A. OVERVIEW

A.1. Introduction

Artificial intelligence (AI) is increasingly integrated into our daily lives. While improving human efficiency and quality of life, technologies that use AI or machine learning algorithms have been shown to reproduce inequities and further marginalize those from non-dominant populations, including women, people of color, and those who live in poverty (Noble, 2018; O'Neil, 2016). Although elementary school-aged children use and have interest in technologies with integrated AI applications (Lovato et al., 2019), they rarely investigate the broader social, historical, and political contexts in which people consume and produce AI technology. In other words, students are not encouraged to engage in ***critical computing*** which means understanding and critiquing existing computational infrastructures and reinventing technologies to promote awareness and social justice (Kafai et al., 2020). Without a critical computer science education, elementary school students will not be prepared to tackle the increasing sociopolitical consequences of algorithmic decision-making as they continue their schooling and careers. Thus, for elementary students to be prepared to participate in a digitally reliant society, ***a robust critical computer science education that includes reflection and action around sociopolitical issues is essential for all at an early age***. Unfortunately, there is still a limited understanding on how elementary students apply critical lenses to computing and few computing education programs available that focus on sociopolitical issues. Moreover, there is limited research on how to design with and for elementary school-aged children to create culturally relevant *and* critical computing educational experiences. My CAREER project proposal addresses these research gaps by conceptualizing, co-designing, and implementing an innovative critical computing education curriculum, what I am referring to as a CritComp Pop-Up, in which upper elementary school students evaluate and develop AI technologies through a critical lens. The CritComp Pop-Up contains three components: a Mission Control digital game, robotics and physical role-playing tools, and teacher-created classroom materials. I have a standing partnership with Title I schools in a South Carolina district with high numbers of African American students and students living in poverty. These students and teachers will participate with me in the co-design of curricula that are culturally responsive for Black students and focus on AI education that is relevant to their communities. The pop-up framing allows elementary school teachers the flexibility needed to integrate non-traditional units into their existing program (Fleer, 2020).

A.2. Research Goals

The research goals in this project are to (1) characterize the co-design processes that involve teachers and researchers designing critical computer science educational experiences with and for children in the context of AI; (2) measure and model upper elementary school students' computer science knowledge and practices when integrated with sociopolitical consequences of digital technologies; and (3) evaluate the effectiveness a critical computing curriculum students' interest and confidence in computer science. The research goals will be accomplished through (1) the design and implementation of a critical computing curriculum using a framework for ***culturally responsive-sustaining computer science education*** and ***design-based participatory research methods*** in which researchers, teachers, and children co-design the curriculum, and (2) the use of ***quantitative ethnography*** to analyze students' critical computing knowledge and practices and their developing interest in computer science. Findings from this project will include characterizations of how children develop computer science knowledge and practices through a critical lens and provide research-based best practices for the co-design of critical computing learning environments. This CAREER project will contribute to my overarching scientific goal to develop a theoretical learning framework for critical computing education, grounded in design-based participatory research methods, that bridges computer science education research and critical pedagogy theories.

A.3. Integrated Education Goals

The integrated educational goals are to develop and implement critical computing education curricula to (1) broaden participation in computing by engaging underserved students in examining the sociopolitical consequences of AI algorithmic decision-making, (2) foster children's interest in computer science through culturally relevant instructional methods focused on AI, (3) provide elementary school teachers with a sustainable model for integrating critical computing in their teaching, (4) provide students' families with social and educational events focused on critical computing, and (5) train undergraduate and graduate students in developing high-quality research competencies and knowledge around critical computing. The educational outputs include a digital learning game focused on sociopolitical issues in AI; flexible teacher guides and culturally relevant instructional materials; and heuristics for co-designing critical computing learning environments with stakeholders. Cycles of design-based participatory research will inform the educational outputs. All curricular materials and guides will be made publicly available as directed by the dissemination plan.

A.4. PI Qualifications

As a learning scientist, my research focuses on two tracks: 1) the design of equitable digital computer science and engineering learning environments, and 2) the development and implementation of inclusive learning analytics to model data from digital environments. I am a self-taught programmer and have a multi-disciplinary educational and professional background that has inspired my research and teaching. As a woman in mechanical engineering, I encountered marginalization and discrimination in my undergraduate studies. This experience fueled my passion for designing and implementing equitable education for all. I also rely on my prior experiences as a middle school computer science teacher and high school mathematics teacher when collaborating with teachers and students.

In my early work, I designed an undergraduate level engineering virtual internship intervention, *Nephrotex*, which broadened participation in engineering and modeled learning/identity development using digital game logs and discourse data (Arastoopour et al., 2014, 2016; Arastoopour & Shaffer, 2013, 2015; Arastoopour Irgens, 2019a, 2021; Chesler et al., 2013, 2015). My intermediate work investigated the integration of computational thinking into K-12 classrooms and co-designing with teachers (Arastoopour Irgens et al., 2019, 2020; Arastoopour Irgens, Bailey, et al., under review; Arastoopour Irgens, Vega, et al., under review; Bailey et al., 2021). Since obtaining a tenure-track position at Clemson University, I have developed a research lab, the IDEA lab, through which I mentor undergraduate and graduate students and collaborate on two NSF-funded research projects in which I am PI and Co-PI. I also developed two graduate courses, *Design of Digital Learning Environments* and *Quantitative Ethnography* that incorporate my research findings.

Intellectual Merit

This project integrates computer science education research and critical pedagogy theories to build new theoretical understandings about the nature of computer science learning in the centered context of sociopolitical issues. This developing learning theory has the potential to extend the learning sciences field's understanding of how children construct knowledge around computer science through a critical sociopolitical lens, provide researchers a framing for future research studies on critical computing education, and be a foundation to develop new critical computer science educational standards and curriculum. Moreover, using participatory design methods with teachers and children offers opportunities to co-design culturally relevant programs with all parties directly involved in the implementation of the curriculum and contributes knowledge about how to best facilitate collaborative experiences. This project will also advance knowledge and understanding of how elementary school students engage in computer science practices in ways that are valued within their own cultures, benefit broader society, and are of interest to children.

Broader Impacts

This project is estimated to involve 500 students, teachers, school administrators, and researchers in the co-design and implementation of a critical computer science education program. This broad reach exposes all stakeholders to computing education. This research takes place in a mixed rural-micropolitan area with schools that have a high percentage of African Americans and youth (Black, Latinx, and White) in poverty. This project serves these youth by providing culturally relevant experiences that may motivate them to pursue STEM majors and careers, thus broadening participation in STEM. Moreover, all youth will be impacted by this program by becoming aware of those who are marginalized by digital technologies and developing inclusive strategies for technology development. Because the program centers sociopolitical issues, this project contributes to the development of an ethical and well-prepared workforce. This project also enhances the career development and interdisciplinary expertise of the PI through an advisory board. The PI is also training graduate students who will be the next generation of researchers impacting ethical computer science education and teacher training/RPPs. Educational materials, such as the digital game, teacher materials, and participatory design heuristic guides, will be publicly available, enabling other school districts at a local and global level to adapt for instructional or research purposes. Research results will be disseminated through journals and conference publications, the PI's global workshop tour, media releases, and social media plan.

B. BACKGROUND AND SIGNIFICANCE

B.1. Everyday AI Experiences as a Pathway for Engaging Children in Computer Science

Computer science (CS) and computational thinking skills are fundamental for students of all ages. In an increasingly digital world, students will need skills for systematic problem solving, understanding complex systems, and creating algorithms (Barr et al., 2011). In turn, opportunities for CS education in K-12 have increased and educational standards have been develop to guide instruction (Computer Science Teachers Association, 2017). Moreover, researchers have developed tools, such as Scratch, specifically for children to engage in computational practices, facilitate their creativity, and become producers of technology (Brennan & Resnick, 2012). However, learning standards and tools have not kept up with the rapid expansion of AI's impact on society. AI is a broad term for describing machines that think or act like humans. AI systems are software and/or hardware systems designed by humans that perceive their environment through data acquisition and then rely on these data to take actions to meet a given goal. Machine learning is a practical implementation of AI. Humans build machine learning models based on training data to make predictions or decisions without being explicitly programmed to do so (Samoili et al., 2021). For example, more than half of U.S. households have some form of a conversational agent that relies on machine learning, such as Amazon's Alexa (Bratten, 2021). Alexa uses machine learning and collects voice data and feedback from users to improve its algorithms. Recent studies suggest that children use conversational agents to ask for factual information or play music (Lovato et al., 2019). However, children are confused about the capabilities of the agent (Sciuto et al., 2018) and anthropomorphize Alexa, assuming the machine to be friendly, funny, and trustworthy (Van Brummelen et al., 2021). Moreover, children are unaware of the ethical implications of how their data are stored or accessed (Szczuka et al., 2022). Conversational agents are one example of children's everyday use of AI devices. There is still much research to be done to uncover how children interact with these technologies and how to leverage their everyday experiences to engage them in CS, particularly from ethical and sociopolitical perspectives.

B.2. The Need for Critical Computing in CS and AI Education

Although there are currently no agreed-upon K-12 standards specific to AI, some researchers have outlined general guidelines and competencies for AI in K-12 (Long & Magerko, 2020; Touretzky et al., 2019). In terms of empirical studies, teams of educators and researchers have developed and tested various K-12 AI educational activities, such as MIT RAISE, AI4All, and AI4K12 initiatives. This current body of theoretical and empirical work is bringing ethics into the conversation for CS and AI education. ***However, ethical and humanistic orientations are not fully integrated throughout the proposed competencies nor tools and curricula***. This isolation of ethics is aligned with Borenstein and Howard's (2021) critique that "ethics should not be a slapped-on component after-the-fact, a standalone lesson, or a second thought. It is integral at every stage when learning about AI" (p. 62). Ethics and humanistic orientations are integral because AI is fundamentally a social enterprise. Each and every AI application has human assumptions, opinions, and biases embedded into the tool (Pea, 1993). When the human designers are not made visible, then such tools may appear singularly truthful and free of bias to users and as a result, this knowledge is fundamentally incomplete and culturally, politically, and historically limited (D'Ignazio & Klein, 2020). In addition, the ethics explorations in CS education tend to focus on a limited form of "microethics," centered on individuals making decisions when faced with dilemmas (Vakil, 2018). This narrow approach ignores the broader sociopolitical contexts of how technologies are developed and presents technologies as ahistorical and neutral. However, all systems, including those in CS, are embedded in existing historical and social systems. For example, Buolamwini and Gebru (2018) evaluated three commercial image classification systems used for facial recognition technology. The study was spurred by Buolamwini's experiences as a Black woman being misidentified when using facial recognition software. The researchers found that darker-skinned females were the most misclassified group, with error rates up to 34%, while the maximum error rate for lighter-skinned males was 0.8%. These error rates become particularly concerning when facial recognition systems are being used by U.S. government agencies to detect unlawful behaviors and in turn, (re)enforcing historic inequities against people of color. ***Thus, disassociating AI applications from the bodies and sociopolitical conditions that produce such technologies provides an inaccurate view of AI and does a disservice in terms of educating our youth.***

B.3. Critical Computing Education Research

To make sociopolitical issues central to the design of CS educational learning environments, researchers have been drawing on critical pedagogy theorists who argue that teaching and learning are inherently rooted in social, historical, political, and economic contexts (Freire, 1970; Giroux, 1985; Vakil & Ayers, 2019). Perspectives from marginalized populations are less visible in society. These include people with histories of slavery, with histories of colonization, who live in poverty, and people of color. Critical pedagogists argue for the examination of and resistance to such oppressive power structures. *Critical computing* is an approach to CS education in which students engage with the political and ethical challenges of the world related to computer science (Kafai et al., 2020). In this integrated approach, CS knowledge and computational practices are not separated from the social, historical, and political contexts in which people consume and produce technology. For example, Vakil (2014) studied how African American high school students in an after-school program created mobile apps that would help their peers access other after-school programs and resources in their community. Vakil discovered that the application of critical pedagogy allowed students to situate programming of the app in a broader sociopolitical context and created opportunities for students to cognitively engage in computational thinking through gateways that related to their strengths and interests. He concluded that "understanding the relationship between computational and critical literacies, including how they can support one another's development, is a rich area for future research" (p. 44). When learners engage in critical computing, they focus on questions such as who develops certain technologies? What are the developers' interests? For whom are these technologies designed? What types of data are used to train machines? What is the history behind the data used? What decisions are made based on the outputs of the algorithms? Educators and learners pose such critical questions, reflect, discuss, and co-develop solutions to disrupt oppressive paradigms related to the development and consumption of modern digital technologies.

Although critical computing education has not yet been implemented with elementary school-aged students, studies suggest that they can engage with sociopolitical contexts. Starting at infancy, children notice differences in terms of race and gender and by early elementary school children judge ingroup members who look like them more favorably than outgroup members (Dunham et al., 2011). Classroom intervention research suggests that upper elementary school aged students are able to consider oppression from multiple perspectives including the broader historical framework of how society is organized and how to create change (Fain, 2008), analyze and interrogate literature around societal issues such as immigration (Braden, 2019), and address and challenge social inequities in their own curricula (Kersten, 2006). Unfortunately, research also suggests that adults avoid discussing race, gender, and oppressive societal structures and fundamentally underestimate elementary school-aged children's abilities to engage in these topics in developmentally appropriate ways (Sullivan et al., 2021).

To overcome teachers' potential hesitation in integrating sociopolitical contexts into their teaching, new literacies and pedagogical tools can be used (Husband, 2012). For example, *pop-up curricula* are defined as customizable courses that engage students through interactive learning in material not covered in the typical curriculum (Tranquillo & Matthew, 2015). Pop-ups vary in length and can be flexibly implemented at various times. For early childhood teachers, digital pop-ups offer opportunities to develop alternative pedagogical practices and to seamlessly integrate digital tools into classrooms (Fleer, 2020).

C. Results from Prior NSF Funding

I have prior NSF support through *BCSER: Modeling and measuring critical data literacies in informal learning environments* ($314,271; ECR-2024965; 8/1/2020–07/31/2023). I am the sole PI and responsible for all research activities and dissemination. In this project, I used participatory design methods to co-design critical data literacy educational activities for 80 children in 4th through 8th grade at three YMCA after-school centers in Greenville, South Carolina. **Intellectual Merit:** This project advanced knowledge and

understanding of how middle-school aged youth engage in STEM practices in ways that are valued within their own cultures and within broader STEM communities (Arastoopour Irgens et al., under review; Arastoopour Irgens et al., under review) and how to successfully engage youth in community programs that promote ethical, culturally responsive, and critical STEM learning (Bailey et al., 2021). **Broader Impacts:** This program's broad reach engaged underserved youth (children in poverty and children of color), after-school staff, and parents in critical data literacies and computing, thus broadening participation in STEM. Curricular materials are publicly available and free to access on the PI's website.

Using quantitative ethnography, a methodology that joins ethnography and statistics to create deep meaning from large datasets (Shaffer, 2017), the findings from this BCSER project provide a foundation to conceptualize critical computing education. I collected pre/post responses from youth about their machine learning knowledge and coded them for three categories: how humans develop machine learning applications (5 codes), harmful machine learning applications (3 codes), and helpful machine learning applications (2 codes). Then, I modeled the connections learners made across the codes using Epistemic Network Analysis (a quantitative ethnography tool that is further explained in section D.2.3). The results revealed that students made zero connections across the codes in their pre responses. However, in their post responses, students made connections among codes related to how people develop machine learning applications and how they can be harmful (Figure 1). For example, when asked to provide examples of unfair algorithms and who they help or harm, LaToya expressed her understanding of the social consequences of facial recognition algorithms. She wrote, "It can deny people property and housing and jobs and can really affect and change people's lives due to the fact that they were different to the person that made the algorithm." Here, LaToya expressed how people in positions of power can design machine learning algorithms that misclassify those who are not in positions to design them, and those misclassifications can lead to further disadvantaging underprivileged populations. Overall, these finding suggest that after participation in a set of activities focusing on bias in machine learning, children had an increased understanding of how classification algorithms work, the limitations of algorithms, and how they can be discriminatory in some cases.

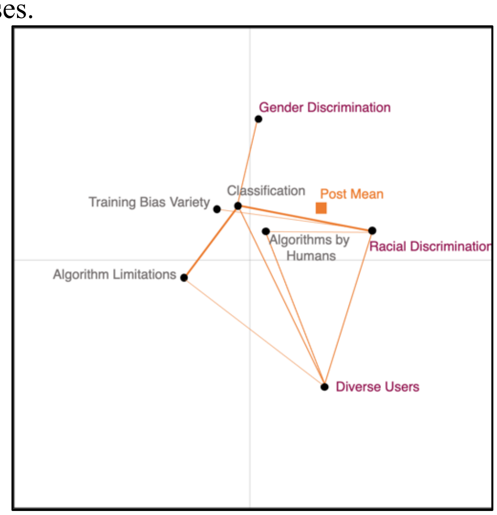


Figure 1. Average ENA network of all youth, displaying connections of codes in their post responses.

Findings also suggested that 1) youth engaged deeply in activities when provided with a *narrative* and allowed to *create their own stories and technologies* and 2) youth intermittently took a critical lens to their work but *they did not fully integrate a critical perspective into their investigations*. We hypothesized that this lack of an integrated critical lens was because some activities included CS practices without a focus on sociopolitical issues, while other activities involved discussion of sociopolitical issues without integrating CS practices. Moreover, students were not invited to explore oppressive histories of marginalized populations, which is important for situating students' understanding of *systemic* oppression. In addition, we adopted existing programming tools that were not specifically designed for students to explore socio-political issues in AI.

The proposed CritComp Pop-Up is an opportunity to implement improvements by developing a cohesive, game-like narrative in which each activity is grounded in a sociopolitical context. Moreover, conclusions from my studies need to be further tested in formal environments in systematic ways to contribute to developing robust learning theory. This CAREER proposal is a natural extension of my funded work with after-school children into new and needed areas of research for formal K-12 CS education.

D. INTEGRATED RESEARCH AND EDUCATION PLAN

D.1. CritComp Pop-Up Design and Development

D.1.1 Research Sites and Partners

For this project, I am partnering with two South Carolina organizations: the YMCA of Greenville after-school program and the Anderson 5 school district. In year 2, I will implement pilot testing of the CritComp Pop-Up at the YMCA after-school centers. I have successfully partnered with the Director of Youth and Family Services, Julie Hollister, for the last three years (see letter of collaboration). The YMCA of Greenville offers an after-school program at 5 branches for primary and middle school aged youth aged 5–14. Pilot testing will be implemented for 2–3 consecutive weeks with a subsection of youth aged 9–12. For the pilot implementation, I anticipate a total sample size of 60 youth. After pilot testing, I will revise the CritComp Pop-Up based on the findings and work with our partners at the Anderson 5 school district. I have met with Anna Baldwin, the district's Director of E-learning and Technology Integration, to discuss the details of this project and our shared interests (see letter of collaboration). Anderson 5 is located in the city of Anderson, South Carolina and is a combination micropolitan/rural area. In years 3, 4, and 5 of this project, I will work with 24 fourth and fifth grade teachers from three Title I elementary schools:

School	Poverty (%)	Black (%)	Number of $4^{th}/5^{th}$ teachers	Number of $4^{th}/5^{th}$ students
Nevitt Forest	94	64	8	166
Varennes	93	46	8	119
Whitehall	85	43	8	176

D.1.2. Design Frameworks

To design and develop the CritComp Pop-Ups, I draw on three research-based learning design frameworks. The core framework will be *culturally responsive-sustaining CS education* (Kapor Center, 2021). This framework was developed by a team of researchers, practitioners, and students and is grounded in decades of culturally relevant pedagogy research from multiple disciplines. The framework contains six core components for creating inclusive CS educational environments: acknowledge racism and enact anti-racist practices; create inclusive and equitable classroom cultures; pedagogy are rigorous and relevant encouraging sociopolitical critiques; student voice and agency are prioritized: family and community cultural assets are incorporated: and diverse professional role models provide exposure. These six components will guide the design of the CritComp Pop-Up and the co-design sessions with teachers to allow for discussions around equity and power in CS education (Goode et al., 2021).

Second, the Mission Control game in the CritComp Pop-Up is rooted in game-based learning research. Decades of research in digital game-based learning have demonstrated positive outcomes in terms of increased motivation and outcomes for content learning (Herro et al., 2013; Tobias et al., 2014) and continues to do so for elementary school-aged children (Hussein et al., 2019; Partovi & Razavi, 2019) and in CS (Silva & Silveira, 2020). The game design will be guided by Nadolny and colleague's (2020) *game-based learning framework for immersive multiplayer games*, in which narrative and interaction are critical components for supporting cognitive outcomes. For example, findings from my prior work designing and implementing multiplayer virtual internship simulation games suggest that learners had positive experiences and increased learning outcomes when role-playing as interns for a company and working on an engineering design problem (Arastoopour et al., 2014; Arastoopour Irgens, 2019a, 2021).

Third, this project is a *research-practice partnership* (RPP) in which researchers and practitioners engage in long-term collaborations to address problems of practice (Coburn & Penuel, 2016). I will rely on the research-based RPP toolkit developed by the Research and Practice Collaboratory (2022), which contains four components: build relationships, design for equity, gather and use evidence, and communicate with different audiences. When co-designing with children, I will draw on techniques from *cooperative inquiry*, which reimagine design approaches such that they are accessible for children (Druin, 2002). For example, design activities involve researchers and children creating and discussing low-tech prototypes using materials such as sticky-notes, clay, string, paper, or markers.

D.1.3 Initial Design and Development

The CritComp Pop-Up contains three components: the Mission Control digital game, robots and physical tools, and teacher-created classroom materials. My team of graduate students and I have begun to develop two components: the Mission Control digital game and the robotics tools. The game will be hybrid physical/digital role-playing. Fourth- and fifth-grade students will role-play as agents-in-training for a secret agency. Their goal is to complete missions and receive badges for each completed mission to reach senior agent status. Students will complete tasks within the digital game but also engage in hands-on learning with physical materials. Importantly, the teacher will be role-playing in the classroom as a senior agent who will guide the student agents-in-training through the game. When they first log into the game, students are introduced to Captain Storm, who will give the agents their first assignment. Captain Storm tells the students that the agency's scientists and researchers have developed time travel technology, and the students' assignment is to travel to the year 2075 to investigate how AI technologies function. After students complete each mission, they will be asked to record their findings in their time travel journals. The travel journal is tri-purpose. First, it serves as a place for the students to reflect individually on their work and respond to prompts through written or recorded oral responses. Second, the journal serves as a formative assessment of the students' work, externalizing the students' thinking along the way for the teachers. Third, the journal serves as an extrinsic motivator for children to progress through missions because they must submit entries to the agency to receive their badges. For students to progress to the next mission, teachers will advance them to the next stage. The teachers will have special logins allowing them to view and assess their students' travel logs, provide feedback, and advance them to the next level.

When students arrive in the future in a large metropolitan city, they discover that the primary mode of transportation is now self-driving vehicles that use facial recognition. Citizens over the age of 8 can use the vehicles without parental accompaniment. As students explore the city, they meet and speak with other children who tell them that they are having trouble accessing the cars because the facial recognition technology does not consistently recognize their faces. Students will access the machine learning algorithms, testing datasets, and training datasets used by the self-driving car company. Using an embedded Google Teachable Machine API revision, they will discover the dataset is biased against children and does not include photos of children of sufficient quantity or variety. They will then develop a fairer dataset and re-train the algorithm. After this initial investigation, students will investigate other forms of racial and gendered bias used in facial recognition software. However, to encourage students to grasp the *consequences* of these technologies, we will engage students with *how* biased and inaccurate technologies are being used. To understand the *impact* of these technologies, we will engage students with the *history* of oppression in the context of technology, such as the examples from Buolamwini's work on biased facial recognition software and examples from the popular *Coded Bias* documentary (Kantayya, 2020).

We have begun to develop programming tools for children that will be embedded within the Mission Control game. We have adapted the Scratch API from the Personal Robots Group at MIT to create our own version (Figure 2) that connects via Bluetooth to a TPBot Robot and removes extraneous options to focus children on the AI tasks using a webcam. The TPBot is affordable, uses a micro:bit, is compatible with Lego pieces for additional construction, and has a child-friendly, blue plastic-covered design. The robot can be programmed through the TPBot Scratch blocks that we have created. In addition, the TPBot robot responds to machine learning applications such as MIT's Text Classification blocks and Google's Teachable Machine. When students return from the future, they will apply what they have learned about algorithm bias and discrimination to create a prototype of a robot for social good that helps people and minimize bias as much as possible.

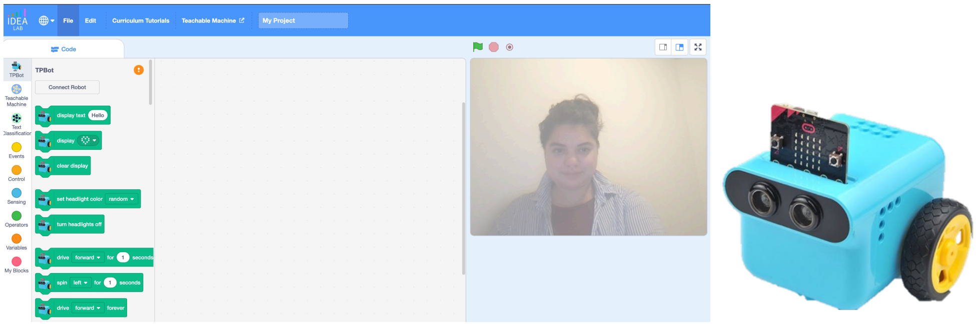


Figure 2. a) Adapted version of Scratch tool that will be embedded into the game and b) TPBot

I will work with teachers and the project's community consultant, Dominick Sanders, the South Carolina CS K-12 State Supervisor, to develop culturally relevant activities to guide students' robot designs. For example, Mr. Sanders was involved in the implementation of the Barbershop Computing program at the Fairfield Career and Technical Center in South Carolina (Lachney et al., 2021). Barbering students used block-based programming to develop hairstyle designs. Because in many Black communities, barbershops are central community spaces and an important aspect of Black culture and history, this was one approach to develop culturally relevant activities to broaden participation in computing. In the CritComp Pop-Up, with teacher guidance, students will draw on their own cultures and histories to develop AI devices for social good.

D.1.4. Designing with Children: Pilot Study

In spring 2022, my graduate students and I piloted four participatory design sessions with 15 fourth and fifth graders from one Greenville YMCA after-school center. We created digital visuals and mockups and presented them to the children (Figure 3).

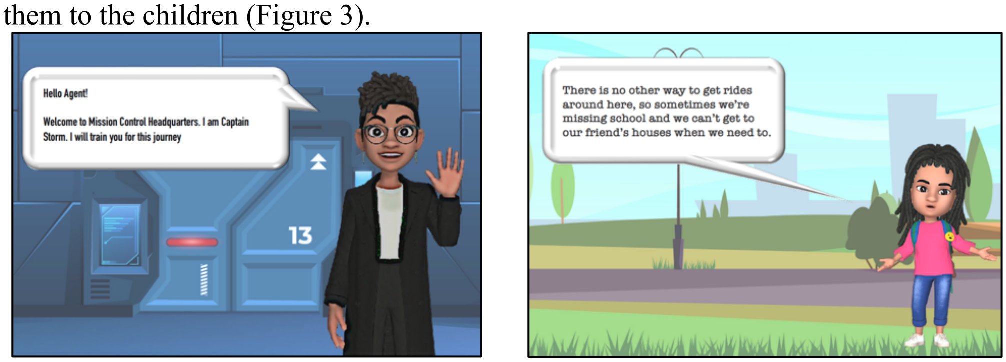


Figure 3. Digital visuals and mockups of the Mission Control game presented to youth.

Based on cooperative inquiry techniques designing for and with children (Guha et al., 2013; Yip et al., 2013), we provided three opportunities for children to gather in groups and provide feedback on the game design and activities. First, we asked them to draw what they imagined game elements would look like and what their functionalities would be. Second, we asked them to provide a name for the agency and choose their own agent names. Third, we asked them to draw and write about harmful versus helpful technologies. All feedback was documented through observational notes, and children's artifacts were collected and analyzed using thematic analysis (Braun & Clarke, 2006). Themes are summarized below:

Design Aesthetics	**Game Narrative**	**Game Objects**
Characters should be animated Soft music in the background Characters should make fun of agents' out-of-style clothes	Future travel place should be a large city (e.g., Los Angeles, New York) Agents can win tokens and buy things Agents can sell badges for coins There should be a villain	Customize and name characters Develop their own avatars Customize a space of their own, such as an office, to display badges

One re-occurring theme was the desire to customize their space and objects. For example, children wanted to customize other characters' appearance and capabilities, which we will now incorporate into the design of the CritComp Pop-Up; the customizable options will be inspired by the children's drawings. In another example, one child expressed the desire to have a personal space to "hang up and look at" earned badges and wanted to decorate this space. Therefore, we will add a customizable space for students to display and admire their earned badges. We also asked the children to test our newly developed Scratch blocks, the TPBots, and the car factory biased dataset scenario. There were no technical issues, and the children were able to engage in the scenario with Google Teachable Machine, Scratch blocks, and TPBots.

D.1.5. Design and Implementation Cycles

The design of the CritComp Pop-Up will be completed in three design-based participatory research cycles (Figure 4). In Design Cycle 1 (Year 1), I will hire undergraduate and graduate students to fill the role of a graphic designer, developer who specializes in UI/UX, front-end developer, and back-end developer. Together, we will create a comprehensive storyboard for the game, detailing the game characters, the role of the student player, and the graphical assets required and their interactivity. The graphic designer and UX specialist will develop or acquire the graphics and assets needed. At the same time, the front-end developer will work with the UX specialist to develop the interactive interface that students will see using CSS/HTML and Javascript. The front-end developer will also work with the back-end developer to create an entity relationship diagram detailing how entities, such as students' user ids and activities, will be stored in a relational database. Because Google Teachable Machine and Scratch are based in Javascript, the game will be developed using mainly Javascript for both the client and server side. Because the game will collect structured data from the student players, such as the pages they are on and which Scratch blocks they are using at a point in time, we will use a relational database management system and MySQL, which is open-source and proven to be secure and stable. Once the app is ready to be deployed, we will use Amazon Web Services LightSail with a LAMP structure to host our game on a secure server. In my graduate work, I led the development of a virtual internship game, *Nephrotex*, (Arastoopour et al., 2014; Arastoopour Irgens, 2019a, 2021) and have experience with LAMP, MySQL, CSS/HTML, and Javascript. I will supervise and direct all the activity and development in the project. After a minimal viable product is determined and developed, I will conduct user testing with the graduate and undergraduate students in the project and those who are members of my lab. The purpose of the user testing in this project is to 1) determine and eliminate any technical issues and bugs, 2) detect and eliminate any misspellings or errors in the content, 3) receive feedback in terms of the usability of the game, and 4) test the load capacity of the database and web application. I will direct the team to re-develop the game and tools after user testing. Next, I will hold two 60-minute participatory design sessions with eight fourth- and fifth-grade teachers from one school during year 1. These teachers will be the "early adopters" in this project. These sessions will involve the eight teachers playing the game and providing feedback. We will focus our sessions on discussing how to improve the game to include topics of interest to their students, determining what additional supports need to be incorporated into the game, and conceptualizing the role of the teacher in the classroom. These participatory design sessions will inform the continuous development of the game and tool in year 1.

In Design Cycle 2 (Year 2), the development of the Mission Control game and embedded programming tools will continue in preparation for participatory design sessions and pilot testing at the YMCA after-school centers. Participatory design sessions will draw on cooperative inquiry techniques (Druin, 2002; Guha et al., 2013; Yip et al., 2013) in which the game will be presented to students, and they will be asked to provide feedback by discussing, writing, or drawing their ideas. We will conduct 3–5 60-minute design sessions, as needed. These design sessions will inform redesigns of the Mission Control game and the programming tools. After redesigns, I will return to the after-school centers to conduct pilot testing, which will occur in 60-minute sessions, 3 times a week, for 3 weeks. The pilot testing will simulate what will occur in a classroom during the CritComp Pop-Up implementation of 10 contact hours. I will play the role of the teacher, and the after-school participants will play the role of students in the classroom. The results of the pilot testing will inform further redesign of the Mission Control game and programming tools.

In Design Cycle 3 (Year 3), I will prepare a 1-week summer training session for the eight early adopter teachers, sharing with them the results of the pilot study. Teachers will simulate the role of students to experience the Mission Control game and narrative. I will model and explain which computing skills and practices are integrated into the game. The training sessions will also include working with teachers to incorporate additional activities outside of the game that align with South Carolina standards and with the Mission Control game narrative. In short, the teachers and I will co-design personalized lesson plans and supplemental materials for each teacher that align with their teaching style and include the Mission Control game, narrative, and tools. I have 5 years of collective experience partnering with teachers and administrators in Chicago and upstate South Carolina to implement similar models in STEM and computing education with follow-up classroom support and data collection. In the fall semester of year 3, the eight early adopter teachers will implement their CritComp Pop-Up that includes the Mission Control game, the robotics and physical role-playing tools, and their unique supplemental materials and guides. In the subsequent summer sessions, the Technical Director at the Anderson 5 school district and I will recruit teachers from one more Title I elementary school in year 4 and in year 5 recruit teachers from all three schools, for a total of 24 teachers. The early adopters will serve as mentors for the subsequent cohorts of teachers. Moreover, the early adopters will shift their roles to co-develop a public online project space to share their supplemental materials. The mentoring and shared material plan allows teachers to create their own versions of the curriculum and supports a stable, sustainable structure for the continuation of CritComp Pop-Up implementations at Anderson 5 and other districts after the research project has concluded.

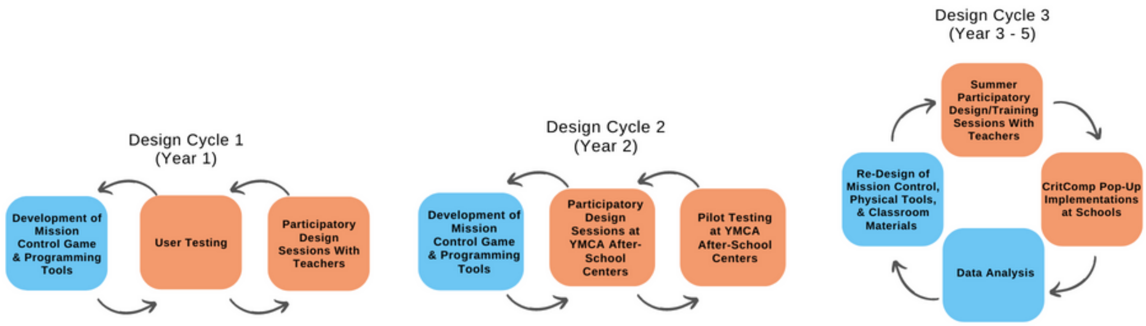


Figure 4. Three design-based participatory design research cycles. Orange boxes indicate data collection.

D.1.6. Design and Development Research Question and Goals

The research question, research goals, and education goals for the design and development portion of this project are summarized as follows:

Research Question	Research Goals	Education Goals
RQ1: What are the **roles, cooperative processes, and tensions** that emerge from the co-design of a critical computing curriculum involving teachers, researchers, and children?	- Characterize the design and development of a co-design RPP with researchers, teachers, and children to contribute to research on equitable RPPs in elementary CS education. - Understand the roles of children when they are involved in the design of their own learning in CS education.	- Inspire and educate children to be co-designers of their and other children's learning. - Increase children's agency and desire to persist in CS. - Increase researchers' and teachers' knowledge and skills for engaging in sustainable co-design RPPs.

D.1.7. Design and Development Data Sources

To answer RQ1, the following data will be collected: ***Observational Field Notes.*** My trained graduate students will conduct observations during the user testing, teacher participatory design sessions, after-school participatory design sessions, and summer teacher training sessions. An observation tool will be created for each design session to include descriptions of the participants and their perceived roles, the purpose of the session, and a narrative portion detailing what happened during the design session. ***Video Recordings.*** Each 60-minute teacher participatory design session and each 60-minute after-school participatory design session will be video recorded to provide additional details to support the observational field notes. ***Reflective Journals.*** During the 1-week summer teacher training sessions and the implementation period, teachers will keep daily digital journals. They will receive prompts with open-ended questions regarding the co-design process, including describing their self-perception of their roles and the researchers roles throughout the project, perspectives on working with me and my graduate students, describing the products they have created and how, challenges they encountered during the sessions and implementations, potential solutions to the challenges, their understanding around biased machine learning algorithms, and their comfort with the programming and robotics materials.

D.1.8. Design and Development Data Analyses

To answer RQ1, I will use a phenomenological qualitative research approach. Phenomenology is appropriate for this research question because I am investigating the co-designing phenomena by describing and interpreting participants' experiences (Dall'Alba, 2010). I will transcribe the video recordings using Otter.ai and make notes about the use of pitch, rate, volume, and gesture from the videos. Then, I will conduct a thematic analysis (Braun & Clarke, 2006) on the observational data, reflective journals, and video transcripts to uncover repeated patterns in the co-design roles and processes that emerge from the data. Last, I will conduct a discourse analysis (Gee, 2011)of the video transcripts to complement the thematic analysis. In the discourse analysis, I will uncover the particular social and situated language that was used in the context of co-design and how language use contributes to particular ways of being, knowing, and thinking that exist in co-design RPPs. In qualitative research, validity refers to the credibility of the inferences drawn from the data from three lenses (Creswell & Miller, 2000). I will assess credibility from the *researcher's lens* by using critical reflexivity (Pillow, 2003; Watt, 2007) to record my assumptions, biases, reflections as I analyze the data. I will assess credibility from the *participants' lens* by meeting with teachers to build their views into the analysis. Last, I will assess credibility from an *external lens* by meeting with the external evaluator on this project (see section E.1.).

D.2. CritComp Pop-Up School Implementations

D.2.1 School Implementation Research Questions and Goals

The research questions, research goals, and education goals for the implementation portion of this project are summarized as follows:

Research Question	Research Goals	Education Goals
RQ2: How do upper elementary students **develop CS knowledge and practices through a critical lens** after participating in critical computing curriculum co-designed by teachers, researchers, and children?	- Measure and model upper elementary school students' CS knowledge and practices when integrated with socio-political perspectives of digital technologies - Further develop theoretical construct of critical computing education	- Increase children's knowledge of critical computing - Develop children's critical computing practices - Provide students' families with social and educational events about critical computing
RQ3: Do upper elementary students have **increased confidence and desire to engage in critical computing** after participating in a critical computing curriculum co-designed by teachers, researchers, and children?	- Evaluate effectiveness of critical computing education in terms of broadening interest and participation in computing	- Broaden participation and access in CS, particularly for Black youth and children in poverty - Provide culturally relevant educational computing opportunities for children

D.2.2. School Implementation Data Sources

To answer RQ2 and RQ3, the following data will be collected: ***Observational Field Notes.*** My trained graduate students will conduct observations during classroom implementations. The team will cover as many class sessions as possible. An observation tool will be created for the team to include descriptions of the participants, the classroom space and tools, and a narrative portion detailing what happened during the class session. ***Video Recordings and Photos.*** Video recordings of the implementation will be taken in the classroom using Swivl robot camera technology provided by the Education Media Center at Clemson University. Teachers will wear a device that records their audio and connects to a 360-degree rotating camera that follows them. I have used the Swivl technology to capture classroom implementations in a previous study (Arastoopour Irgens, Herro, et al., under review), and it provided excellent audio and video capabilities to capture teaching and learning data in the classroom. I will use two Swivl sets to record two teachers per year of the implementations to collect in-depth classroom data to supplement the observational field notes. The team will also take photos of artifacts that children create and the classroom space. Field notes, photos, and video recordings will be necessary to capture data from the physical robotics activities and other activities designed by the teachers. ***Digital Game Data Logs.*** When students log into the Mission Control game, all their moves will be recorded in a MySQL database. These moves include timestamps of when they log in and out of the game; entries in their travel journal; choices they make to customize their badges, Buddy Bot, and travel pods; page that they are viewing at a certain point in time; snapshots of Scratch blocks that they choose to use when they program their robots; snapshots of their Google Teachable Machine models; and resources that they choose to use as they solve problems and engage in the digital activities. ***Surveys.*** Surveys will be given to students at the beginning and end of the CritComp Pop-Up implementation. There are no validated surveys available to measure student's interest, confidence, or desire to engage in socio-politically motivated CS. Thus, I will administer two separate surveys and analyze them together. First, I will administer the Elementary CS Attitudes (E-CSA) survey instrument (Vandenberg et al., 2021). The E-CSA has been found to be an equitable scale and has been validated through a combination of classical test theory and item response theory with upper elementary students (grades 4 and 5, ages 8 to 11), which is the exact population of my proposed study. There are 11 items that measure two constructs: CS self-efficacy and personal outcome expectancy, aligning with the aims of the research question to measure confidence in and desire to engage in CS. Items include *I am good at building code* and *I am interested in what makes computer programs work*. Second, I will adapt the validated 17-item Sociopolitical Control Scale for Youth (SPCS-Y) instrument (Peterson et al., 2011) to measure political perceptions, civic engagement, and agency. Items include *Certain racial or ethnic groups have fewer chances to get ahead*, *All groups should be given an equal chance in life,* and *It is my responsibility to get involved and make things better for society*. On both surveys, students respond to each item through a 5-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree." Students who need additional reading supports/accommodations will be identified by teachers and supported accordingly. ***Focus Groups.*** After students have taken the post-surveys, I will conduct two focus groups with students to more fully gauge their interest in the CritComp Pop-Up, interest and confidence in CS, and desire to further engage in CS-related activities. The purpose of the focus group is to collect dialogic data to accompany a statistical analysis of survey data (Axinn & Pearce, 2006). In addition, focus groups mitigate equity and data collection issues by giving EFL (English as a foreign language) students or those who have reading difficulties an alternative method for voicing their experiences (Kennedy et al., 2001). Finally, focus groups can be used to create a safe peer environment for children and alleviate some of the power imbalances between researchers and participants (Adler et al., 2019). For the focus group data collection, I will use convenience sampling to select students who participated in the entire CritComp Pop-Up curriculum, completed the pre and the post survey, and are available and have consented to participate in the group interview. Then, I will select a sample of students who scored higher than the median score on the E-CSA survey and place them in one focus group and select a sample of students who scored lower than the median score on the E-CSA survey and place them in the second focus group. I will select students such that each focus group is proportional to the gender, racial, and class demographics of the students in the school.

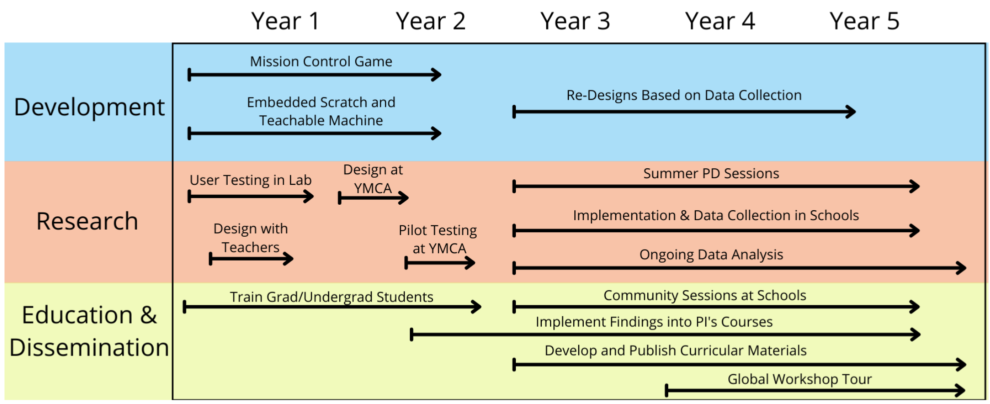
D.2.3. School Implementation Data Analyses

Quantitative Ethnography. To RQ2, I will use *quantitative ethnography*, a novel methodology that integrates qualitative and quantitative analyses (Shaffer, 2017). This methodology brings together ethnography and the tools of statistics to create deep meaning from large datasets. The statistical analyses allow for discovering unexpected patterns in large datasets and measuring the strength of relationships among variables. The ethnographic analyses allow for interpreting meanings behind what learners are doing and saying in order to tell their stories. Using quantitative ethnography, researchers can analyze discourse data computationally analyzed to understand broader patterns of interactions that can be attributed to a group culture. In this project, I will use two quantitative ethnography tools, nCoder and Epistemic Network Analysis (see below), to infer and make meaning of the field notes, video recordings, and game logs and develop network visualizations of how students' learn. ***nCoder.*** To analyze the data, I will use a grounded analysis guided by existing CS/AI education frameworks and critical pedagogies to uncover learners' emerging critical CS knowledge and practices. However, because the datasets will contain large amounts of data, it will be difficult to identify and code all the themes by hand. Therefore, I will use nCoder, a learning analytics platform for developing and automating coding schemes (Cai et al., 2019; Shaffer et al., 2015). The nCoder assists researchers by providing a user-friendly interface for developing sophisticated keyword lists that automate the hand-coding process. To validate the automated process, the machine coded data are compared to a subset of data coded by human raters and inter-rater reliability is measured. Once reliability measures are acceptable, the machine codes the remainder of the data. ***Epistemic Network Analysis.*** To analyze the coded data, I will use Epistemic Network Analysis (ENA), a tool that measures and visualizes connections among codes in data (Shaffer, 2018; Shaffer & Ruis, 2017). ENA measures when and how often learners make links between domain-relevant elements during their work, which in this case would be links among computing knowledge, practices, and sociocultural contexts. It also identifies the co-occurrences of coded elements and represents them in weighted network models. When a learner repeatedly makes a link between elements over time, the weight of the link between those elements is greater. Furthermore, ENA enables researchers to compare networks both visually and through summary statistics that reflect the weighted structure of connections. Thus, researchers can use ENA to model discourse networks and quantitatively compare the discourse networks of individuals and groups of people in a variety of domains (Arastoopour et al., 2014; Arastoopour & Shaffer, 2013; Arastoopour Irgens, 2021; Nash & Shaffer, 2011). These features also allow researchers to make claims about assessing knowledge development (Arastoopour et al., 2016). In this project, I will use ENA to model students' developmental trajectories of critical computing knowledge and practices by measuring the co-occurrences of these elements and modeling their relationships over time. I will establish validity by ensuring that the interpretation of the quantitative network models are supported by evidence directly from the qualitative data. In quantitative ethnography, this process is referred to as *closing the interpretive loop* (Arastoopour Irgens, 2019b). ***Linear Mixed Models.*** To answer RQ3, I will construct three linear mixed-effects (multi-level) models that nest participants within the four schools, within their classrooms. In the first model, the E-CSA post survey results will be the dependent variable and the independent variables will be the E-CSA pre survey results and participant demographic information (as covariates) and the four schools and classrooms as grouping variables to determine if there are significant changes in students' self-efficacy and desire to engage in CS. In the second model, the SPCS-Y post survey results will be the dependent variable and the independent variables will be the SPCS-Y pre survey results and participant demographic information (as covariates) and the four schools and classrooms as grouping variables to determine if there are significant changes in students' socio-political perceptions. In the third combined model, the dependent variable will be changes (post minus pre) in socio-political perceptions and the independent variables will be changes (post minus pre) in attitudes toward CS to determine if increased positive attitudes toward computing predict increased socio-political awareness at any or all of the schools and various classrooms.

D.3. Additional Education Plans

Community Sessions. My partner teachers and I will organize annual student showcases that will be open to parents and the local community during weekends or evenings. These showcases will be in a science-fair style and framed as a community celebration of their children's work designing AI robots for social good. Students will be encouraged to attend and prepare a demonstration of their robots. I will also conduct a presentation of the teachers' and children's accomplishments and summarize the project for the broader community. ***Global Workshop Tour.*** I will offer in-person and virtual workshops to increase knowledge of the CritComp Pop-Up, provide directions for implementation, and research findings. These workshops will be open to academics, teachers, and administrators. Currently, my colleagues at University of Wisconsin, University of Copenhagen, and Monash University have expressed interest in these workshops. ***Integration of Findings in Courses.*** I teach an undergraduate course, *Foundations of Digital Media and Learning*, and two graduate courses, *Quantitative Ethnography* and *Design of Digital Learning Environments*, that I developed and have been added to the Learning Sciences PhD program at Clemson University. The findings from this project will augment these course offerings. ***Expansion of the IDEA Lab.*** This CAREER project will help me sustain and expand my multi-disciplinary research lab housed in the learning sciences. I will be able to recruit more students and continue to mentor my 7 graduate and 1 undergraduate student and continue to offer opportunities for students to co-author publications, receive feedback on their writing and research work, and participate fully in the design of experimental research.

D.4. Project Timeline



E. Project Evaluation and Advisory Board

E.1. External Evaluator

A formative and summative evaluation will be conducted by the STEAM Education Research Group (STEAMER), LLC, a woman-owned business that will serve as the external evaluation on this project. Dr. Eliza Gallagher will be the lead evaluator. The goal of evaluation is threefold: 1) ongoing improvement of project activities; 2) formal assessment of research findings, education activities, and project deliverables; and 3) informed recommendations for propagation and expansion of results. Dr. Gallagher has worked with me to develop a set of mutually agreed upon formative and summative evaluation questions, activities, and deliverables. ***Formative Evaluation Plan.*** The ongoing formative evaluation component will provide recommendations for project improvement and serve as a first external checkpoint in reviewing research findings and educational activities of the project, as well as the integration of the two. Questions include: To what extent are teachers, graduate students, and upper elementary students engaged in the design cycle? How can emerging research results be leveraged to enrich the educational activities for all parties? In what ways are graduate and undergraduates students engaged in the research? To what extent do participating teachers across partners schools adapt the practices introduced in the PD workshops in years 3 - 5? To what extent do the community outreach events engage the local communities? Which practices need to be improved and which are scalable to additional sites? What results are emerging from analysis of the research data? How are those findings being leveraged to improve project implementation and iteration? What additional data needs to be collected and what additional analyses need to occur to ensure valid results? ***Summative Evaluation Plan.*** The summative evaluation component will assess and document how well the project succeeded in meeting its larger goals and objectives. Questions include: To what extent did the iterative design cycle meet educational goals for engaging teachers, researchers, and elementary students? To what extent did the project meet research and education goals? Were project research questions answered with fidelity to the data collected? Were project results propagated effectively through professional and local communities? ***Evaluation Administration and Deliverables***. On an ongoing basis, Dr. Gallagher will review development and delivery of project activities; review emerging research results and education outputs; make recommendations for course corrections and help address unforeseen challenges; and track indicators of success that result from project activities. To achieve this, Dr. Gallagher will meet with the me monthly, review notes and/or video records from meetings with participating teachers and from the PD workshops, collect survey data and conduct focus groups with participating instructors and graduate students, review research drafts, meet annually with the advisory board, and attend the annual NSF project directors' meeting. At the end of each grant year, Dr. Gallagher will provide a written report regarding the progress the team has made towards meeting benchmarks. At the end of the project, Dr. Gallagher will provide a written report regarding the performance of the team and the overall success of the integrated research and education plan.

E.2. Advisory Board and Community Consultant

I organized an advisory board of three experts in equitable CS education, RPPs, and game-based learning in AI: Dr. Joanna Goode, Dr. Jean Ryoo, and Dr. Danielle Herro. I, the external evaluator, the advisory board, and the research team will meet annually virtually to discuss the project. I will also meet with each advisory board member virtually or in person 2 times a year to receive directed feedback on the project and mentoring on professional development as a woman scholar in CS education and writing a book based on this research. Mr. Dominick Sanders, K-12 CS state supervisor, will be a community consultant on the project. I will meet with him 2 times a year for consultation on the development of culturally relevant CS curricula and assistance on disseminating findings and materials across the state and nationally.

JOANNA GOODE, PHD
ADVISORY BOARD MEMBER
SOMMERVILLE KNIGHT PROFESSOR
UNIVERSITY OF OREGON

Contribution: Advising on equitable K-12 CS education
Expertise: Culturally relevant CS education research
Experience: Research-based CS curriculum, co-author of Stuck in the Shallow End: Education, Race, and Computing (MIT Press, 2008/2017)

JEAN RYOO, PHD
ADVISORY BOARD MEMBER
DIRECTOR OF RESEARCH,
CS EQUITY PROJECT AT UCLA X

Contribution: Advising on RPPs in CS education
Expertise: Research around creating equitable RPPs
Experience: Equitable CS education in formal and informal environments, Co-author of Power On! (MIT Press, 2020)

DANIELLE HERRO, PHD
ADVISORY BOARD MEMBER
PROFESSOR,
CLEMSON UNIVERSITY

Contribution: Advising on game-based learning and AI education
Expertise: Game-based learning research
Experience: Teacher professional development for middle school AI curricula, Co-author of An Educator's Guide to STEAM (Teachers College Press, 2019)

ELIZA GALLAGHER, PHD
EXTERNAL EVALUATOR
CONSULTANT,
STEAMER GROUP, LLC.

Contribution: External evaluation on project
Expertise: STEM education research
Experience: Program evaluation and broadening participation in STEM.

DOMINICK SANDERS, MS
COMMUNITY CONSULTANT
CS STATE SUPERVISOR,
SC DEPARTMENT OF EDUCATION

Contribution: Consultant for CS education for Black youth
Expertise: CSTA equity fellow
Experience: Responsible for K-12 CS education programs and professional development across South Carolina

F. FOUR-FACTOR STRATEGIC DISSEMINATION PLAN

The dissemination plan has four factors, each with particular goals for dissemination and strategically developed to reach different stakeholders.

Media Releases
Children, families with children, policy makers, general public

- Work with Clemson University's PR staff to generate media releases for news outlets in Clemson, Greenville, Anderson, Columbia and other areas in South Carolina
- Work with the YMCA, Anderson 5, and the SC Department of Education to distribute media releases through communication outlets

Academic Venues
Academic and Research communities

- Publish in journals such as Journal of Learning Sciences and International Journal of Child–Computer Interaction
- Present at conferences such as SIGCSE, CHI
- Attend and present at CISE and PI meetings

Social Media
Global general public

- Post updates, photos, and links to disseminated materials on the IDEA lab Twitter page
- Interact with partners through social media

Project Website
Teachers, administrators, non-profit organizations

- Provide access to Mission Control game, links to purchase robots and other materials, teacher-created supplemental materials, and heuristics for participatory design with/for children
- Create white papers and infographics with easily consumable language to be distributed through websites