Outcomes, Indicators, and Measures

Strategies	**Outcomes**	**Indicators of Success**	**Measures**
Objective 1. Build and test *The Pack* intervention and continuous improvement			
Strategy 1.1 Identify a teacher design team	Outcome 1.1 Describe selection criteria (i.e. years teaching, technology experience, etc.), commitment)	Indicator 1.1a. Existence of criteria and their application in designer selection Indicator 1.1b. On-time selection of design team	Application that clearly outlines selection criteria for design team
Strategy 1.2 Develop *The Pack* supplementary curriculum for teachers	Outcome 1.2 Create implementation guidelines for using *The Pack* in classrooms; including set-up, materials, and framing activities and game challenges	Indicator 1.2. Gather pertinent guidelines and tips for implementation based on design research with teachers	Curriculum guide produced Design teacher evaluation surveys on appeal, comprehensibility, and usefulness of guide activities
Strategy 1.3 Develop *The Pack* professional development activities for teachers	Outcome 1.3 Create a series of activities to support teachers understanding of the game and fit with teaching of cross-cutting concepts in science domains	Indicator 1.3a. Teachers engagement evident in online postings and videoconference sessions Indicator 1.3b. Teachers' ratings of activities for CT understanding Indicator 1.3c. Teachers'	Observations of CoPs Professional development online weekly evaluation forms Post Critical Incident Surveys re: teacher professional

		report of impact on understanding and teaching	development experiences
Strategy 1.4 Train design team teachers	Outcome 1.4 Fully trained teachers	Indicator 1.4a. Teacher ratings of professional development effectiveness; Indicator 1.4.b. Teacher participation in professional development	Content analysis of teacher learning products; Applied Value Cycles measures (Wenger-Trayner, 2015) applied to online discussions
Strategy 1.5 Refine materials, procedures for each Objective 1 strategy	Outcome 1.5 Improved activities, resources and online CoP space	Indicator 1.5. On-time revisions of resources	Program records Completion of project website
Objective 2. Implement *The Pack* in classrooms with fidelity, ongoing support, and continuous improvement			
Strategy 2.1 Train teachers	Outcome 2.1. Fully trained teachers	Indicator 2.1a. Teacher ratings of workshop effectiveness Indicator 2.1b. Teacher attendance at workshop	Post-professional development surveys Attendance records from professional development
Strategy 2.2. Support the online CoP for teachers Strategy 2.2a Develop design clinic for Design Team Strategy 2.2b Design Pack Integration Clinic for Cohorts 1, 2, 3	Outcome 2.2. Establish an online CoP that includes resources, discussions, courses and structures for design clinic Outcome 2.2a&b Teachers participate in online community via posts and content sharing	Indicator 2.2. On time creation of CoP structure and resources	Documentation of online course structure, Resource lists Analysis of number of teachers' online posts and content analysis of CT and crosscutting science concepts explored in CoP
Strategy 2.3 Support Participate in cultivating the online CoP for teachers	Outcome 2.3a Establish facilitation strategies and feedback loops. Outcome 2.3b Teacher leaders are mentors and facilitators in the online CoP	Indicator 2.3a. Facilitation strategies yield more postings and participation Indicator 2.3b. Teacher leaders initiate and sustain discussions with teachers	Analysis of CoP records for facilitation strategies employed
Strategy 2.4 Implement all 12 game challenges	Outcome 2.4 Trained teachers implement curricular activities with fidelity	Indicator 2.4a. Number of activities implemented Indicator 2.4b. Integration of CT with NYSSL expectations	Survey of curricular use Classroom observations *The Pack* analytics to document implementation of curriculum activities
Strategy 2.5 Support teachers via a CoP	Outcome 2.5 Participate in online community via readings, posts, and content sharing	Indicator 2.5a. Teacher participation in check-in meetings Indicator 2.5b. Teacher participation in online CoP	Platform analytics Teacher survey and interview responses about CoP relevance
Strategy 2.6 Monitor and refine activities under Objective 2	Outcome 2.6 Improved implementation of curriculum at the classroom level	Indicator 2.6. Increase across teacher cohorts in curriculum implementation and participation in CoP	Surveys of usefulness and usability of curriculum and materials Teacher interview responses

Objective 3. Test the effectiveness of *The Pack* intervention to increase students' CT skills and engagement as measured			
Strategy 3.1 Evaluate outcome measures	Outcome 3.1 All outcome measures are valid and reliable	Indicator 3.1. Rasch statistics indicate strong fit; reliability exceeds 0.80	Output from Rasch analyses
Strategy 3.2 Design and implement impact study with rigor	Outcome 3.2 Data collection, analysis, and write up findings	Indicator 3.2. Study meets WWC standards without reservations	Consult with EIR evaluation technical assistance provider
Objective 4. Finalize RCT and disseminate result findings			
Strategy 4.1 Continue to execute impact study	Outcome 4.1 Study completed as intended	Indicator 4.1. Study meets WWC standards without reservations	Feedback from EIR evaluation technical assistance provider
Strategy 4.2 Disseminate results & findings	Outcome 4.2 Write draft article and conference presentations	Indicator 4.2. Publish a peer-reviewed article and present at two major conferences	Disseminate materials in peer-reviewed journal, conferences, and through Participate.com and NYSCI networks

B.2. Feedback and Continuous Improvement Procedures. We propose a four-phase approach to continuous improvement (Table 3). The NYSCI team will engage in iterative formative research to inform the design and implementation of the supplemental curriculum resources, the professional development and the CoPs, and will apply Wenger-Trayners' evaluation framework to track teachers' value perceptions of activities over time. Real-time platform analytics from the CoPs (see Appendix I2), annual evaluation forms and surveys, critical incident essays, and content analysis of discussions and teacher learning products will be used to assess the immediate value of program activities, the potential value for practice, applied value to the classroom, the realized value for their teaching practices, and their reframing value, where there is actual evidence of change in teachers' practices and student learning.

AIR will support the NYSCI project team with a structured process for continuous improvement of the teacher workshops, CoPs, and supplemental curriculum resources. As described in Section D, AIR will collect data from surveys, extant data, interviews, and classroom observations during a pilot study (Cohort 1) to provide a detailed understanding of program implementation and teacher and student reactions to the intervention. AIR will report these data frequently to allow for mid-course adjustments during the pilot study and revisions to intervention components in advance of the experimental trial. AIR will collect continuous improvement data during the experimental study and final implementation testing, excluding the observations and interviews, as NYSCI and Participate continue to refine the professional development, CoPs, and curriculum through the final year of implementation.

Table 3. Four Phases of Implementation and Testing of *The Pack*

Year 1	Year 2	Year 3	Year 4
Design Phase 10 Design Team teachers	**Pilot Study** Cohort 1 (*n* = 6)	**Experimental Study** Cohort 2 (*n* = 24) and delayed treatment control (*n* = 24)	**Final Improvement Testing** Cohort 3 (former delayed treatment control) (*n* = 24)
	Continuous Improvement Data Collection		
	Outcomes and Implementation Data Collection		

n = number of schools

B.3. Broad Dissemination. NYSCI's **partnership with Participate is a key strategic** element of this proposal, because of Participate's extensive prior work with New York City community school districts, as a provider of professional development and professional support networks. Participate has an established track record and relationships both in New York City and across the country, and deep expertise in providing training about best practices for improving science learning for high-need students who are under-represented in STEM fields.

Participate's nationwide system of professional development and CoPs will support the proposed early-phase study, and enable this work to be sustained **for the long term**. If *The Pack* is proven to be effective in increasing the computational thinking achievement of students in New York City, Participate has agreed to **integrate *The Pack* intervention into their ongoing, nationwide professional development offerings.** Participate has agreed to assist in **developing nationwide strategies** for the scale up of *The Pack* professional development and CoPs through its online platform. We also anticipate that organizations including the NYC Foundation for

Computer Science Education and the national CS4All network will be able to support future scale-up of *The Pack* in NYC as it is tightly aligned with their goals and priorities.

C. RESOURCES AND MANAGEMENT PLAN

The project team has articulated a **four-year management plan** with tasks, timelines, and milestones (see management plan in Appendix I4) to address the project's **four objectives**.

C.1. Management Team Responsibilities and Expertise. To ensure the effective implementation of this project plan, **NYSCI—the lead organization**—has assembled a team of researchers, professional developers, and advisors with expertise in K-12 STEM education, including computational thinking, deep knowledge of New York State education leadership structure and systems of support, and the distinctive needs of students from backgrounds underrepresented in STEM. NYSCI will provide project leadership and oversight of all program activities, including developing the curriculum, professional development activities and the CoP model, and will maintain communications with all partners. ***NYSCI's Lead Staff*** are Stephen Uzzo, project director; Dorothy Bennett, co-project director; Michaela Labriole, program coordinator; Margaret Honey, senior project advisor; Katherine Culp, research advisor; and Leilah Lyons, computer science advisor (see Appendix B for resumes).

NYSCI is one of the nation's leading science and technology centers, offering STEM education through informal, hands-on learning programs, products and services to **300,000 K-12 students per year**, and highly effective professional development to approximately **2,000 teachers each year**. NYSCI's professional development offerings range from half-day workshops to intensive coaching and extended multi-week institutes. NYSCI engages teachers as professionals in learning, reflection, and dialogue; enables them to acquire STEM content and skills that are closely aligned with classroom practice and education frameworks; and provides resources that have been proven to work in classroom settings.

Participate will lead the online CoP model in New York City. Working with thirteen NYC community school districts, Participate will oversee the development of the online CoP platform, provide ongoing support to teachers to ensure the fidelity of implementation, and create a sustainability plan for the ongoing dissemination and use of the program in New York City. ***Participate Lead Staff***: Julie Keane, project manager; Elizabeth Radzicki, instructional designer (see Appendix B for resumes).

Participate is a for-profit education technology organization working with over 50,000 educators across the U.S and in more than 50 countries, including 390 teachers in New York State. Participate partners with organizations and school systems to build intentional online CoPs that engage educators in blended learning experiences. Participate's collaborative learning platform provides partners with tools and resources to build and scale meaningful learning experiences that strengthen relationships among educators. Participate serves 5,000 active teachers through roughly 150 CoPs every month. Participate's CoPs foster active, social learning and promote continuous cycles of learning, application, feedback and reflection. The staff includes educators, researchers, instructional designers, and technologists that provide support to educators to ensure effective development and implementation.

AIR will lead the independent evaluation. AIR will oversee the study design and execution, monitor quality assurance, and provide methodological direction. ***AIR Lead Staff***: Lawrence Friedman, co-project director; Jonathan Margolin, co-project director; Ryan Williams, analytic lead; Jingtong Pan, evaluation coordinator (see Appendix B).

AIR has 65 years of experience evaluating education implementations for local and state education agencies, the U.S. Department of Education, and private sector entities. NYSCI and

AIR's past partnership on an i3 development study (2012-2017) yielded a rigorous study of Playground Physics' impact (Friedman, Margolin, Swanlund, Dhillon, & Liu, 2017), and has resulted in a mid-phase EIR scale-up of the Playground Physics curriculum in New York State.

C.2. Management Team Interactions. Project leadership (project director, co-directors, project coordinator and Participate manager, advisors) will hold **monthly meetings** to monitor progress, recommend direction and make any necessary adjustments. They will ensure the project's research agenda is pursued effectively and remains aligned with project goals, and ensure that sustainability plans are developed.

The project directors and project coordinator will meet **bi-weekly** to review and discuss key implementation components, including recruitment of schools and teachers, product development, training of teachers, implementation support, evaluation studies, and dissemination. The evaluation team will join these check-in meetings as needed. This process will afford rapid responses to implementation challenges.

The project coordinator and relevant NYSCI and Participate staff will hold **weekly meetings** with a focus on training and supporting teachers and cultivating the online discussion forums. This team will work closely with district and school administrators and participating teachers to address their needs and ensure successful implementation in each district and school.

An **interdisciplinary team of advisors** will strengthen the work of the project team. The advisors include Andee Rubin, **senior scientist at TERC**; Stephanie Wortel-London, **research associate at CS4All**; Mark Guzdial, **professor of electrical engineering and computer science** at the University of Michigan; and Matthew Berland, **associate professor of digital media** at the University of Wisconsin - Madison (see Appendix B for resumes). Advisors will meet with project staff four times to assist with planning and mid-course modifications.

C.3. Timeline and Milestones The project timeline is organized into four phases: Launch and product development and testing in Year 1, implementation in Year 2, RCT evaluation in Years 3 and 4, and dissemination in Year 4.

Phase I: Launch and Product Development (Fall 2019 - Summer 2020): NYSCI will recruit ten teachers to serve as a Design Team to co-develop the game challenges and other curriculum guide resources with NYSCI and Participate. They will receive professional development and CoP support and will develop the resources and test them in their classrooms. They will also receive training on online facilitation, and will serve as mentors in the CoP for cohorts 1-3 in Years 2, 3, and 4. AIR will develop and test research instruments.

Phase II: Implementation (Fall 2020 - Summer 2021): In Year 2, Cohort 1, consisting of 24 teachers from 6 schools, will be trained (August 2020) and will implement the intervention in their classrooms. This implementation study will involve 3000 students, assuming five classes per teacher (25 students per class) and a total of 500 participating students per school. This pilot will allow us to evaluate the effectiveness of the planned implementation model and identify areas for improvement prior to conducting the RCT.

While implementing the intervention in their classrooms, pilot study teachers will have access to the online CoP platform, where they can access resources and connect with colleagues and project staff who can support their implementation efforts. Teachers within each school will coordinate with each other to facilitate use of materials and technology as needed.

Phase III: RCT Evaluation (Summer 2021 - September 2022): In Year 3, we will conduct an RCT to test the impact of *The Pack* intervention on students' CT engagement and skills. 192 teachers from 48 schools will participate in the RCT. 96 teachers from 24 schools will be randomly assigned to receive professional development in Summer 2021 and implement during the 2021-22 school year (Cohort 2). 96 teachers from 24 additional schools will be assigned to a delayed-treatment control condition and will be able to implement the intervention in Year 4.

Phase IV: Evaluation and Dissemination (Summer 2022 - September 2023): In Year 4, we will offer professional development to the delayed-treatment control group (Cohort 3), collect continuous improvement data to support a final round of program improvements, finalize the RCT findings, disseminate them broadly, and make final revisions to *The Pack* intervention.

D. PROJECT EVALUATION

AIR will perform an independent formative and summative evaluation throughout the four-year project. The proposed evaluation team consists of AIR experts who have led successful experimental evaluations of science curriculum and instructional interventions, including an experimental study of the *Playground Physics* program developed by NYSCI with an i3 grant (#U411C110310) (Friedman et al., 2017). The team will evaluate *The Pack's* logic model in two phases: A formative evaluation phase will provide feedback on the program's quality and usefulness and provide detailed information on implementation using mixed methods. A summative evaluation phase will measure the fidelity of implementation and impact of *The Pack* with a study designed to meet What Works Clearinghouse (WWC) evidence criteria without reservations. The team will support continuous program improvement in both phases.

D1. Formative evaluation. AIR will conduct a formative evaluation to provide NYSCI and Participate with timely evidence to support continuous improvement of each component of *The Pack* as it is being pilot tested with Cohort 1 teachers (participating from Fall 2020 to Spring 2021 and not in the experimental study). The formative evaluation will use mixed methods to provide feedback related to teacher perceptions of the quality and usefulness of key components of *The Pack*, document teacher participation in online CoPs, describe teacher and student use of *The Pack* in classrooms, and highlight barriers and facilitators to implementation (Table 4).

Table 4. Formative evaluation research questions, data sources, and analysis methods.

Formative Questions	**Surveys**	**Inter-views**	**Class Obs.**	**Extant Data**	
				CoP	**Pack**
FQ1. To what extent do teachers perceive *The Pack* components as useful for supporting integration of CT into science classes?	X	X			
FQ2. To what extent and in what ways are teachers participating in professional development and online CoPs?				X	
FQ3. To what extent and in what respects do teachers and students use *The Pack* in science classes?	X	X	X		X
FQ4. What are barriers and facilitators of *The Pack* implementation?	X	X	X		

FQ = formative question.

Formative data sources. The evaluation team will use qualitative and quantitative methods to depict perceptions of the program and implementation of program components. Post-professional development workshop surveys will capture perceptions of professional development quality and effectiveness and suggestions for improvement (FQ1). Data obtained from the online CoP platform will provide metrics of teacher participation in Design Clinics and extent and type of interactions among teachers (FQ2). Classroom observations will provide in-depth real-time data on classroom implementation (FQ3 and FQ4); we will observe eight teachers (two each in four schools, sampled randomly) twice per year, for a total of 16 observations, with each of the twelve game challenges observed at least once. Trained observers will record enactment of activities and instructional strategies (e.g., use of algorithms, student discussion, application of CT to scientific problems) with structured rubrics. Usage data from *The Pack* will describe duration of app use across all participants (FQ3). A teacher survey, administered upon completion of CT skills instruction, will ask teachers to identify which New York State learning standards related to computational thinking they addressed with *The Pack* (FQ3), and what barriers they encountered (FQ4). Semi-structured interviews with the same eight teachers sampled for the observations will address all formative questions.

AIR will conduct descriptive quantitative analyses, providing graphical summaries of findings (e.g., survey response frequencies, percentages of classrooms implementing each game challenge, average duration of usage of *The Pack*). AIR will conduct a systematic qualitative analysis by coding and categorizing interview data and content of online CoP discussions, deriving the initial coding structure from the logic model and verifying interrater reliability.

Formative evaluation deliverables. During the pilot study, AIR will share continuous improvement reports with NYSCI and Participate at three points: following the professional development workshops (Fall 2020), following the first semester of classroom implementation (Winter 2021), and upon completion of classroom implementation (Spring 2021). During the formative phase, AIR will also pilot test, refine, and finalize the implementation fidelity and outcome measures to be incorporated into the summative evaluation.

D2. Summative evaluation. The summative evaluation will focus on the implementation and outcomes of *The Pack* across schools in Cohort 2. Program implementation and data collection will occur during the 2021-22 school year, with data analysis, reporting and dissemination in 2022-23. Three confirmatory research questions aligned with *The Pack's* logic model and project goals will guide this phase (Table 5). The evaluation will incorporate multiple sources of implementation data and established, psychometrically sound outcomes measures. Additional analyses will examine two exploratory research questions.

Table 5. Evaluation Questions and Data Collection Tools and Measures

Confirmatory Research Questions	Data Collection Tools and Measures
RQ1. To what extent are key components of *The Pack* implemented with fidelity?	a. Post-workshop surveys b. Professional development workshop attendance records c. Extant data on participation in online CoP d. Teacher survey on *The Pack* implementation e. *The Pack* usage data on student participation
RQ2. What is the effect of *The Pack* on 6^{th} – 8^{th} grade students' engagement in computational thinking during science class?	Student engagement survey (Wang, Fredricks, Ye, Hofkens, & Linn, 2016)

RQ3. What is the effect of *The Pack* on 6th- 8th grade school students' computational thinking skills?	Computational Thinking test (Román-González, Moreno-Leon, & Robles, 2017)
Exploratory Research Questions	
RQ4. What is the relationship between extent of classroom implementation of *The Pack* and students' engagement in computational thinking and CT skills?	
RQ5. Does the impact of *The Pack* on students' engagement in computational thinking and CT skills differ as a function of student or school demographic characteristics?	

Evaluating fidelity of implementation. AIR will evaluate the fidelity of implementation of Cohort 2 (RQ1) with reference to the key program components: 1) facilitation of professional development and online CoPs by NYSCI and Participate trainers; 2) teacher participation in professional development and online CoPs; and 3) classroom implementation of *The Pack* (see intervention logic model, Appendix G1). AIR will co-construct indices with NYSCI to indicate thresholds for implementation fidelity for each intervention component, and will use these indices to investigate which intervention components need additional supports to ensure fidelity of implementation. Each component may have multiple indicators (e.g., classroom implementation will include number of game challenges implemented and duration of classroom use of *The Pack*). The analysis of each component involves first determining fidelity for individual teachers, then determining the level of fidelity across teachers for the indicator, and then considering the fidelity levels across indicators to determine the component-level fidelity. Implementation measures will be derived from the quantitative data sources included in the formative evaluation (see Table 5). Further detail about the measurement of key components is offered in Appendix I5. AIR will conduct a descriptive quantitative analysis to depict variations in implementation based on school and classroom contexts. This information will be used for continuous improvement of *The Pack* intervention.

Valid and Reliable Measures of Primary Outcomes. Two student outcomes in *The Pack* intervention logic model will be measured for students in Cohort 2 and in a delayed treatment control group during 2021-22, once prior to the start of instruction related to CT skills, and once upon completion of instruction related to CT skills: (1) **Students' engagement in science class** (RQ2) will be measured using items adapted from the Science/Math Engagement Scale (Wang, Fredricks, Ye, Hofkens, & Linn, 2016). The items in this scale address three related dimensions: active participation, enjoyment, and strategic thinking in learning while participating in science class. Example items include "I enjoy learning new things about science," and "I try to understand my mistakes when get something wrong." This scale has shown good measurement invariance and predictive validity of science course grades in a 6^{th}–8^{th} grade student sample with an internal reliability of 0.92. In addition, the scale has been reported with structural validity in culturally diverse samples (e.g., Zhang & Lee, 2018). (2) **Students' computational thinking skills** (RQ3) will be assessed by the Román-González, et al. (2017) Computational Thinking test (CTt). This assessment focuses on formulating and solving problems by using the logic of programming languages of basic sequences, loops, iteration, conditionals, functions and variables. The assessment tasks align with the CT skills that are the focus of *The Pack* and that are described in the K-12 Computer Science Standards (CSTA, 2017). The CTt is a multiple-choice test of 28 items administered in a maximum time of 45 minutes. The CTt has been reported with good convergent validity ($r > 0.5$ with a previously validated measure) in prior studies in multiple samples of 6^{th}–8^{th} grade students with an internal consistency of 0.92 and test-retest stability of .70 (Román-González, Pérez-Gonzàlez, Moreno-León, & Robles, 2018).

Evaluation design that meets WWC standards without reservations. AIR will conduct an experimental study using a cluster-randomized design to determine whether students attending schools randomly assigned to participate in *The Pack* have different outcomes than students attending schools randomly assigned to a delayed treatment control condition. AIR will conduct the random assignment at the school level, because the intervention is a whole-school design in which all science teachers participate in the professional development and online CoP.

AIR will randomly assign participating schools to the treatment group (i.e., Cohort 2) and the control group. School-level randomization reflects the anticipated school level-adoption of *The Pack.* Science teachers in schools assigned to the treatment group will receive *The Pack* intervention professional development, support, and materials and implement the program in their classrooms 2021-22. Science teachers in schools assigned to the delayed-treatment group will provide business-as-usual science instruction in 2021-22, and then receive *The Pack* and participate in final improvement testing in the following year. This period of contrast is sufficient to estimate the effects of *The Pack* because the program's ongoing support (via the online CoPs) is expected to enable teachers to achieve full classroom implementation in one school year.

Sample. The estimated sample for the impact study includes 48 schools, 192 science teachers (including treatment and control teachers), and 24,000 students in grades 6, 7, or 8 during 2020-21. NYSCI, supported by AIR, will recruit 48 middle schools from the thirteen New York City community school districts (which encompass 214 schools that serve middle school students) that have already agreed to participate (see letters of support in Appendix D and district demographics in Appendix I3). NYSCI and Participate have strong relationships to these districts through ongoing educational outreach. Because the intervention is at the school level, we will seek to secure study participation from all science teachers in each school and their students.

Power Analysis. In accordance with the sampling strategies, a power analysis estimated that the minimum detectable effect size (MDES) for student outcomes is 0.21, accounting for 8%

school-level attrition.[1] This estimated MDES is comparable to results from research syntheses of 6^{th}–8^{th} grade interventions using standardized achievement measures such as the NAEP assessments (Hill, Bloom, Black, & Lipsey, 2008). Details and assumptions of the power analysis are presented in Appendix I5.

Student Outcome Analysis. The analysis of the impact of *The Pack* on student outcomes will use a three-level model with students/teachers nested in schools nested in districts. The main impact model (addressing RQs 2 and 3) will be a mixed-effects regression model (see Appendix I5 for the analytic model and additional details). AIR will also use descriptive and correlational analyses to address two exploratory research questions: the relationship between extent of classroom implementation and students' computational thinking skills and engagement (RQ4), and whether impact differs as a function of student or school demographic characteristics (RQ5).

D3. Effective strategies for implementing and scaling. AIR's evaluation of *The Pack* intervention will generate guidance about effective strategies for implementing and scaling the program. The formative evaluation analyses will identify barriers to and facilitators of program implementation, and suggest classroom contexts or school conditions that may be best suited to benefit from the program. The summative evaluation will provide findings regarding the extent to which intervention components are implemented with fidelity, providing guidance for further improvements to the intervention and its implementation model. Exploratory analyses will identify which components are most critically related to improved student outcomes, and whether these outcomes differ among students with different demographic characteristics or from different school contexts.

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[1] The school-level design is robust to attrition because there will be multiple participating teachers per school, and school clusters can be retained with one teacher remaining.

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