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Furthering Rural Adoption of Computers and Technology through Artistic Lessons (FRACTAL)

WestEd, Katabasis, Empirical Education Inc. (Empirical), and Bertie, Granville, Jones, and Robeson County Public Schools in North Carolina (NC) propose an early-phase Education Innovation and Research (EIR) project to enhance, extend, and experimentally test an innovative intervention to improve access to and interest in computer science (CS) among high-needs rural students. These students include students in groups that have been historically marginalized in computing (e.g., Black, Latinx, and Native American students), students in the lowest achievement quartile, students with disabilities, and students from low-income and under-resourced backgrounds. High-need groups frequently have limited access to technology, at home and at school, and limited opportunities to learn about CS. The Furthering Rural Adoption of Computers and Technology through Artistic Lessons (FRACTAL) project will be built upon Katabasis's successful implementation of STEAM+CS camps where students build computers, learn how they work, develop coding and computational thinking skills, and get to ***keep the computers*** at the end of the camp experience. Art and design are heavily emphasized in each activity, to recontextualize CS as dynamic and culturally relevant. By working with the teachers and students in partner counties, WestEd and Katabasis will co-design an extension of a middle school art and CS curriculum that integrates computational thinking, Universal Design for Learning (UDL), and Culturally Responsive Pedagogy (CRP) for rural students. FRACTAL will (a) ignite middle school students' positive attitudes toward CS, STEM (Science, Technology, Engineering, and Mathematics), and STEAM (also known as STEM + Art); (b) increase these students' participation in STEM and STEAM; and (c) foster their CS knowledge and skills. By focusing on and emphasizing the cultural relevance of STEAM for rural communities, we will help students develop identity and agency with CS and STEAM, and we will help many students take the first step toward potential high-paying careers in CS.

This project addresses Absolute Priority 1, *Demonstrates a Rationale*; Absolute Priority 3, *Field-Initiated Innovations: Promoting STEM, With a Particular Focus on Computer Science*;

Competitive Preference Priority 1: *Promoting Equity in Student Access to Educational Resources and Opportunities*; and Competitive Preference Priority 2: *Innovative Approaches to Addressing the Impact of COVID–19 on Underserved Students and Educators*. For more details on how FRACTAL meets these priorities, please see Appendix J.1. This work focuses on the needs of ***rural students*** and their teachers and meets the EIR requirements for a rural applicant. This project is a partnership between three nonprofit organizations, one located in a rural setting (Katabasis), and four rural local educational agencies. FRACTAL will engage eight teachers and 100 high-need students across four rural NC counties during the co-design phase, and 57 teachers and 3,420 high-need students in 19 rural NC middle schools during the pilot study. This project's multidisciplinary team will create vanguard methods for promoting the adoption of a STEAM+CS curriculum in rural school districts to motivate rural students to enter the field of CS. We will accomplish this by co-designing STEAM+CS lessons that appeal to diverse rural students, supporting the formation of new CS identities, while reducing implementation barriers for teachers. Our goal is to make FRACTAL innovations available to rural student populations throughout the country.

Significance

Over the past few decades, advances in computing power and the widespread adoption of the internet have completely transformed the ways that people obtain information, communicate, educate, shop, and conduct business. Estimates suggest that the technology sector now accounts for more than $1.9 trillion of the economy, which is more than 10 percent of the U.S. gross domestic product (CompTIA, Inc., 2021; Sava, 2022). Further, it has been estimated that computer-related occupations will grow three times as fast as non-STEM occupations, contributing half a million new jobs in the next decade (Zilberman & Ice, 2021). Nearly all for-profit, nonprofit, and government entities require computers, software, and networks in order to maintain daily operations (National Research Council, 2012; CompTIA, Inc., 2021), and nearly all enterprises use technology as part of their strategic efforts to create value and to be more efficient. All of this work requires some level of computer literacy, and the work frequently requires CS skills (e.g., web design, Microsoft applications, and mobile-app navigation). Jobs in the technology sector are highly desirable, provide access to economic mobility for millions of Americans, and account for 10 percent of all jobs (CompTIA, Inc., 2021). However, leading companies cannot fill vacancies and must recruit workers through programs such as the H-1B program (Lin, 2021). The need for CS and computational thinking skills is only likely to grow (Zilberman & Ice, 2021), and it is imperative that CS education expands equitably.

Inequality and Inequity in Computers and Computer Science

Unfortunately, access to technology and to the training required to enter the technology sector are not equitably distributed in the United States (Dorn et al., 2020). These inequities—often referred to as the *digital divide* (U.S. Department of Education, 2021)—have been exacerbated by the COVID-19 pandemic, which has highlighted dramatic and pervasive inequities that have existed for generations. In some areas, families and school districts had access to computers, networks, and skills that enabled them to easily transition to fully online learning. In many other areas—notably in rural areas—access to hardware, software, and the internet was absent or inadequate during the pandemic (Gallup, Inc., 2020). This has resulted in under-resourced districts and communities disproportionately suffering during the pandemic (U.S. Department of Education, 2021). The urban–rural divide is a growing issue that affects many aspects of American life, including economic prospects, politics, and access to goods and services such as technology (Kopperam, 2020). Even before the pandemic, students in rural communities had less access to CS or STEM courses than their peers in suburban or urban areas (Cowie et al., 2020).

Compounding the difficulties that many people face when entering the technology field, the urban–rural divide also disproportionately affects people in groups that have been historically marginalized in computing and who live in rural areas. A lack of diversity in the technology field has been documented in the demographics of employees and of management, and in popular culture (Gallup, Inc., 2020). The workplace culture of many technology companies has been described as a “frat culture” where white men are welcomed and promoted and nearly all other demographic, racial, and cultural groups are either excluded or marginalized (Greenfield, 2012). Women represent just 28 to 42 percent of employees at Google, Apple, Facebook, Amazon, and Microsoft (Google LLC & Gallup, Inc., 2016b). Black, Asian, Latinx, and Native American employees make up 16, 16, 12, and .005 percent of the technology workforce, respectively (Google LLC & Gallup, Inc., 2016a). This ongoing pattern creates poor outcomes both for individuals and for the industry, depriving companies of the benefits that a diverse workforce brings to product design and market success (Gallup, Inc., 2020).

Reasons for These Gaps

The reasons behind poor access to technology, CS, and technology-sector jobs are many, varied, and often resistant to change (National Center for Science and Engineering Statistics, 2021). Many young people do not see individuals they identify with in technology leadership positions (Smith et al., 2017). This disparity can discourage girls and young people of color from taking CS and other STEM courses. It is imperative that students receive welcoming visions of CS early in their school careers (González-Pérez et al., 2020).

In addition to the lack of role models in CS in rural areas, CS as a course of study remains largely outside of the standards-based STEM curriculum in many U.S. schools. For example, CS is part of the curriculum in only 39 percent of schools in California, though the state is known as an epicenter for technology (Computer Science for CA, 2022). The lack of access is amplified further in rural schools, schools that predominantly serve children and youth of color, and under-resourced schools (Scott et al., 2019). Even in schools where CS education is available, the manner in which CS pedagogy has been historically implemented is a barrier for many students (Oldham, 2021). CS curricula that are heavily text-based, formal practice-based, exercise-based, and culturally irrelevant do not meet the needs of many potential students and do not align to the UDL framework (Yadav et al., 2016; Scott & White, 2013). There is a clear lack of CS curricula that meet the needs of students in rural and under-resourced areas and of children and youth of color and that are innovative, accessible, and culturally relevant. Our team is passionate about overcoming these barriers through engaging students in rigorous, culturally relevant, and hands-on CS experiences.

STEAM

STEAM education builds critical thinking skills by breaking down barriers between disciplines and is a promising method for making materials more socially and culturally relevant (Kant et al., 2018). STEAM provides students with engaging content, hands-on activities, and product-oriented activities, and engages student creativity. STEAM education has shown significant positive effects on learners in high-poverty areas in mathematics and science (Graham & Brouillette, 2016), creative thinking skills (Harris & De Bruin, 2018), and literacy (Inoa et al., 2014). These results also extend to struggling students and students with disabilities (Hwang & Taylor, 2016). However, these innovations are typically located in urban hubs; thus, extending STEAM+CS to greater numbers of rural communities is essential.

One of the overarching aspirations of STEAM is to motivate students to transition from being consumers of technology into being designers of technology (Honey & Kanter, 2013) and to meet the increasing demand for workers (CompTIA, Inc., 2021). Whereas STEM education has been criticized for not attracting diverse students (Vossoughi et al., 2016; Barton et al., 2017, STEAM has demonstrated tremendous potential for attracting and retaining a diverse set of students. This has been demonstrated with Black (Allen-Handy et al., 2020), Latinx (Lindberg et al., 2020), and Native American (Kant et al., 2018) students. These interventions lead to meaningful and lasting interactions with both STEM and art (Peppler & Wohlwend, 2018).

When personally motivated by self-expression, students demonstrate the ability to conquer complex coding problems (e.g., arrays, conditionals, and loops) to help their artistic visions come to life (Allen-Handy et al., 2020; Lindberg et al., 2020; Kant et al., 2018). These effects are in large part because of STEAM's ability to be highly culturally responsive, and to follow Hammond (2015)'s advice to "gamify it," "make it social," and "storify it."

Katabasis, a key member of our multidisciplinary team, runs ***free*** STEAM+CS camps for under-resourced rural youth, which provide students with informative experiences about hardware, programming, the internet, software, and games. In addition to building interest and efficacy in CS and STEAM, the camps enable participating students to ***keep the computers they build.*** The urgent goal of FRACTAL is to bring this innovative approach to school settings so that many more students can benefit, in order to address inequity in CS among rural students and to contribute to the knowledge base about successful programs. To meet this goal, we will co-design, build, and test four engaging STEAM+CS expeditions (sets of lessons around a core STEAM+CS theme) to be deployed in rural settings with high-need students.

Dissemination

The dissemination of FRACTAL expeditions, materials, lessons, insights, processes, and products will involve high-priority ongoing activities to reach the many audiences (e.g., rural communities, youth, educators, curriculum designers, technology companies) that are interested in FRACTAL, its findings, and in replicating it elsewhere. We will develop a project website and maintain an active social-media presence on Twitter, Facebook, Instagram, Snapchat, TikTok, and YouTube. This social-media presence will include project descriptions, lesson plans, examples of student work, student postings, how-to videos, materials, and research findings. Student work will also be showcased in local community centers and libraries. We will share our work nationally (e.g., National Rural Education Association, Computer Science Teachers Association), with NC education organizations (e.g., NC School Board Association, NC Art Education Association), and with technology organizations (e.g., CSforAll). We will present at education and innovation conferences, including the National Rural Education Association, American Educational Research Association, SXSW, and ISTE conferences, and we will submit manuscripts to practitioner and research journals, including the *Journal of Research on Educational Effectiveness*, the *Middle School Journal*, *Computers & Education,* and *Rural Special Education Quarterly*.

Quality of Project Design

FRACTAL is a unique and exciting collaboration between cutting-edge nonprofit organizations committed to improving the lives of children and four rural school districts to engage middle school students in STEAM+CS. FRACTAL brings together rural middle schools, students and their teachers, and experts in STEAM, UDL, CS, education innovation, and evaluation. Our logic model (see Appendix G) outlines the inputs, outputs, and outcomes. Our conceptual framework (see Appendix J.5) provides a visualization of the co-design process and intended impacts.

Our Approach

To improve STEAM+CS access and outcomes for students in rural communities, solutions need to (a) address the unique barriers that these students face; (b) be culturally relevant; (c) be based on hands-on experiences; and (d) encourage CS and computational thinking skills. To accomplish this goal, we will rely on UDL and CRP frameworks. Both UDL and CRP address ways in which "non-traditional" students (i.e., non—White cisgender males) experience barriers in traditional forms of instruction (Kieran & Anderson, 2019). Both the UDL and CRP frameworks encourage teachers to proactively consider students' differences as strengths and adjust their educational approaches to match the needs of their students.

Universal Design for Learning (UDL). UDL is a goal-driven instructional framework that brings together proactive and iterative cycles of instructional planning, proven educational practices, data collection and decision-making, and continuous improvement across a learning environment (Basham et al., 2020; Meyer et al., 2014). The basic premise of UDL is that barriers to learning occur in the interactions among learners' strengths, challenges, and preferences and the characteristics of curricula and that barriers are not solely inherent in the capacities of the learner. Three principles, based on neuroscience and educational research, underlie the framework of UDL: (a) multiple means of engagement, (b) multiple means of representation, and (c) multiple means of expression and action (see Appendix J.2; Meyer et al., 2014). The UDL framework enables curriculum designers and educators to anticipate, reduce, or eliminate barriers to learning by making the goals, methods, materials, and assessment flexible. UDL is increasingly being adopted as an instructional framework to address many education issues in K–12 settings across the United States. UDL is noted in the Every Student Succeeds Act (2015), the Individuals with Disabilities Education Act (2004), the Higher Education Opportunity Act

(2008), the Carl D. Perkins Career and Technical Education Act (2006), and the 2017 National Education Technology Plans (U.S. Department of Education, 2017).

UDL has been applied to a wide range of education challenge areas, including reading instruction for struggling readers and English learners (Dalton & Proctor, 2008; Proctor et al., 2007; Proctor et al., 2009), writing (Gravel, 2018; Hall & Graham, 2014), mathematics and science ([redacted] et al., 2018; Rose et al., 2008; Rappolt-Schlichtmann et al., 2013; Yu et al., 2020), and social studies ([redacted] et al., 2018). UDL is also useful for diverse student populations, from preschool (Horn et al., 2016) to postsecondary (Burgstahler, 2013; Kumar & Wideman, 2014) levels, as well as for students with significant cognitive disabilities (Coyne et al., 2012).

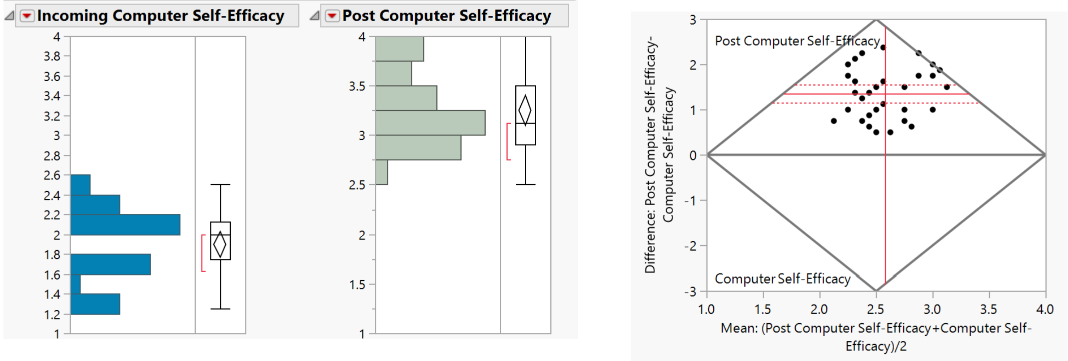
Culturally Responsive Pedagogy (CRP). In addition to the UDL framework, FRACTAL will be driven by CRP (Ladson-Billings, 1995). CRP is a theoretical instructional framework that targets multiple aspects of student achievement and engagement by supporting the varied identities of students in the classroom. CRP is student-centered, with teachers identifying and nurturing the individual, cultural, and linguistic strengths of students in the context of learning in the classroom (Gay, 2002, 2010). In CRP, student strengths are viewed as essential to academic engagement and achievement (Gay, 2010; Sleeter, 2012). Further, the CRP framework includes three essential dimensions that align and strengthen UDL as a framework: (a) maintaining high academic expectations with appropriate scaffolding; (b) reshaping curriculum around cultural competence, building on the “funds of knowledge of students,” and (c) cultivating relationships with students and families; and developing the critical consciousness of power relations and societal inequalities (Ladson-Billings, 1995). Teachers who utilize CRP practices privilege students’ cultural and linguistic resources and view these resources as capital to build upon, rather than as barriers to learning. CRP has been applied to STEM (e.g., Abdulrahim & Orosco, 2020; Davis & Allen, 2020) and STEAM (e.g., Emdin, 2010; Kant et al., 2018), and it has been used with a wide range of learners, including elementary, secondary, and postsecondary students and pre-service and in-service teachers (Brown et al., 2019; Webb & LoFaro, 2020).

Katabasis STEAM+CS Camps. The preexisting Katabasis STEAM+CS summer camps embrace student variability by using the UDL and CRP frameworks and will serve as a starting point for this project. In the summer camps, students learn about computer engineering and CS, are exposed to artificial intelligence (AI) and concepts from robotics, and make connections between their personal lives and computing through hands-on, experiential learning. The camps have a heavy emphasis on art and design, and learners build and decorate computers to take home. Through these experiences, students learn that their computers are not mysterious black boxes, and skills they gain will allow them to use their computers and fix them if they break at home. These camps provide children with the computing materials that they lack and increase student self-efficacy in computing.

Katabasis's four-day STEAM+CS camps are ***free*** and are implemented in partnership with community organizations that serve low-income rural areas. The first day of camp focuses on hardware. Students learn how each component (e.g., motherboard, power supplies, CPU, RAM, I/O) functions and how to put the pieces together, and they paint and individualize the computer case. The second day focuses on other programmable devices, such as drones and robots; students program a drone to fly around an obstacle course that they create and innovate designs for new robots that could help them overcome day-to-day challenges (e.g., picking up trash or filling in potholes). The third day focuses on understanding and utilizing the internet; basic web design; and group discussions about how to be safe online. Staff teach students how to train their own AI programs to recognize pictures and hand gestures, and then help learners understand reasons for misidentification of images. The final day of the camp focuses on installing software and analyzing games that the students have played, applying their new computational thinking skills to theorize about how the game works.

To evaluate the promise of the Katabasis camp experiences, we conducted pre-post surveys of campers who attended the camps which resulted in students taking home a working computer. Campers reported significantly higher levels of computer efficacy (Figure 1). These findings were also robust across gender and racial categories.

Figure 1. Differences in Incoming and Outgoing Computer Science Efficacy



Broadening Katabasis' Reach into Middle Schools (Years 1–3)

To reach more students in rural settings, we will collaborate and co-design with teacher partners to extend and enhance the Katabasis STEAM+CS camp program by developing, implementing, and testing FRACTAL in schools. Co-designing with teachers involves them in the entire iterative design process, leveraging their expertise to make joint decisions with the research staff (Roschelle et al., 2006). This equitable relationship between teachers in Bertie, Granville, Jones, and Robeson Counties and our research team will result in a set of four expeditions (sets of lessons around a core STEAM+CS theme) that are founded on teacher perspectives and expertise and that are aligned with UDL and CRP frameworks. Incorporating teacher perspectives into the co-design process will support the development of FRACTAL expeditions that are culturally relevant, feasible for school implementation, and aligned with the needs of students. We will partner with both STEM and art teachers for the co-design process and will continue to iterate the process and create expeditions in each of the first three years of the project. These teachers can advocate for the needs of rural students and will be respected on the design team as experts on their students' needs and on the curricula they teach. This collaboration will fuel our development process, and we will continue to collaborate with teachers as co-authors and co-designers throughout the co-design portion of this project.

To guide our co-design efforts, we will utilize the Stanford D. School Design Thinking Process (see Appendix J.4). This process involves five actions: ***empathize, define, ideate, prototype,*** and ***test***. We will begin the co-design process by building rapport and relationships between the participating teachers and the research and development team to mitigate potential power differentials and build understanding of one another's points of view through sharing expertise and knowledge. We will also introduce, or refresh the teachers' knowledge of, UDL, CRP, and technology/AI concepts that we plan on teaching in FRACTAL, through a two-day professional development workshop prior to the beginning of the semester in which the teacher is co-designing FRACTAL. Teachers will be asked to engage in reflective exercises to co-design the professional development protocols needed to support teachers in building knowledge and capacity, as well as implementation procedures. To continue supporting teachers in implementation and in building knowledge and capacity, we will provide a biweekly coaching professional learning community (PLC) during implementation of FRACTAL expeditions. In the PLC, teachers will be able to share their expertise and experiences with one another, and to troubleshoot problems and receive technical support from research staff.

The FRACTAL expeditions will be co-designed with participating teachers and include three foundational STEAM+CS tenets in each expedition. (1) ***Computational Thinking*** allows students to take a complex problem, understand what the problem is, and develop possible solutions that a computer, a human, or both can understand. There are four key techniques in computational thinking: (a) decomposition—breaking down a complex problem or system into smaller parts; (b) pattern recognition—looking for similarities among and within problems; (c) abstraction—focusing on the important information only; and (d) algorithms—developing a step-by-step solution to the problem or the rules to follow to solve the problem (Kalelioglu et al., 2016). (2) ***Design Thinking*** provides an iterative, solution-based approach to solving problems. In this process, students seek to understand problem, challenge assumptions, and redefine problems to identify alternative strategies and solutions that might not be initially apparent (Arifin & Mahmud, 2021). (3) ***Digital Expression*** refers to the use of technology tools to illustrate, communicate, and create meaning. An example in this project is algorithmic art, which is computer-generated art whose design is created automatically by an algorithm or code. The applications of digital expression are ubiquitous and growing, including graphic representations (e.g., pictures, maps, or graphs), infographics, memes, avatars, emojis, Instagram stories, and TikTok videos. In addition, music creation has been influenced technology (Behmer, 2005). These forms of expression and consumption have become the vocabulary for the digital age.

Each expedition will utilize these tenets to structure the motivation of the project and the class discussions to promote ideas that are unique and personally and culturally relevant to each student. The first expedition will introduce students to digital art tools and have them create artifacts that represent meaningful elements in their community (e.g., family, friends, school). The second expedition will then have the students reflect on how computers "think" and implement algorithms to generate art. The third expedition will be a deeper dive into how computers "think," introducing the students to AI concepts and having them train an AI to generate abstract images inspired by student artifacts from the previous expeditions and by training inputs selected by the student. The final expedition will ask the entire class to create an AI that includes elements of each student's creations thus far, merging and resolving conflicts within code, to create an illustration that represents the entire classes' and journey through FRACTAL. Computer building occurs across all expeditions and culminates in the final one.

Table 1. Proposed Themes, Elements, and Deliverables of Expeditions

	Expedition 1	Expedition 2	Expedition 3	Expedition 4
Theme	Foundations of Digital Art	Algorithmic art	AI "Dreaming"	Collaborative AI
Participants	Individual students	Individual + AI	AI (semi-supervised ML)	Group + AI
Knowledge elements	• Graphic design • Cultural representation	• Algorithmic art • Human/computer interaction	• Machine learning (ML) • Teachable AI	• Merging rules • Human/computer teaming
Deliverables	• Culturally relevant artifacts • Elements for input into follow on expeditions	• Rules-generated algorithmic art • Rules for generating FRACTAL art style	• Three AI models • Reflection on what caused differences in model artifacts	• Group projects • Picking best elements from individual projects to merge into group artifact

Together, teachers and the FRACTAL design team will plan how to integrate these concepts and expeditions into teachers' classrooms and existing classroom routines. In our co-design work with teachers, we will employ a systematic iterative approach from improvement science, called Plan, Do, Study, Act (PDSA) cycles (Bryk, 2015). Within this approach, we collaborate with teachers to: (1) ***Plan***, including defining the objectives, design lessons, materials, and procedures; (2) ***Do***, including implementing the approach with small numbers of students; (3) ***Study***, including using data to evaluate the practicality, resonance, and effectiveness of the approach; and (4) ***Act***, including using the observed process and outcome data to make changes to improve approaches, materials, or procedures. In FRACTAL, we will use PDSA cycles repeatedly during the co-design phase to reach solutions that are both practical and efficacious.

The FRACTAL design team will use well-established co-designing techniques, such as character profiles, mind mapping, and affinity diagramming, with participating teachers to promote a robust ideation phase. By revisiting the co-design process frequently, we will be able to leverage real data to improve our ideas. We will build, mockup, and iterate expeditions together. The expeditions will be engaging, content rich, and culturally relevant; will promote personal connection and creativity; and will be feasible for enactment in schools. Expeditions will be tested in the co-design and pilot-study phases, and we will collect both quantitative and qualitative data to understand the feasibility, acceptability, and potential impacts of each lesson within the expedition. The two and a half years of FRACTAL co-design will result in the development of four two-week-long expeditions, with each expedition containing a set number of related lessons around a STEAM+CS theme.

After the co-design process, the fully developed co-designed program will be manualized via videos, how-tos, and online resources. Critical features of FRACTAL include: (a) increasing computer and CS self-efficacy; (b) teaching students critical CS and STEAM skills; (c) building student computing skills, including the ability to build a fully functioning computer; and (d) motivating rural high-need students to pursue careers in technology. FRACTAL expeditions will be innovative, motivating experiences that are appropriate for all middle school students.

Teacher Support and Project Sustainability. To facilitate the adoption of these expeditions into the classroom, we will create a web portal to host lectures, how-to videos, materials lists, teacher training materials, and support forums where teachers can connect and learn from one another. This web portal will be co-designed with teacher partners and iteratively improved throughout the project. The guiding principles in its design will be: (1) non-technical ease of use; (2) support for a wide range of teachers (e.g., experience, familiarity with technology), and (3) facilitation of an open and inclusive environment.

Student Experience Vignette. To illustrate a learner experience with the envisioned program, consider the following scenario with a young girl named Zoey. Zoey is twelve years old and in seventh grade. She enjoys her middle school art classes very much, but has been hesitant to take technology classes, due to her lack of access to a computer in her home and her general feeling of anxiety that she would break a computer if she had one. Her grandmother has told her many times that they do not have the money to replace items that she breaks. In the week that her art class began the FRACTAL STEAM+CS program, she built her own computer and used it to learn about graphic design and to create digital art that expresses her interest in music and her love of her family's annual summer BBQ. In the following week, she was introduced to the branch of graphic design called algorithmic art. Over the course of that week, she learned about how computers could generate interesting and beautiful patterns and geometries based on algorithmic input. As she learned more about these algorithms, she was able to use them to experiment and develop her own creations. Her classmates were very impressed with her infinite sunflower, and throughout the rest of the expedition, she was an eager participant in the class; her CS self-efficacy has increased significantly, and she has been proud to show off her infinite sunflower on social media. The next week is the week that she has been looking forward to most. In this week, she will learn how to teach a computer to generate unique art, based on her aesthetic interests and on iterative guidance that she inputs with each round of "AI dreaming" machine learning guidance. Two weeks earlier, she would have found the prospect of programming an AI to be daunting, but after seeing firsthand how the rules in the previous week's expedition activities produced such fascinating designs, she is eager to experiment with the new computational techniques to train her AI.

Project Plan

Goals, Objectives, Activities, and Outcomes. Table 2 specifies the five project goals and associated objectives, activities, measures, and outcomes. Goal 1 is to improve access to, achievement in, and interest in computers and STEAM+CS among high-need students in rural areas. Goal 2 is to develop and collaboratively co-design and refine interdisciplinary content from CS and STEAM to increase rigor and relevance in CS curricula and pedagogy in preparation for implementation. Goal 3 is to create professional development materials to support implementation and increase teacher self-efficacy, knowledge, and practice in STEAM+CS. Goal 4 is to conduct an experimental evaluation of FRACTAL's effects on students' knowledge, self-efficacy, and practice in STEAM+CS. Goal 5 is to support dissemination and scaling of FRACTAL for use in other rural communities.

Table 2. Goals, Objectives, Activities, and Outcomes

Goal 1: Improve access to, achievement in, and interest in STEAM+CS among high need students in rural areas		
Activity	Measure	Outcome
Objective 1.1: Increase the number of computers owned by rural, low income middle school students		
1.1.1 Build computers in partner classrooms	# of computers built and taken home	Increased access to computers in low-income households
Objective 1.2: Increase computer literacy and STEM achievement		
1.2.1 Analyze CS/STEM scores	% increase in test scores and % grades increase	Improved CS/STEM achievement
Objective 1.3: Increase student interest in pursuing CS and STEM knowledge/careers		
1.3.1 Improve attitudes toward CS and STEM	CS Interest Scale; STEM Career Interest Scale; CS Self-Efficacy Scale	Increased representation of target populations in CS fields
Goal 2: Develop and collaboratively co design and refine interdisciplinary content from CS and STEAM to increase rigor and relevance in CS curricula and pedagogy in preparation for implementation		
Activity	Measures	Outcomes
Objective 2.1: Build and test FRACTAL expeditions, content, procedures, and implementation supports		
2.1.1 Recruit teachers	# STEM and art teachers participating	Letters of agreement signed
2.1.2 Conduct curriculum survey	# of teacher surveys of existing STEM, STEAM+CS, and technology	Complete scan of curriculum and resource coverage
2.1.3 Co-design PDSA cycles	# expeditions identified and developed, including resources and materials	Four expeditions designed, refined, and tested
2.1.4 Field test design and data collection procedures of co-designed PDSA cycles	# of FRACTAL expeditions designed # of surveys # of observation protocols, # of procedures documents	Spring and summer tryouts include four expeditions, including training, process, workflow, and procedures tested Surveys created, tested, and entered into Qualtrics
2.1.5 Field test	# of FRACTAL expeditions fully implemented and tested	Four expeditions piloted; survey, performance/process data collected
2.1.6 Analyze field test	See FRACTAL measures in Appendix J.8	Procedures, assessments, protocols revised

results and revise		based on pilot results
Goal 3: Create professional development materials to support implementation and increase teacher self efficacy, knowledge, and practice in STEAM+CS		
Activity	Measures	Outcome
Objective 3.1: Create professional development (PD) materials		
3.1.1 Create PD resources	# of PD materials	Draft FRACTAL PD materials created
Objective 3.2: Increase teacher confidence in implementing a new STEAM lesson		
3.2.1 Analyze teacher CS & STEAM self-efficacy	BaCCT Scale; Computer Science Pedagogical Content Knowledge Instrument	Increased teacher STEAM self-efficacy
3.2.2 Hold biweekly co-designed PLC meetings for teachers	# of PLC meetings attended by teachers	Draft PLC materials and resources created
Goal 4: Conduct experimental evaluation of FRACTAL's effects on student knowledge, self efficacy, and practice in STEAM+CS		
Activity	Measures	Outcome
Objective 4.1: Conduct experimental evaluation		
4.1.1 Two-day professional development prior to implementation	# of professional development sessions	Teachers have background knowledge, practice, and technology skills to implement expeditions
4.1.2 Implementation in partner schools	# of FRACTAL expeditions implemented	Teachers implement a minimum of four FRACTAL expeditions. Teacher capacity is increased. Students gain engagement, CS/STEAM knowledge.
4.1.3 Teacher and student survey, observation, and performance data	# of onsite observations conducted % response rate on surveys of attitudes, reactions, and recommendations # of tests completed following FRACTAL expeditions # of STEAM+CS assessments completed	90% response rate. Data exist on implementation, CS motivation, and knowledge. Unit data exist Performance data exist Data shared
4.1.4 Analyze data	# of analyses, tables, and visual displays	Implementation, impact, mediation, moderation analyses conducted. Implementation fidelity and outcomes available.
4.1.5 Evaluation report	# of evaluation reports submitted	Formal summative report of evaluation findings submitted
Goal 5: Support dissemination and scaling of FRACTAL for use in other rural communities.		
Activity	Measures	Outcomes
Objective 5.1: Build knowledge, evidence, and practical tools needed to support dissemination and further scaling of FRACTAL in high need rural schools		
5.1.1 Sustainability strategy development	# of cost effectiveness analyses # of updated PD resources # of online resources developed	Cost information available. Online resources created.
5.1.2 Complete development of PD resources	# of PD resources created	Resources exist to support schools interested in adoption or experimentation
5.1.3 Dissemination	# social media posts; one-pagers, videos, how-to guides; conference presentations and journal articles	A rich array of information is available for different audiences and applications

Quality of Project Personnel

Overall project leadership will be the responsibility of [redacted] Research Director, Learner Variability and Impact, at WestEd. [redacted] has 25 years of experience in the design and implementation of innovative projects and interventions. His recent work has focused on innovation and UDL, including i3 projects in both development and evaluation roles. He is currently the principal investigator on an i3 project and NSF projects that created the Google App *Corgi* to support higher-order thinking in STEM among students with disabilities. He served on the Technical Panel for the 2020 National Education Technology Plan and teaches at the Harvard Graduate School of Education. He will be responsible for the overall design, implementation, analysis, reporting, fiscal management, and dissemination required for this project. FRACTAL's work will be carried out by the teams described in Table 3 (Staff resumes are included in Appendix B)

Table 3. FRACTAL Teams

The **Leadership Team** includes [redacted], PhD (WestEd), [redacted], PhD (WestEd), [redacted], PhD (Katabasis), and [redacted], PhD (Empirical). Dr. [redacted] is an expert in UDL, with experience in designing and evaluating education technologies. Dr. [redacted] has extensive experience in the creation and evaluation of interventions for high-need learners. Dr. [redacted] is an educational technology designer and creator of Katabasis's innovative STEAM+CS camps. Dr. [redacted] has extensive experience on EIRs with cluster randomized controlled trials involving technology.
The **Co-Design Team** includes [redacted] (Katabasis), [redacted] (Katabasis), [redacted], PhD (WestEd), and [redacted] [redacted], PhD (WestEd), and will lead the co-design and development of FRACTAL expeditions, materials, and procedures, including formative research efforts. Mr. [redacted] is a textile engineer with experience in product development and field evaluations. [redacted] is a computer scientist with experience in supporting students with barriers to technology. [redacted] has experience in implementing STEM interventions for high-needs learners.
The **Professional Development (PD) Team** includes [redacted] (Katabasis), [redacted] (Katabasis), [redacted] (WestEd), and [redacted], PhD (WestEd), and will collaborate on the co-design of development of FRACTAL professional development.
The **Research and Evaluation Team**, led by [redacted], PhD (Empirical Education Inc.), involves independent evaluation efforts, including instrument design, procedures, data collection, and impact analyses. [redacted], PhD (WestEd), will lead design research operations, including usage and usability data analyses.

Adequacy of Resources and Quality of the Management Plan

Management Plan—Project Timeline

The following timeline of activities and milestones (Table 4) listed below (see the Gantt chart in Appendix J.6 for more detail). Our team is experienced in collaborative and agile project management. We will meet regularly to review progress, to examine qualitative and quantitative data, to identify challenges and barriers, and to make timely changes when necessary.

Table 4. Timeline of Activities and Milestones

Activity	Milestones	Y1	Y2	Y3	Y4	Y5	Personnel
Objective 1: Increase the number of computers owned by rural, low-income middle school students							
1.1.1	Computers built and taken home	√	√	√	√	√	1, 2
1.2.1	Conduct analysis of CS, STEM achievement	√	√	√	√		1, 2
1.3.1	CS Interest Scale, STEM Career Interest Scale; CS Self-Efficacy Scale	√	√	√	√		1, 2
Objective 2: Build and test FRACTAL expeditions, content, procedures, and implementation supports							
2.1.1	Recruit teachers	√		√			1, 3
2.1.2	Curriculum survey	√		√			2, 3
2.1.3	Co-design PDSA cycles	√	√	√			2, 3
2.1.4	Field test design, data collection procedures		√	√			2, 3
2.1.5	Field test		√	√			1, 2, 3
2.1.6	Data analysis		√	√			2, 3
Objective 3: Create professional development (PD) materials							
3.1.1	PD resources		√	√	√	√	3
3.2.1	Analyze teacher CS & STEAM self-efficacy		√		√		3
3.2.2	Biweekly co-designed PLC meetings for teachers		√	√	√	√	
Objective 4: Conduct experimental evaluation							
4.1.1	Two-day professional development			√	√		3, 4
4.1.2	Implementation in partner schools			√	√		3, 4
4.1.3	Teacher and student survey, observation, and performance data			√	√		3, 4
4.1.4	Data analysis				√	√	1, 4
4.1.5	Evaluation report				√	√	4
Objective 5. Build knowledge, evidence, and dissemination tools							
5.1.1	Sustainability strategy development			√	√	√	1
5.1.2	Development of PD resources		√	√	√		1, 2
5.1.3	Dissemination	√	√	√	√	√	1, 2, 3, 4

1 = Leadership Team; 2 = Co-Design Team; 3 = PD Team; 4 = Research and Evaluation Team

Organizational Infrastructure and Strength of Partnerships

The FRACTAL organizational partners (see Table 5) share a mission of improving outcomes for all learners and have collaborated on multiple projects over many years. Staff from the FRACTAL partners will work in interdisciplinary teams to ensure that project activities are successfully carried out.

Table 5. FRACTAL Organizational Partners

WestEd will oversee FRACTAL. WestEd is best known for innovative applications of education interventions developed in collaboration with local schools. WestEd staff have expertise in design research and curriculum creation, including i3 and EIR initiatives.
Katabasis is the creator of the STEAM+CS summer camps upon which FRACTAL will be based. Katabasis is a nonprofit educational technology organization committed to bringing much-needed computer hardware and educational software to rural low-SES communities across NC. Programs have focused on delivering CS and STEAM content to middle school students in NC.
Jones County Public Schools (JCPS) will be a co-design and research partner for FRACTAL. JCPS serves 1,100 students across five sites. Jones Senior High School includes 163 7th and 8th grade students. Ninety-nine percent receive free or reduced-price lunch (FRPL); 38% are Black, 48% are White, and 11% are Hispanic.
Bertie County Public Schools (BCPS) will be a co-design and research partner for FRACTAL. BCPS serves 2,080 students across seven sites. Bertie Middle School includes 450 students, 84% of whom are Black and 95% of whom are FRL eligible.
Granville County Schools (GCS) will be a co-design and research partner for FRACTAL. GCS serves 7,055 students (58% FRPL eligible, 39% White, 34% Black, and 21% Hispanic/Latinx) across fifteen schools.
Public Schools of Robeson County will be a co-design and research partner for FRACTAL. Robeson County serves 21,083 students (100% FRPL eligible, 38% Native American, 24% Black, and 8% Hispanic) across 36 schools.
Empirical Education Inc. will oversee the external evaluation activities throughout the project. Empirical is an independent education research organization known for conducting experimental studies and evaluations in education, including i3 and EIR projects.

Cost Study

The proposed budget, totaling [redacted] over five years, is reasonable and adequate to support the efforts of FRACTAL staff and partners to fulfill project goals and objectives. We will leverage existing Katabasis and WestEd assets, including the STEAM+CS summer camp program and connections to computer vendors, to maximize the value of EIR investment. All FRACTAL students will build and keep a computer at no cost to the project through external donations. WestEd will lead a cost effectiveness study at the end of the project, using the ingredients method (Levin et al., 2017) and the impact effect sizes estimated by Empirical to evaluate implementation costs relative to effects.

Quality of Project Evaluation

Empirical will lead an independent evaluation of FRACTAL, including process, implementation, cost, and impact data, to address evaluation questions that prioritize Standards for Excellence in Education Research (SEER; https://ies.ed.gov/seer/). This proposal refers to SEER standards in the order listed by IES (SEER 1–8). Empirical has conducted more than 50 rigorous impact, formative, and process evaluations, including i3/EIR grants, a multiyear cluster randomized controlled trial (RCT) with 66 schools across multiple districts, and an IES-funded, STEM-focused RCT with randomization of 700 public schools.

The evaluation will include studies of (1) impacts of FRACTAL on confirmatory outcomes, using a design that meets What Works Clearinghouse (WWC) 4.1 Standards Without Reservations, preregistered in the Registry of Efficacy and Effectiveness Studies (REES) (SEER1); (2) fidelity of implementation (FOI) (SEER3 and SEER4); (3) a process study with rapid-cycle feedback to inform FRACTAL about FOI and factors that facilitate or impede program development, scaling, and potential replication (SEER8); and (4) a cost analysis and cost effectiveness study (SEER5) using the ingredients method (Levin et al., 2017) to support sustainability and to understand how resources may be directed to achieve maximum benefit.

Evaluation Questions

The evaluation will address questions concerning the implementation of key program components, and confirmatory and exploratory impacts on intermediate and final outcomes.

Table 6. Evaluation Questions and Data Sources

Evaluation Question	Data Sources
Are fidelity of implementation thresholds reached?	Results from teacher surveys and program records
What are the barriers and supports to successful implementation?	Teacher and developer surveys and interviews
What is the achieved treatment-control contrast?	Teacher surveys (per course section) regarding core CS activities aligned to FRACTAL implementation
Confirmatory Impact Question	
Is there a positive intent-to-treat impact of FRACTAL, relative to business as usual (BAU), on: 1. Computational thinking and self-efficacy in computational thinking? 2. Student achievement in mathematics and science? 3. Student interest/engagement in STEAM+CS?	Computational Thinking Test (CTT) (α = .80) Computational Thinking Efficacy Survey (α = .91) From district data: NC End-of-Grade (EOG) Test scores (α = .90 for math; α =.92 for science) Computing Interest-Confidence-Perception Survey STEM Career Interest Survey (C-SIS) (science α = .77; math α = .0.85; technology α = .89; engineering α = .86) Student Attitudes Toward STEM (α = .83)
Exploratory Impact Questions	

Evaluation Question	Data Sources
Impacts on potential mediators Is there a positive impact of FRACTAL on potential mediators of impact of confirmatory outcomes, including student interest/engagement in STEAM+CS?	CTT α = .80) and Computational Thinking Self-Efficacy Survey (α = .91)
Moderating/differential impacts Is there a differential impact of FRACTAL on outcomes listed above, depending on race/ethnicity, gender, disability status and specific disability, English Learner status, free/reduced-price lunch status, age/grade, prior year math and science achievement, and school students are enrolled in?	Computational Thinking Test (CTT) (α = .80) and Computational Thinking Self-Efficacy Survey (α = .91) Student demographic data collected from districts

Each key data source in Table 6 is described fully in Appendix J.9.

Fidelity of Implementation Evaluation

A. Fidelity of Implementation (FOI). The implementation study will utilize the FOI reporting system incorporated into FRACTAL. This system includes Specific, Measurable, Attainable, Realistic, Timely (SMART) goals/thresholds for monitoring objective performance measures and for integrating feedback. We will assess adherence to an ongoing adaptation of the program logic model (Appendix G), including key components, outputs related to inputs, and attainment of fidelity thresholds (SEER 3 & 4). Key components and fidelity thresholds are: FRACTAL recruits 57 teachers (19 schools x 3 teachers per school) for the RCT; FRACTAL provides all three-day blended trainings; FRACTAL delivers all core components of the program; at least 50 teachers attend at least 80 percent FRACTAL trainings; at least 50 teachers deliver at least 90 percent of program. Findings will be regularly shared with the FRACTAL team to decide whether key components of the program and fidelity thresholds have been met and to make adjustments if they have not been met.

B. Variation in Implementation. To understand barriers and supports in FRACTAL implementation (SEER4), during each phase (fall year 3, spring year 3, fall year 3), Empirical will survey all FRACTAL and BAU teachers three times (pre, during, post) regarding their instructional practices and routines, and will interview a purposively selected sample of 10 FRACTAL teachers to expand on themes in survey responses and to identify barriers and supports to implementation. This information will be reported to the FRACTAL team to support the program model during the project and to inform the development of a replicable model, including specification of a refined logic model. Surveys will cover beliefs about teaching computing, including self-efficacy (Teacher Beliefs about Coding and Computational Thinking [TBaCCT] survey; Cronbach's alpha = .70–.94), and CS pedagogical content knowledge (Science Pedagogical Content Knowledge Instrument alpha = nr).

C. Treatment-Control Contrast. Data from FRACTAL and BAU conditions about coverage of CS topics (especially of core topics such as computational/design thinking, human–computer interactions, graphics-related activities, algorithmic thinking, STEAM) will be obtained through teacher surveys, to evaluate the planned and realized treatment–control contrasts (Cordray & Pion, 1993; Weiss et al., 2014) and achieved relative strength of FRACTAL (Hulleman & Cordray, 2009).

D. Potential for Sustainability and Scale-Up. Surveys and interviews of key participants (including FRACTAL developers, teachers, and administrators) will establish school- and classroom-level conditions for sustaining FRACTAL (SEER8). This information will inform FRACTAL adjustments and support replication/scaling for new contexts.

Impact Evaluation That Meets WWC Standards Without Reservations

The confirmatory and exploratory research questions address key program components, main proximal outcomes, and final outcomes from the logic model. The confirmatory research question is as follows: Is there a positive intent-to-treat (ITT) impact of FRACTAL relative to business-as-usual (BAU) on computational thinking skills and self-efficacy in computational thinking? We will also explore ITT impacts on students' achievement in science and mathematics.

Samples. The study will examine impacts of FRACTAL on outcomes for 3,420 grades 6–8 students among 57 teachers in 19 rural middle schools in four rural counties in NC.

Randomization. We will randomly assign the 19 middle schools to either the treatment (FRACTAL) or control (BAU) condition, using the *blockTools* (Moore, 2012) package in *R*. Randomization will block by student and teacher demographics (e.g., race/ethnicity, free or reduced-price lunch [FRPL], school enrollment, numbers of art and STEM/CS teachers) to ensure that the schools are equivalent on key school-level characteristics in each condition at baseline. Schools will be randomly assigned in three cohorts, each lasting one semester: fall 2025 (6 schools), spring 2026 (6 schools), or fall 2026 (7 schools). We will recruit three teachers per school; we anticipate recruiting two art teachers and one STEM/CS teacher per school, or vice versa, with balance across the full sample. Typically, each teacher has three class sections (one per grade level) with 20 students per class.

The cluster-level RCT is designed to meet WWC 4.1 standards without reservations. Random assignment is of 19 schools, 57 teachers (3 per school), and 3,420 students (60 per teacher). We will exclude joiners after randomization, per WWC 4.1. Given the compressed implementation periods, realistically, we do not expect schools to attrite; however, for the power analysis, we assume, conservatively, a loss of two schools, five teachers (among non-attriting schools), and 300 students (among non-attriting teachers).

Statistical Power. We evaluated the minimum detectable effect size (MDES) for confirmatory impacts on proximal student outcomes (computational thinking skills, computational thinking self-efficacy), assuming a school randomized trial, with 17 schools, 52 teachers, and 3,120 students remaining post-attrition. We explored multiple scenarios, with several plausible assumptions about variance partitioning. We assumed 80 percent power, Type-1 error rate 5 percent, effect size multiplier of 3.1, and specific values of the ICC, R-squared and other parameters described in Appendix J.9. The MDES ranges between .25 and .30, and conservatively, we assumed the latter. This effect size is smaller than effect sizes observed in previous studies of impacts of similar interventions on similar outcomes (e.g., Scherer et al., 2020; Sun et al., 2021). We assume the two confirmatory outcomes to be from two different outcome domains; therefore, we do not apply corrections for multiple comparisons.

Impact Measures. Impacts will be assessed on outcomes listed in Table 6. Confirmatory analyses will be assessed using the Computational Thinking Test (CTT) and Computational Thinking Self-Efficacy surveys. Exploratory impacts will be assessed on distal student outcomes, including achievement on the eighth grade NC EOG tests in science and mathematics (α = .92

for both science and mathematics EOG tests) and interest in STEM classes and careers (as measured by the STEM Career Interest Survey (α = .77–.89). We will also have all teachers complete the TBaCCT (Rich et. al., 2020; α = .92) and the Computer Science Pedagogical Content Knowledge Instrument (Yadav & Berges, 2019; α = nr) to examine FRACTAL effects on teachers and for exploratory analyses.

Impact Analysis. Intent-to-treat estimates of impacts will be obtained using hierarchical linear models (HLM) (Raudenbush & Bryk, 2002; Singer, 1998) applied to cluster-level RCTs (Bloom et al., 1999; Bloom, 2005). The standard form of the benchmark impact model (detailed in Appendix J.9) will include an indicator of treatment status, student-level baseline covariates (e.g., gender, grade level, pre-intervention measures of the CTT and computational thinking self-efficacy surveys, FRPL eligibility, and race/ethnicity), teacher covariates, fixed effects for cohort, a limited set of school covariates (to reserve degrees of freedom for estimating impact), and school, teacher, and student random effects. Standard methods for imputing missing data will be explored, following WWC requirements, to allow the study to meet standards without reservations, including multiple imputation and the dummy variable method, in which cases with missing outcomes or pretests are listwise deleted (Puma et al., 2009).

For exploratory analyses, we will assess differential impacts on confirmatory outcomes for important student moderators (e.g., race/ethnicity, gender, disability status, English Learner status, FRPL status, age/grade, prior achievement scores) and teacher moderators (e.g., years of experience, beliefs about coding and computational thinking, and CS content knowledge). Analyses will be performed by adding the necessary interaction term into the main impact model. Questions of mediation of impact through preliminary impacts on distal outcomes through proximal outcomes will be conducted using a regression framework (e.g., Krull & MacKinnon, 2001) and principal stratification approaches (Frangakis & Rubin, 2002; Jo et al., 2011; Page, 2012). We will follow topic-area review protocols to report all statistics necessary to support WWC review. Analyses will be conducted using PROC MIXED and GLIMMIX in SAS, as well as specialized programs such as remediation (Tofighi & MacKinnon, 2011) and mediation in *R* (Imai et al., 2010).

Other Analyses. Researchers will also conduct a series of sensitivity analyses to test the robustness of benchmark impact estimates. These analyses will include conducting an Ordinary Least Squares (OLS) analysis with all outcomes and covariates aggregated to the school level, using full and restricted maximum likelihood estimation, excluding the middle (teacher) level, and using R software. For the confirmatory impact analyses, we will follow WWC topic-area review protocols to report all necessary statistics, including obtaining sample sizes at each stage in executing the study design, determining baseline equivalence on demographics and pretests, and calculating standardized mean difference effect sizes.

Evaluation Performance Feedback

A chief goal of the evaluation is to provide frequent performance feedback to project staff and assessment of progress toward intended outcomes that will allow ongoing adaptation and improvement of the FRACTAL model and its implementation. The co-design phase and implementation of the RCT pilot study will allow the evaluators to work with the project team to monitor progress and serve as a critical and independent thought partner, helping the FRACTAL team refine its logic model, titrate fidelity thresholds, and establish which program components are being implemented successfully or need refinement. As previously described, the process will follow PDSA cycles from improvement science (Bryk et al., 2015; Lemire et al., 2017). Working together in semester-long PDSA cycles during the co-design and the pilot study, WestEd, Katabasis, and Empirical, will identify specific questions that are critical to the continuous improvement of the program. The cycles provide an opportunity to evaluate evidence of each semester's implementation of FRACTAL, using data gathered during that time period. The long-term goals are to refine the program logic model and to provide data to support a viable and scalable process that is suited to mid-phase validation, dissemination, and scalability.

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