Interactive Murals: New Opportunities for Collaborative STEAM Learning

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Figure 1: Our interactive mural during the day (left) and at night (right). The mural, which is 32 ft wide by 10 ft tall (approximately 10 x 3 meters), was designed and built by a group of high school youth.

ABSTRACT

This paper introduces interactive murals—artworks that combine longstanding traditions in community mural painting with ubiquitous computing—as new sites for collaborative STEAM learning. Using research-through-design and participatory design methods, we conducted an intensive spring and summer workshop in which high school students were introduced to electronics and programming through the process of creating an interactive mural. We describe the workshop activities, the mural design process, and the data collection and analysis methods. Through documenting student learning in programming and electronics and the collaboration that occurred, we build an argument for the novel learning affordances of interactive murals, emphasizing the unique opportunities that they provide for collaborative STEAM learning.

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CCS CONCEPTS

• **Human-centered computing** → *Collaborative content creation*; *Collaborative and social computing*.

KEYWORDS

interactive murals, steam, computing education, educational technology, participatory design

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1 INTRODUCTION

Wall-based interfaces can provide novel, beautiful, and attention-grabbing displays at architectural scales [30, 31]. They can support collaborative [2, 11] and full-body [73] interactions while capturing and displaying data in new ways. To develop interactive wall-based systems, researchers, designers, and artists have used projectors [9, 71], large screens [18, 20, 21, 52, 66], and embedded hardware [17, 72, 73].

We aim to expand the potential of wall-based interfaces by connecting them to *culture, community,* and *learning*, creating community-based *interactive murals.* Our purpose is multifaceted. First, we believe that interactive murals can be compelling and novel works of art. Blending technology with traditional murals enables new kinds of expression along with new kinds of interactions. Second, we believe that interactive murals can serve as rich sites for STEAM Learning. We believe they can provide engaging entry points for learning electronics and programming as well as art, particularly for minoritized youth and communities with rich mural painting traditions. We aimed to structure a project that was deeply situated in an existing public arts community in which minoritized youth learned foundational skills in electronics and programming. We also aimed to explore and understand unique educational affordances of interactive murals. We were guided by the following research question: *What are the unique learning affordances of interactive mural activities?*

To achieve these goals, our interactive mural blends ubiquitous computing with longstanding traditions in community mural painting. We embedded electronics—including sensors, actuators, and microcontrollers—into a painted mural. Our effort was led by Author 1, a technology designer and HCI researcher, and Author 2, a professional muralist. This complementary expertise provided the foundation for the project. Authors 1 and 2 collaborated with a group of high school students—all who had expertise in painting or drawing and an interest in art—to design and build the interactive mural shown in Figure 1. We aimed for the interactive mural to function as both a new and compelling work of public art and as a site of collaborative STEAM learning.

Our research took place in the context of two workshops. In the spring of 2022, we taught a six-week after-school workshop, introducing youth to programming and electronics in the context of interactive paintings. Participants each built a small interactive painting using the materials and tools we would later employ in the large mural. In the summer of 2022, we held an intensive (five hours per day, four days per week) six-week workshop during which youth designed and constructed the mural shown in Figure 1. The completed mural was then unveiled at a city-wide art walk attended by community members.

Building the mural and achieving our project goals required overcoming a significant set of challenges. The design and construction of the interactive mural was a technical challenge, as no similar wall-based interfaces have been built at this scale or conceived as *permanent outdoor installations.* Our collaboration with youth added complexity to the project. It is rare for students to participate so deeply in active technical research—learning and building alongside researchers and serving as genuine co-authors of the work. The design of the learning activities that enabled youth to participate was critical. Finally, the scale and ambition of the project required deep community engagement. Students spent most of their summer working on the mural. This required gaining the trust of students and their families and navigating countless logistical and life challenges, including transportation issues, the provision of meals, scheduling issues, and parent involvement.

This paper focuses on two outcomes of the project–STEAM Learning and Collaboration. First, we document student learning in electronics and programming over the course of the project, verifying that interactive murals can serve as sites for STEAM learning. We find that students with no previous experience in electronics or programming can develop significant expertise in both of these areas through the process of designing and building an interactive mural. The experience also helped students develop confidence and interest in these fields. Second, we focus on answering the research question posed above. We identify and discuss the unique learning affordances provided by interactive murals, focusing on the opportunities that they provide for collaborative learning. We find that the large scale of murals facilitates and requires collaboration, providing novel opportunities for students to support and learn from each other. The primary contributions of this paper are:

(1) The introduction of interactive murals as a context for STEAM learning in programming and electronics.
(2) The identification and discussion of the unique learning affordances of interactive mural activities, emphasizing their simultaneous support for a) community-situated collaborative learning and b) autonomy and personal expression.

2 RELATED WORK

2.1 Research Through Design and Participatory Design Methods

In RtD, knowledge is generated through the process of designing a future-oriented system—critically, one that has not been built before. Careful documentation and analysis of the design process allow researchers to understand the impact that the new system or class of systems is likely to have on creators, users, and society at large [68, 74]. In this work, we aimed to help youth develop skills in electronics and programming within the context of building an interactive mural. We employed an RtD approach to structure and make sense of the project. We collected all of the artifacts that the students created during the design and construction of the mural and carefully documented the entire process. Author 1 conducted semi-structured interviews with students at the end of each workshop. This data enabled us to understand what students learned and how the context of interactive murals impacted and shaped that learning.

Our approach to designing the interactive mural was also guided by participatory design (PD) approaches [23, 34]. We structured the project so that students played a leading role in the design and construction of the mural. We wanted students to serve as, and see themselves as, genuine co-authors–designers, muralists, and engineers. We aimed to support an authentic sense of student ownership over the interactive mural.

2.2 Community Murals and Culturally Responsive Pedagogy

Murals can be painted on almost any wall using low-cost and readily available materials. They have emerged as a potent community-driven public art form that enables communities to have a unique voice in the media landscape of their local communities and the world at large. They provide a particularly important platform for minoritized communities who typically have little access to traditional media outlets (television, billboards, etc.). Murals provide a large, highly visible platform that communities can control and leverage to tell their own stories, an especially powerful platform when these stories may otherwise be invisible [19, 29, 41].

There is a rich tradition of engaging youth in community mural painting [5, 8, 36, 67]. These projects provide complex, multifaceted learning opportunities. They encourage youth to engage with and learn about their communities and provide them with the experience of working on a large-scale collaborative project. Students learn how to tell a compelling visual story and develop technical skills in mural painting. Painting a successful mural requires nontrivial practical math skills. The process involves carefully measuring a large wall, generating small-to-scale design sketches, and then mapping these sketches back onto the wall. But, perhaps most importantly, murals provide youth the same opportunity they provide communities: to tell stories about themselves that may otherwise not be seen or heard.

Community mural projects are a wonderful example of a learning activity that employs culturally responsive pedagogical approaches [7, 32, 55, 56, 62]. Culturally responsive pedagogy is a learning theory that stipulates that learning experiences should engage students as full people. Rather than requiring youth to conform to the dominant culture's educational and social expectations, learning experiences should draw on students' diverse individual, cultural, and community experiences. Students' diverse backgrounds are seen as wells of legitimate and important knowledge.

Our interactive mural project is grounded in and draws from these traditions. We collaborate with a local non-profit arts organization, Working Classroom (WC), that specializes in engaging minoritized and low-income youth in community mural projects. Author 2 is a professional mural artist whose career focuses on creating site-specific community murals [16] and who has organized and led several projects with youth. We build upon these foundations, blending community-mural practice with technology to create a new kind of community-based public art and a new community-situated STEM learning experience.

2.3 Interactive Walls and Paper-Based Electronics

The technical development of our mural was informed by previous work in wall-based interfaces and paper-based electronics. We used materials, techniques, and educational approaches introduced by Qi et al. [57, 58, 60] to build most of the circuitry in our interactive mural. Circuitry was built primarily from copper tape [3, 58] and a copper-based conductive paint [42]. Our workshops drew on and expanded popular paper-electronics learning activities [47, 58–60].

This work was also informed by research on wall-based interfaces with embedded circuitry. Zhang et al.'s Wall++ [73] and Wessely et al.'s Sprayable Interfaces [72] projects, which both used conductive paints to create custom wall-based sensors, were particularly inspiring. So was Cheng et al.'s DUCO project [17], in which wall-based interfaces were constructed by a wall-mounted fabrication device that draws circuits with conductive ink. The visual design of our mural was influenced by Buechley et al.'s Living Wall [15], which employed conductive and non-conductive paints to create a sheet of decorative wallpaper that also functioned as a general-purpose controller for devices in the home.

Most similar to our work are several mural-inspired electronics projects and learning activities that have been developed within education research communities. In Telhan et al.'s "community murals" project, youth contributed personalized paper circuits to a 4' x 4' (approx. 1 m x 1 m) foam poster board to build a quilt-like structure [69]. Ananthanarayan's "health monitoring mural" was constructed on a 6' x 4' (approx. 2 m x 1 m) pre-made painting that youth could attach customized wearables to, visualizing health and other data [4].

Our project differs from these previous works by functioning as an actual rather than a metaphorical mural and as an outdoor public art installation rather than an indoor interface demonstration. Specifically, our interactive mural is *permanently painted on a very large wall on the exterior of a building*. At 32' x 10' (10 m x 3 m), it is at least an order of magnitude larger in size than any previous wall-based interface. We also situate our work in a new context by partnering closely with the local community and working collaboratively with youth on each element of design and construction.

2.4 Collaborative STEAM Learning

It is well established that STEAM (Science, Technology, Engineering, Art, and Mathematics) activities can provide a compelling entry point into learning in STEM fields [37, 50, 54], particularly for girls [53] and youth of color [39, 55, 64]. The arts provide natural opportunities for personal engagement [13], cultural connection [63, 65], and meaning-making [10]. STEAM education can enable students to look at design or engineering problems through the lens of artistic or aesthetic experience [33]. This project builds especially on prior work that has explored connections between artistic practices and different communities and cultures. For instance, Qi et al. demonstrated how integrating programming and electronics with paper craft engaged scrap-booking communities in working with electronics [59]. Similarly, Buechely et al., Peppler et al., and Searle et al. have explored how electronic textiles can provide new ways for women and girls [14, 53] and indigenous communities [63, 64] to engage with technology.

An educational aim of the interactive mural project is to create a *new context* for STEAM education that adds a new set of creative opportunities to the STEAM landscape. The opportunities that interactive murals provide are anchored in a different set of artistic traditions—painting, drawing, and potentially graffiti art—which we hope will appeal to and engage new groups of diverse young people.

Within the STEAM learning context, we focus particularly on *collaborative learning* [26, 28, 40, 43, 61]. Collaborative learning can lead students to higher achievement, greater productivity, greater psychological health, social competence, and self-esteem [40]. Collaborative learning activities have also been shown to improve engagement, creativity, innovation, and problem-solving [61].

We document and categorize student learning in electronics and programming, utilizing the K-12 Computer Science Framework [38]. We then employ an assessment developed by Herro et al. [35] to identify ways in which the interactive mural's large scale and interdisciplinary nature, encouraged and, in many cases, required collaboration.

3 METHOD

3.1 Research Team

Carrying out this project required bringing together a diverse team of researchers, artists, and community members, each with a different background and set of skills. Author 1, who led the technical aspect of the project, is a Hispanic/Latina Ph.D. student in Computer Science whose work focuses on HCI, ubiquitous computing, and technology education. She grew up in a nearby city and has strong ties to the local community. Author 2, who led the artistic aspect of the project, is a Dine (Navajo) and Chicana artist and a native of our city. She is an internationally recognized painter and muralist[1]. She is also a trained educator; she worked as a public school teacher for seven years before becoming a full-time artist. Author 3 is a comic artist, STEM educator, and postdoctoral researcher focusing on the design of STEAM learning environments for Black and Brown youth. Author 4 is a postdoctoral researcher whose work revolves around developing interactive materials and systems. Author 5 is a professor who runs the HCI research lab in which the research took place. The diversity of expertise in our team underscores the collaborative nature of the project.

3.2 Community Context

Working Classroom (WC), a local non-profit arts organization, was an essential partner. WC, which was founded in 1988, has a longstanding mural program in which local muralists and youth collaborate to paint murals across our city, typically during the summer months. WC is located in a diverse, low-income neighborhood and serves youth ages 11-18. 75% of WC student members are the first in their family to attend college; 73% are Hispanic, and 23% are Native American [2]. WC was responsible for student recruitment for this project. They also provided a physical location for the mural as well as classroom space for both workshops. Most WC staff members are artists, and many of them have established relationships with some or all of our student participants.

The city in which this work was conducted is a majority-minority city with Latinos/Latinas and Native Americans making up the majority of the population [70]. All of the students, along with Authors 1, 2, and 3, are members of minoritized groups and bring their distinct but overlapping experiences and community ties to the project.

3.3 Participants

All of our students were existing members of the WC community who were recruited individually by WC staff to participate in our workshops. Seven students of color, ages 15-19, enrolled in the spring workshop, and four (out of these seven) participated in the summer workshop. Demographic information can be seen in Figure 2.

At the beginning of each workshop, students and their parents were given IRB-approved consent forms. Participation in the research component of the workshop was voluntary. Summer students were paid a stipend for their work on the mural. The stipend provided students who might otherwise need to take on summer jobs with financial support. Each student is referred to by a pseudonym in this paper.

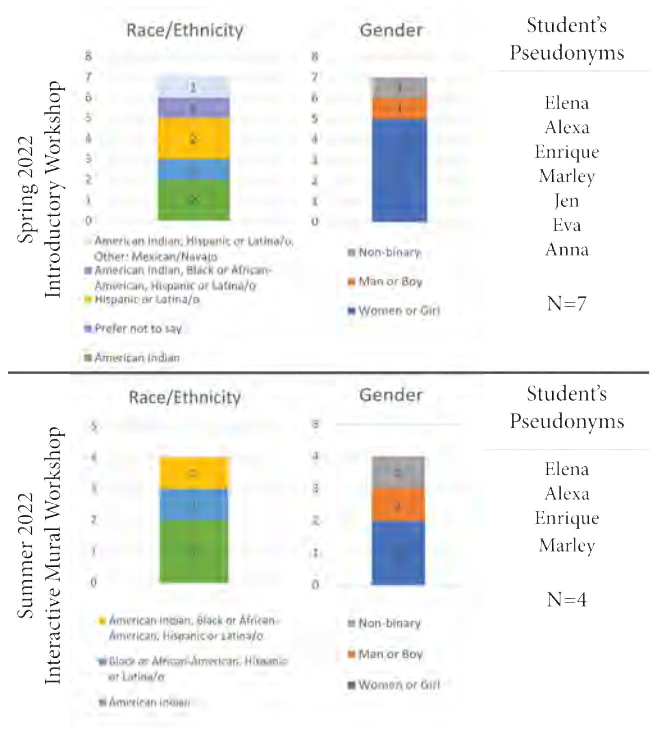

Figure 2: Demographic information for both the spring (N=7) and summer (N=4) 2022 workshops. This information includes the race/ethnicity data (Note some students identify with multiple races/ethnicity), gender data, and the student's pseudonyms

3.4 Overview of Spring and Summer Workshops

3.4.1 Spring Workshop: Introduction to Programming, Electronics and Mural Design. To provide youth with the skills they would need to build an interactive mural, Authors 1 and 2 taught a six-week workshop in the spring of 2022, in which students created interactive paintings, see in Figure 3. Students worked two days per week for three hours each day (i.e., 36 total workshop hours). This workshop focused on developing technical and mural design skills.

Author 1 began the workshop by introducing students to electronic circuits via a paper circuit activity in which students added LED lights and copper tape to drawings they had made. She then led a series of programming activities, employing the AdaFruit Circuit Playground [1] and the MakeCode visual programming environment [44]. She used a peer programming approach so that students could help each other write and debug their programs [43] and gradually introduced key programming constructs from the K-12 Computer Science Framework [38], including *variables*, *conditionals*, and *loops*, as well as digital and analog inputs and outputs. She focused on teaching students how to use LED lights

[1] https://www.nanibahchacon.com/
[2] https://workingclassroom.org/

and capacitive touch sensors, which students would employ in the summer mural.

Author 2 led a series of activities focused on mural-design and painting. Students were then presented with a design prompt to create an interactive mandala. Each student was given a 18" x 18" (approximately 46 cm x 46 cm) board, one Circuit Playground, a strand of LED lights, and conductive material for making capacitive touch sensors. Students spent most of the workshop designing and building interactive paintings based on the mandala theme. Students first sketched their visual design. Then, they drew an electrical layout on top of this design indicating where LEDs, sensors, and the Circuit Playground would be placed and how the components would be connected. They then installed the electronic components according to this diagram and programmed their pieces. Finally, they painted over their electronics while continuing to troubleshoot and fine-tune their programs.

A showcase of the student's work was held at the University of New Mexico. Students, friends, family, and Working Classroom community members attended; see Figure 4. Faculty and students from the art department and computer science department attended to talk to students and family members and help celebrate student work. At the end of the showcase, students and attendees were invited to tour the research team's lab.

Figure 4: Interactive mandala showcase at the local university where families, friends, and community members supported our student's work.

3.4.2 Summer Workshop: Building an Interactive Mural. Approximately one month after the spring workshop, Authors 1 and 2 led four of the seven students from the spring workshop in the creation of the large-scale interactive mural shown in Figure 1. The interactive mural is located on the east-facing wall of Working Classroom's building. The design and construction of the interactive mural took place over six weeks, meeting for five hours per day, four days per week, in the summer of 2022 (i.e., 120 total workshop hours). To design and build the mural, we followed the workflow depicted in Figure 5.

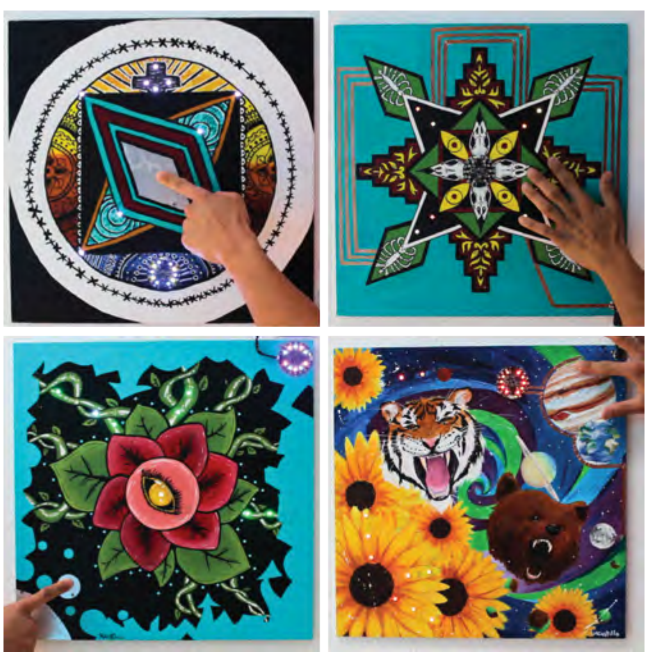

Figure 3: Elena, Alexa, Enrique, and Marley's interactive mandala paintings.

(1) *Workshop Plan.* Before the summer workshop began, Authors 1 and 2 developed a workshop plan. We aimed to develop a workflow that would help the students participate successfully as co-authors of the mural, in both the artistic and technical domains. This entailed providing clear and specific guidelines that would 1) enable each student to contribute individual elements to a cohesive mural design and 2) enable students to leverage and build on the technical skills they developed in the spring workshop. Author 2 developed the thematic focus for the mural–orienting the visual theme and a companion set of design activities around local plant life. Author 1 defined technical constraints —choosing to focus on interactions based on touch, light, and sound. Due to our intensive workshop schedule, it was critical to pick technical elements students were familiar with from the spring workshop.
(2) *Visual Design.* Students participated in a series of activities designed by Author 2 to develop a collaborative and coherent visual design. They began by exploring the neighborhood, taking photographs of local plants, and recording sounds. They then sketched these plants, building the foundation for the visual design, Figure 5 top left. Next, they worked together to combine their individual sketches into a cohesive visual design, which the students later extended to include local fauna.
(3) *Interaction Design.* As the visual design came together, students began to develop a plan for the interaction design. They determined how different light patterns and sounds would be activated by touch.

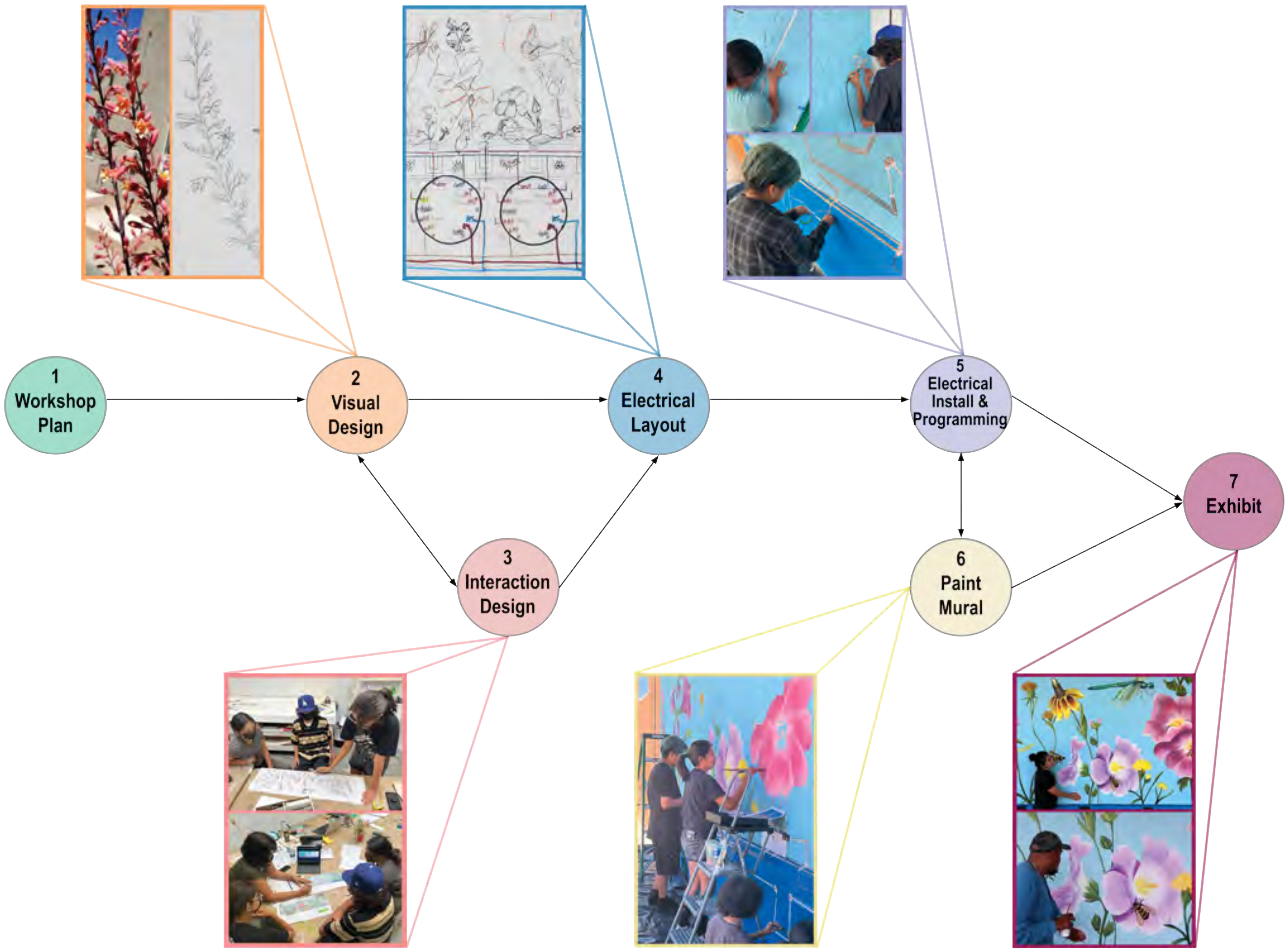

Figure 5: The workflow used to create the interactive mural.

(4) *Electrical Layout.* Once the high-level design was finalized, the students created an electrical layout. Each student — working with one Circuit Playground, LED lights, and touch sensors—was in charge of creating an electrical layout for a section of the mural.
(5) *Electrical Installation and Programming.* After finalizing all aspects of the design, students began construction by installing electronics on the wall. Students programmed and tested sections of the wall as the electronics were installed.
(6) *Mural Painting.* Finally, students painted over the installed electronics. Troubleshooting and programming continued during this phase of construction.
(7) *Exhibition.* Our completed mural was unveiled during a city-wide art walk at the end of the summer. The mural unveiling was attended by students and their families and friends, other WC community members, neighbors, art enthusiasts, and university members, including art and computer science professors. Community members engaged with and admired the mural with enthusiasm. Figure 6 shows images from this event, including community members interacting with the mural via the touch sensors that were painted onto the wall.

3.5 Data Collection

We carefully documented each aspect of the spring and summer workshop. This documentation includes photographs and videos of student work, field notes, and copies of student sketches, electronic diagrams, and computer programs. We also documented our activity design process, collecting meeting notes, lesson plans, and other educational materials. We conducted pre- and post-surveys for each workshop, using the validated National Center for Women and Information Technology (NCWIT) Computing Program Participant and Computing Interest Confidence Perception surveys [51]. After each workshop, Author 1 conducted one-hour semi-structured interviews with each student participant.

3.6 Thematic Coding of Interview Data

To analyze the interview data, Authors 1 and 3 first conducted open coding of two students' interview transcripts from the summer

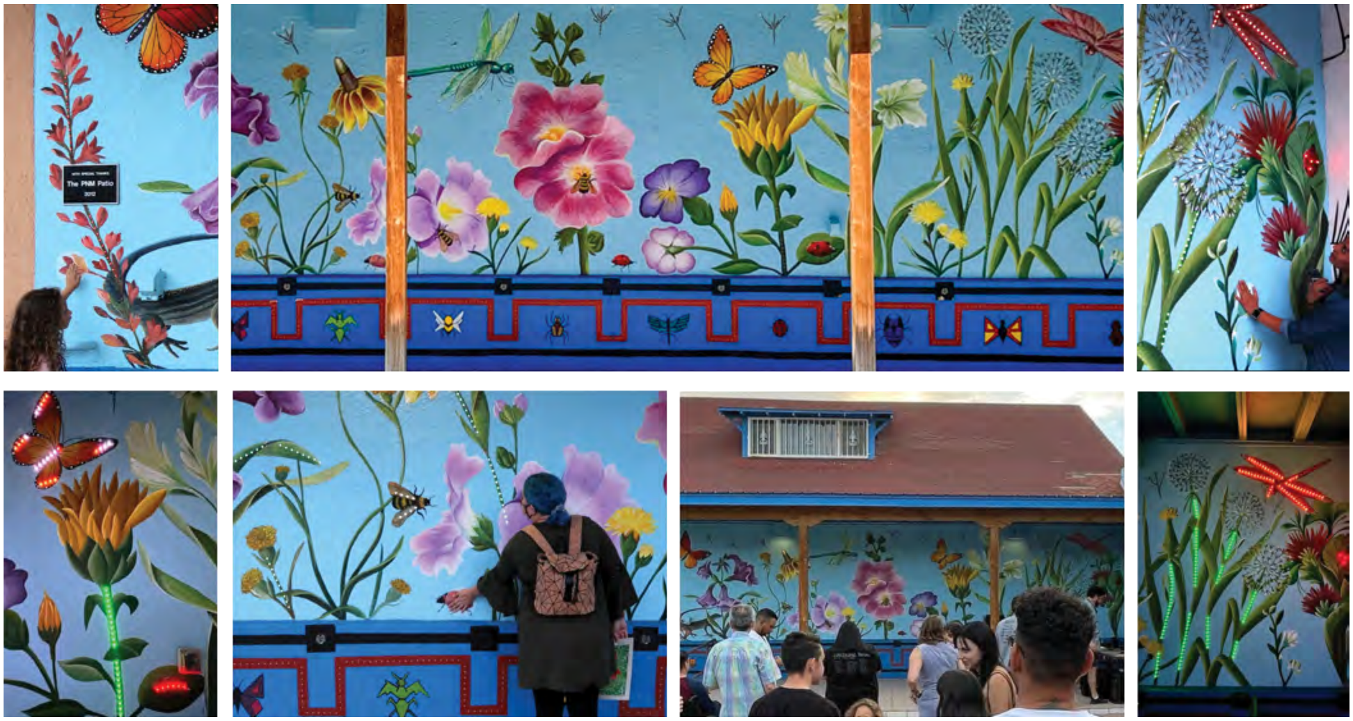

Figure 6: The mural unveiling event at a city-wide art walk, where community members interacted with the mural for the first time.

mural workshop to generate a set of approximately 200 preliminary conceptual codes [22, 48, 49]. They then extracted seven of the most prominent codes and refined them.

Sub-codes were then defined for these seven prominent codes. Authors 1 and 3 reviewed the previous two interviews using these codes and pulled quotes defending each code and sub-code. We met again to discuss each quote we found and determined if we agreed that it was placed appropriately under a particular code or sub-code. We revised and redefined the codes as necessary. Based on this analysis, we arrived at seven primary codes and seventeen sub-codes. Authors 1 and 3 then coded the remaining interviews from the summer workshop.

We then applied the focused coding scheme to student interviews from the spring workshop. After analyzing the additional data, the final round of analysis focused on developing thematic categories concerning students' learning in the context of creating an interactive mural. The following are the primary themes, also shown in Appendix A Table 1, that we developed through this process.

- Prioritizing **student agency** provided opportunities for students to feel an investment in and ownership over the mural and what they learned.
- Providing opportunities for **cultural expression and community engagement** were key to establishing youth's sense of belonging and connecting what they learned to their life experiences.
- Engaging students in integrated technology and art–**STEAM**–activity supported technical learning and positive shifts in students' perspectives on computer science.
- Fostering **collaboration**, by creating a rich social ecosystem and leveraging large-scale murals, helped students navigate complex problems together respectfully and generously.

Due to the amount of rich data we collected and analyzed, this paper focuses on the last two themes—STEAM learning and collaboration. We want to note the fact that these two themes are intertwined with each other and the other two themes. Collaborative learning environments support students in STEM learning. Combined, these themes facilitate deep engagement and help students develop technological and artistic knowledge and skills. We aim to expand and examine student agency, cultural expression, and community engagement in future publications.

3.7 Analysis Methods

3.7.1 STEAM Learning. To assess learning in programming and electronics, we refer to the K-12 Computer Science framework. A broad collection of stakeholders developed this framework to guide and foster K-12 Computer Science teaching [38]. At the core of the framework are fundamental concepts and practices that represent important ideas and skills in computing. We use the framework to assess STEAM learning, specifically relying on three of the concepts and three of the practices identified.

- ***FC1: Concept 1 Computing Systems*** — Understanding the relationships between hardware and software.

- ***FC4: Concept 4 Algorithms and Programming*** — Designing and writing effective and efficient programs.
- ***FC5: Concept 5 Impacts of Computing*** — Understanding the social implications of technology, including equity and access to computing.
- ***FP2: Practice 2 Collaborating Around Computing*** — Performing a computational task by working with others; either in pairs or on a team.
- ***FP5: Practice 5 Creating Computational Artifacts*** — Developing computational artifacts to embrace both creative expression and the exploration of computational problem-solving.
- ***FP6: Practice 6 Testing and Refining Computational Artifacts*** — Understanding the deliberate and iterative process of improving a computational artifact.

We will refer back to these numbered components of the framework in our analysis.

3.7.2 Collaboration. We employed the Co-Measure assessment rubric that was developed by Herro et al. to assess collaboration in STEAM learning activities [35]. The Co-Measure rubric identifies four key components of collaboration in STEAM:

- ***H1: Peer Interactions*** — Students monitor tasks and check for understanding with peers; students negotiate roles and divide work to complete tasks; students provide peer feedback, assistance, and/or redirection.
- ***H2: Positive Communication*** — Students respect others' ideas and compromise; students use socially appropriate language and behavior; students listen to each other and take turns.
- ***H3: Inquiry Rich/Multiple Paths*** — Students develop appropriate questions and methods for solving problems; students verify information and sources to support inquiry.
- ***H4: Transdisciplinary Approach*** — Students discuss and approach problem-solving that incorporates multiple disciplines; students share connections to research or relevant knowledge; students negotiate relevant methods or materials to solve the problem; students use tools collaboratively to approach tasks.

4 RESULTS

4.1 STEAM Learning

It is well documented that young people of color have historically had few opportunities to engage in computing-related activities [45, 56]. In line with these findings, our students reported in our pre-surveys having no knowledge of computing classes at their school, no knowledge of or access to these kinds of activities outside of school, and no prior experience with electronics or programming. Almost none of the students knew what "computer science" or "computing" meant. At best, students had a vague understanding of these terms that were associated with harmful stereotypes.

> *Before this workshop, I was kind of blanked on computer science.* –Alexa[3]

> *I didn't even know what (computer science) was. When someone brought that up, I thought it was some crazy stuff...Like, in the future.* –Enrique

> *Whenever I heard computer science, I (thought) you must be really smart in order to do that...you must have a really big brain in order to do that...I can't picture myself doing that.* –Elena

We wanted students to develop fluency in building electronics and programming by participating in both workshops. We wanted to support computational empowerment, helping students view electronics and computation as creative materials they could access, understand, and control [27]. Our activities were designed to provide a context where minoritized students could develop skills and interest in these new areas in a familiar and supportive environment free of stereotype threat.

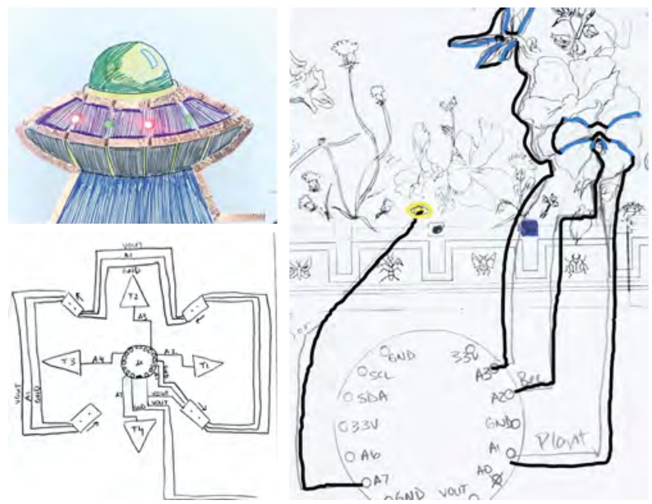

Figure 7: Left top: A student's creative paper circuit from the spring workshop. Left bottom: A student's mandala circuit layout, created with help from Author 1. Right: A student's circuit layout for their section of the mural during the summer workshop.

4.1.1 Electronics. Students were introduced to foundational electronics knowledge and skills in both the spring and summer workshops. In the spring, students learned 1) how to design and build functioning series and parallel circuits that included LED lights and batteries and 2) how to, with support from Author 1, design and build circuits that involved a microcontroller, LEDs, and sensors—developing an understanding of the relationships between hardware and software (FC1) by creating computational artifacts (FP5). Figure 7 top-left shows an example of a simple student-designed circuit and an electronic layout for an interactive painting that includes only LEDs. As the spring workshop progressed, the students designed and built a more complex circuit for their mandala interactive painting, seen in Figure 7 bottom-left, with significant help from Author 1. In the summer workshop, students built on the skills from the spring to independently design much larger and more complex circuits that involved microcontrollers, programmable LEDs, and

[3]All student names are pseudonyms.

sensors. Figure 7-right shows an example of a complex electronic layout for the summer mural that a student built independently.

In the spring, students also began to learn how to use a multimeter to identify and locate electrical problems, including short circuits and broken connections (FP6). Once the students in the summer workshop started to install the electrical components in the mural, they were prepared to use a multimeter to test connections. Before starting this workshop, students were unsure about computing and electronics and did not feel confident working with technology. It was evident in the interviews that when asked to describe how they constructed the interactive mural, they were able to talk confidently about what tools and techniques they used.

> *We individually tested all of the lights after we cut them to size and when they didn't work we had to...test them with the multimeter.* - Enrique

Students were also introduced to soldering in the spring workshop. Students were hesitant during the first day of learning how to solder. None of the students had any previous experience with soldering. However, each student successfully soldered the electrical connections for their interactive paintings. While building the interactive mural in the summer workshop, students further developed deep soldering expertise. Constructing the electronics required soldering countless connections on a vertical wall at awkward angles, frequently while standing on a ladder. By the end of the summer workshop, students expressed confidence in their soldering skills as they described what they had soldered on the mural:

> *We had to solder the LEDs, those little stripped ends together. And that took a while. And then once it was on the mural we had to solder...the copper tape and then we had to solder our own circuit boards...I think I'm pretty okay with soldering.* -Alexa

> *[Soldering] was pretty easy.* -Marley

An important part of what characterized students' electronic learning was the fact that it always took place in a visual context created by the students. From the first paper circuit activities onward, students created circuits and electronic layouts on top of their visual designs. The visual design constrained and guided the electronic design. This approach to integrating circuit design into concrete visual and physical media has been shown to have distinct learning benefits, with a particularly positive impact on retention [53].

In summary, students demonstrated that their ability to construct and design circuits developed significantly over the course of both workshops. Students also developed soldering expertise and began learning how to use electronic troubleshooting tools, including a multimeter. They were also able to talk confidently about what tools and techniques they would need to use on electrical problems.

4.1.2 Programming. During the spring introductory workshop, the students were introduced to programming for the first time via the Circuit Playground and MakeCode, as seen in Figure 8. They were guided through activities that touched on fundamental programming concepts, including *variables, conditionals, and loops* (FC4). They then applied these skills to design and create interactive paintings (FP5) independently. During the summer workshop, students

Figure 8: Students programming during the workshop.

expanded on what they had learned to create larger and more complex programs. An important part of programming literacy is that students are able to understand the relationships between hardware and software, such that they can apply techniques to new problems (FC1). Alexa demonstrated this in her interview as she described how the spring workshop provided her with the knowledge that she could use on the larger project in the summer workshop.

> *I think (the spring workshop) really did a great job of preparing for (the summer workshop), especially the coding and stuff...I actually took notes of the MakeCode. I was referencing back when we did the (summer mural).* –Alexa

From the programs we collected, we were able to observe a clear progression in the programs students wrote over the course of the spring and summer workshops. Figure 9 shows a progression of how students' knowledge evolved over time. Programs were written in the visual programming environment MakeCode [44]. The code on the left-hand side of the figure shows the first program a student wrote for her interactive painting. The code on the right-hand side shows the final interactive painting program that she developed on her own. This program is significantly more complex than the first iteration of her program.

Figure 10 shows the code written to control a section of the mural. As can be seen in these Figures, students began by writing very simple programs. The code on the far left of Figure 9 employs a single loop and a single if statement to change the color of an LED strip from blue to red when a switch is pressed. The final code for the mural, shown in Figure 10, includes several more advanced structures, including variables, nested conditional statements, and compound boolean expressions (FC4). The program is also evidence of a more complex understanding of the relationships between hardware and software (FC1). Here, the student is using analog sensors and programming threshold values to trigger events. She also controls individual LEDs on her light strip instead of turning the entire strip into a single color. We documented similar progressions for all students.

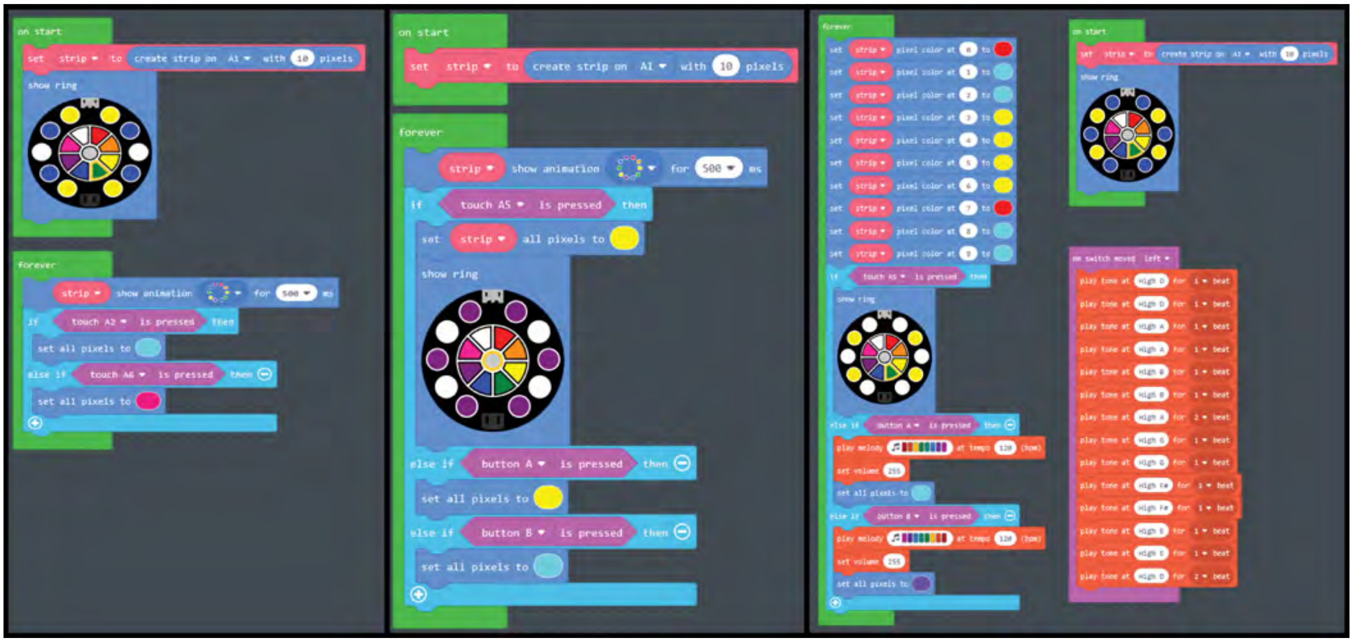

Figure 9: An example of increasingly complex code. A student's first program for her interactive painting is shown on the left. The final code for the interactive painting is shown in the third column.

Figure 10: Elena's final code for her section of the interactive mural that is more complex than the programs she first started creating in the spring workshop.

In addition to students learning how to program and build with electronics, their views on these fields shifted. In interviews, students reflected on their learning and their changing perspectives in nuanced ways.

> *Before this...I could barely turn on a computer...I learned a lot on the computer that I probably would never have learned in my life if I didn't work on [this project], but you guys showed me how.* –Enrique

> *I feel like everybody thinks it's just...code code code 1, 2, 3...I feel like the overall public has this concept that only like quote-unquote smart people can do technology stuff or like computer science...but I feel like now I'm a little bit more confident that I'd be able to do it as well...So I definitely am a little bit more confident and interested.* –Jen

> *[Before], I wasn't really, the person that'd be coding anything or wiring...nothing like that...But, ever since we did this workshop...I'm starting to look at things. Like I was putting up these fairy lights in my room and I'm like, I wonder how you program these...I've learned new things. I've learned things that I never really thought I would be able to do or really have an interest in...I wanna do another one...It's just really cool.* –Elena

Students developed significant programming skills through their work on this interactive mural. As the above quotes illuminate, students' perspectives on computing and its relationship to their interests and identities began to shift in subtle but powerful ways. We believe that students' experience of the project suggests ways in which a new learning context, like interactive murals, can open up new pathways into STEM and STEAM for minoritized youth. By supporting students' interest in art and working in an existing community (WC), we created a learning environment that was safe, comfortable, and relevant to students' interests. Beyond this individual project, we hope that we have provided an example of a context (community-situated interactive murals) that can provide new opportunities for minoritized youth to develop technological fluency and ultimately bring their unique perspectives and voices to the realm of technology design.

4.2 Collaborative Learning

The K-12 Computer Science Framework defines the important practice of Collaborative Computing (FP2) as "*the process of performing a computational task by working in pairs and on teams...Collaboration requires individuals to navigate and incorporate diverse perspectives, conflicting ideas, disparate skills, and distinct personalities. Students should use collaborative tools to work together effectively and create complex artifacts.*" We believe that, in many ways, the interactive mural project embodies this practice. To better understand the different kinds of collaboration that took place during the project, we employed Herro et al.'s co-Measure rubric [35], analyzing interview data and artifacts including students' sketches, visual designs, color studies, electronic layouts, and programs.

We introduced some collaborative approaches in the spring workshop. In particular, we had students work in pairs while we introduced them to programming. Eva, a student participant, reflects on these activities (HP1):

> *I feel more confident now in coding and figuring out different problems 'cause I had also helped other people with theirs, so I feel more confident in like helping with problems now.* –Eva

It is important to point out that Eva had never programmed before the spring workshop, but afterward, she felt confident enough to help other students with their programs.

The enormous scale of murals affords collaborative design and construction. Integrating technology into a traditional mural added a new layer of collaboration between artists and technology designers to this project. In addition, to successfully engage a group of youth, each workshop needed to support and integrate students' different perspectives, interests, and skills.

4.2.1 Collaboration in the design process. The design and construction of our interactive mural provided many rich opportunities for collaborative learning while still providing students with spaces for agency and self-expression. These began with the mural's visual design. After students created individual sketches of plants, the sketches needed to be combined into a cohesive design. Author 2 facilitated this process through an activity in which students sat together around a light box to build a design that incorporated contributions from everyone. Students photocopied and cut out elements of their sketches and then rearranged them on the light box to create the final design, see Figure 11. This collaborative-making activity, grounded in peer interaction (H1), was crucial in designing a collaborative yet cohesive visual design. Elena described the process eloquently:

> *At first, we were trying to fit every single plant that we drew inside...But then it came to a point where I was like, alright guys, we need to cut some loose...It was kind of like a puzzle trying to figure out which plants would look good together...everyone was like, are you sure you're okay with this? Should we do it like this? Everyone was throwing out ideas...At first, everyone was shy...And then we were like, well, how do you feel about this or this? And then we were like, oh yeah, that looks good. Everyone at the end loved it.* –Elena

Figure 11: Students collaborate around a lightbox to design the visual of the mural.

The collaborative nature of this process was embodied in the final visual design. Figure 12 shows a diagram of the design where each student's contribution is highlighted. As seen in the figure, the mural combines and balances contributions from all students. This diagram also highlights collaboratively designed elements (shown in orange) that were added specifically to tie the piece together. These include bugs that are scattered through the mural and along its bottom edge. To achieve this result, students respected each other's suggestions and took turns offering ideas. Students expressed appreciation for and admiration for the work of other students, exemplifying Positive Communication (H2).

> *Someone came up with the idea to put bugs in each empty slot and it was just super cool...If nobody came up with these ideas then the mural wouldn't be half of what it was...It really took teamwork.* -Elena

> *We used some of everyone's designs for the bottom. I like the bottom. It's really nice.* - Enrique
> *The other students are really nice and had great input. And I think we (each) put our own ideas into the mural.* - Alexa

Students' collaboration on the visual design led naturally to collaboration on the interaction design. Students worked together to develop several whole-mural interactions. For example, when a user presses the far left touch sensor, all the bugs across the mural light up. Some of these interactions required the addition of new visual elements, which the students discussed and then added to the design—see Figure 13-bottom. For example, Elena designed an interaction that led to the addition of a row of dandelion seeds at the top of the mural that was embraced by the other students:

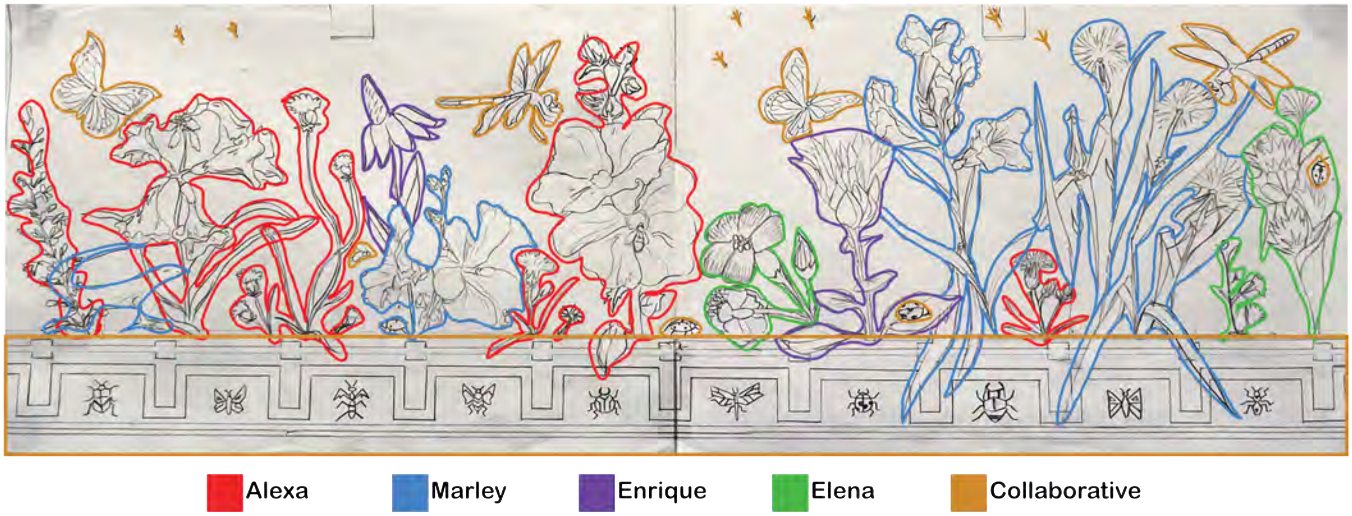

Figure 12: The visual design of the mural depicts what each student individually contributed and what the students collaborated to contribute.

> *I had...the idea of putting [LEDs] on the dandelions going up and I said, whenever the touch sensor was being touched, then [light] would go up on the dandelion and then the little offspring dandelion would light up, going with the wind that way...I wanted it to be one after another...like one, then [one of] the line of offspring would turn on and then the next one, and then the next one.* – Elena

Students were considerate about using electronic elements and interaction design to highlight mural elements contributed by their peers. Enrique described how, for his section, he added LEDs to Elena's flowers since they were small, and he felt that *"they needed a bit more attention"*. Another example of this was when Alexa thoughtfully left space for Marley's designs:

> *I think Marley's, theirs is kind of like more up (towards the top) of the mural, so I placed mine (my LEDs) more at the bottom with the lizard and the stems. I just want(ed) them to have more breathing space.* –Alexa

The color study for the mural—the plan for how color would be used throughout the piece—was also developed through a process of respectful negotiation and compromise. Each student was given a line drawing of the visual design to color. Authors 1 and 2 then worked together with the students to determine which colors from each individual color study would be incorporated into the final mural color pallet, Figure 13-top.

4.2.2 Collaboration in the installation process. The scale of the mural shaped the electronic installation. Many electrical components (i.e., LED strips) spanned large areas across the mural. Students had to work together to attach these to the wall—see Figure 14. Students worked in teams of two, with one person soldering connections and another adhering components to the wall, developing an effective and collaborative approach that solved the challenge posed by the construction of large-scale electronics (H3).

Figure 13: Top: Students review their color studies with Author 2 to decide the final colors of the mural. Bottom: Students work together to decide on what types of interactions they will include in the mural.

During electronics installation and programming, students worked together to troubleshoot problems that inevitably arose, a process that blended FP6 (Testing Computational Artifacts) with H1 (Peer Interaction), H2 (Positive Communication, and H3 (Inquiry Rich Paths). Here is Elena discussing steps in the collaborative debugging process that emerged during the workshop:

> *First...(identifying) where is it going wrong? And then finding what was wrong and then soldering that and then going to retest it...All of us were working together,*

Figure 14: Left: Students installing LED strips across the mural and supporting each other on the ladders. Right: Troubleshooting: Students work together on programming and checking connections.

> *and it was like, oh, that part is broken. Here, I’ll solder it. And it was like someone was doing a job, someone was soldering what was broken, and then someone was checking the connection points, but we were rotating on everything.* –Elena

Students faced an array of complex troubleshooting challenges while building the mural. LED strips fell off the wall, copper tape broke, and soldered connections required fixing; see Figure 14.

> *The paint was getting under the lights and the adhesive was like coming off and then the lights would fall off.* -Enrique

> *Sometimes the copper tape would break and then we’d forget that it broke.* -Marley

> *The challenge was having the copper tape stay together and figuring out where to solder it...So I just had to rip off a piece of copper tape and place it next to the rip to remind myself there’s a rip I would need to solder* - Alexa

Students shared their successful troubleshooting approaches. For example, Alexa shared her method of marking broken connections, and everyone then began employing it. As they built the mural, students developed increasing collective and individual skills in identifying common problems and solving them (H3, FP6).

> *There was another (electrical) problem that...I’ve already seen, so I already knew how to (fix it). (I am) able to kind of do it by myself and recognize what was wrong.* –Elena

Finally, the painting process was collaborative, see Figure 15, and interwoven with programming and troubleshooting, exemplifying the Transdisciplinary Approach (H4). Students painted their sections but also worked across the whole mural. They worked together on several elements and shared painting techniques with each other. Author 2 supported students during this process; see Figure 15-right. For example, she worked with students to shade all elements using the same light source so that the final mural would be visually cohesive. Alexa reflected on how Author 2 provided important insight while painting the mural:

> *I never really painted flowers so (Author 2) kind of had to show me. (She helped with) shading and lighting of the flower. I think I was going to light with my shadings...so she had to tell me to put more of (these) light rims of the shapes of the flower* – Alexa

In summary, we believe that creating an Interactive Mural is an intrinsically collaborative endeavor, with novel affordances that arise from the large scale of murals and the interdisciplinary nature of blending technology with mural painting. These natural features of interactive murals make them a uniquely rich and authentic context for collaborative learning in STEAM. The opportunities that interactive murals provide for collaborative STEAM learning can be deepened with thoughtful pedagogical choices, a topic we return to in our discussion.

Figure 15: Students painting over the electrical components of the interactive mural.

5 DISCUSSION

5.1 Deep Multi-layered Collaborations

This project, as we have already described, is inherently interdisciplinary and collaborative. The project was facilitated by collaboration between the lead designers and educators, Authors 1 and 2. We have very different and complementary skills, and developing both the mural and workshop structure required mutual respect, communication across disciplinary boundaries, negotiation, and compromise.

We initially designed our workshop plan so that artistic and technical activities were separate and distinct. Students would work on visual design for several days and then work on electronic layout and programming. But, as the workshop progressed, visual design, interaction design, and electronic layout increasingly blended together. So did painting, programming, electronics installation, and troubleshooting. Each activity informed and impacted the others in unanticipated ways. At the very end of construction, for instance, students decided to paint halos around all of the insects in the mural to indicate where people should touch them.

Figure 16: Students install LED strips across the mural.

We believe that the foundational collaboration between the primary organizers—characterized in part by a deep mutual appreciation for the artistic and technical components of the project—helped model and facilitate student collaboration. Students witnessed, and sometimes were part of, an ongoing dialogue between Authors 1 and 2 as they worked together to design a novel artifact and learning experience.

In addition to the collaboration between Authors 1 and 2, the project benefited from the support and collaboration of many other researchers and community partners. WC provided a wall for the mural, classroom space for teaching, and deep community grounding for the project. Staff members at Working Classroom introduced us to students and their families, helping us build strong relationships and community ties. Research team members each brought different skills to the project. For example, Author 3 led the qualitative analysis of the data.

We believe that the multi-layered nature of our collaboration is intellectually significant. The project has been *mutually beneficial* to both researchers and artists [24, 25]. We believe that projects like ours can also be beneficial and influential to students and communities, but their success depends on the depth of the collaborative relationships that are established between all parties.

5.2 The Physical Scale of Murals

Perhaps the defining characteristic of murals is their physical size [41]. Paintings executed at an architectural scale are qualitatively different than smaller ones. This enormous scale is a large part of what gives rise to the unique collaborative learning affordances of interactive murals.

Murals often require a collaborative construction process; they are simply too big for one individual to construct in a reasonable amount of time. Our interactive mural, which is 32 ft wide by 10 ft tall, contributes to a long history of collaboration design and construction in community mural projects [5, 19].

The scale of our mural provided an authentic purpose and context for collaboration and collaborative learning. A collaborative workflow was not applied to the project; the project *genuinely required one.* The impact of the physical scale on the project was perhaps most striking during electronics installation and troubleshooting. The size of electrical traces and LED light strips made collaboration essential in simple and unavoidable ways. Electrical components spanned much of the entire wall, up to 32 feet. Students *had* to work together to install them; see Figure 16. Similarly, students *had* to work together on troubleshooting and programming.

We believe that the simple authenticity of the collaboration that is required on interactive murals—guided as it is by physical constraints—provides clear and compelling motivations for collaboration. Murals' large scale provides a unique and powerful affordance that can be leveraged to help students develop collaborative skills in an authentic, real-world context.

5.3 Activity Structures that Support Collaboration

The natural collaborative affordances of murals were heightened and reinforced by some of our pedagogical choices. First and foremost, the relationships we developed with community members, students, and their families allowed us to gain students' trust. It was also essential to create a learning environment that students felt comfortable in. We believe that the key element of the environment was the art-focused context that enabled students to utilize and build on their expertise and experience in the arts, coupled with our commitment to student agency and expression. Establishing trust and building a comfortable and supportive learning environment established a critical foundation that enabled students to work and communicate comfortably and openly.

The most important activity structures that enhanced student collaboration were a *mural theme* that enabled students to contribute individual designs into a cohesive whole and a *visual design* *process* that laid the collaborative foundation for the rest of the project.

Our focus on local flora found around WC as the mural theme provided students with a structure in which they could make personal individual contributions—-by choosing specific plants and flowers–to a cohesive larger work. Students' plant observations and sketches could be combined into a larger botanical design, maintaining their individual character while coming together into a single design. Not all mural themes or topics provide this kind of support for collaboration. For instance, a portrait mural would not support individual contributions in the same way. Let us say that the students were allowed to pick people who inspired them for the portrait mural. They might not agree on one person. Or if they each got to pick an individual of their choosing, there is a possibility that the mural will have several individuals that are not related to one another, diminishing the overall story the mural tells. Students may have different reasons to find individuals inspiring. This will result in the mural not having a site-specific theme, which is traditional in how murals are designed. By focusing on local ecologies, we speak to the site-specific environment and culture that are entangled with the flora and fauna. This seemingly small detail of the workshop design was a significant contributor to its success and the ability of the students to work productively together. Although it was collaborative, the students were still given opportunities to make it their own as co-authors of the artistic and technical components.

The second critical activity structure was the collaborative visual design process described in section 4.2 and shown in Figure 11, in which students worked together to create a visual design by combining, rearranging, and layering their individual plant sketches. Small elements of this activity were important. The fact that student could cut out and copy their drawings at different scales was important. The fact that new elements could be layered on top of other elements in the design was significant. Students created and photocopied new drawings as the design came together. They also placed tracing paper on top of the original design and drew new elements on this surface.

This activity established a student-led collaborative workflow that continued for the remainder of the project. The process initially required patience and trust on the part of both students and instructors. Elena describes the beginning of the activity well:

> *It was kind of quiet at first and it was kind of awkward...it was difficult at first, but...once people started to open up, then it was share what knowledge you have. And then we all basically worked together.* - Elena

As Elena observed, once students began talking and sharing ideas, the design process moved forward quickly. We believe that providing minimally guided, open-ended, and student-led activities early in the workshop established the collaborative dynamic that students then maintained for the rest of the session. Since the electronic layout and interaction design were guided by the visual design, students naturally continued to collaborate around these elements of the project.

While the affordances of interactive murals provide unique opportunities for collaborative learning, our experiences helped us understand how careful pedagogical choices can emphasize and deepen these opportunities.

5.4 Community-Based Work Challenges

The amount of planning and undertaking that went into organizing this project was extensive. The project involved the integration of many different components, including choosing appropriate research methodologies, designing learning activities, organizing workshop logistics, and actually building a functional interactive mural. However, integrating all of these moving parts was extremely rewarding for us, the students, and the community.

From a research perspective, we believe that it is important for HCI researchers to undertake complex real-world projects like this one [5, 6, 8, 12, 36, 46, 67]. One easy-to-overlook but important takeaway for us from this project is simply that *it is possible to develop a novel technology in collaboration with youth*. We were able to authentically engage youth in co-designing and building an interactive mural–a piece of experimental technology that had never been built before. Moreover, we were able to do so in the context of a real-world community-oriented public art project.

We believe that this project, and ones like it, provide fertile ground for large-scale and multifaceted research projects that can extend beyond a single paper and ultimately be more important and influential than most lab-based studies.

We faced challenges in structuring learning activities that would teach students about electronics, programming, and electronics. We created learning activities that focused on each of these independently, but we believe there is room for innovation and in teaching these topics in a more integrated fashion.

Another critically important element of the project was workshop organization. Our work with WC staff and student families to coordinate workshop details served as key components of community building. It is how we got to know WC staff members, students, and their families. We spoke regularly with parents and students about what they needed to bring for certain workshop days (for example, what to bring and wear for painting days) and coordinated drop-off and pick-up times. We collaborated with WC staff members to ensure meals and snacks were always available for the students. We worked with several families to help find transportation for students from school to the workshop and then home from the workshop. We often stayed late with students until parents were able to pick them up.

Navigating these daily challenges and small details was critical to establishing trust with participants and their families. Through these interactions, we began to form real relationships and establish lasting personal and community ties. The long-term and intensive nature of the project provided us with the time to get to know participants, their families, and WC staff. We cannot overstate how essential developing these relationships was to the project. We believe that the openness, creativity, and enthusiasm students exhibited are largely a result of us building genuine relationships and trust with students, their families, and the rest of the WC community. For example, Alexa now works in our research lab as an undergraduate research student on the Interactive Mural project led by graduate student Author 1. Alexa majors in Art Education at our university, and she has started incorporating technology within her own art. Elena and her parents asked Author 1 to participate in the Big Brothers Big Sisters of America [4] organization as a mentor for Elena.

Though these organizational details are not typically discussed in the context of research, this labor established the foundation for the rest of the project, and we believe it warrants attention as a significant component of research conducted in community settings.

5.5 Technical Challenges

We also encountered significant and interesting technical challenges in building a functional outdoor interactive mural. The mural was constructed during the summer months when daytime temperatures in our city are often above 100°F (38°C). This constrained our working time to the mornings when it was cool enough to work outside. The mural is located on a porch with a roof that provides some shade and protection from the elements. However, we were unable to work outside for several days because of significant rainstorms. This delayed our progress and required us to adjust our schedule.

We are currently monitoring the mural to see how it holds up over time. As of the writing of this paper, it has been installed for a little over a year and is still functioning. We anticipate that the mural will likely require maintenance and repair over time, another topic for ongoing research.

6 CONCLUSION

This paper presents interactive murals as new community-based contexts for collaborative STEAM learning. We introduced a group of diverse high school students to electronics and programming through the design of an interactive community mural. We identified distinctive learning affordances of interactive murals, highlighting how they provide deep support for collaborative learning. We propose the process of building an Interactive Mural as an intrinsically collaborative endeavor, with unique affordances arising from murals' large scale and interdisciplinary character.

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A THEMES AND FOCUSED CODES

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Themes	Primary Codes	Sub-Codes
Student Agency	**Youth agency:** How youth describe having the agency to be in charge of the design (i.e., visual, interaction, etc.)	***Visual design process:*** *How the students describe their input in the visual design process.*
		Interaction design process: *How the students describe their input in the interaction design of the mural and their input in how the electrical components will be incorporated.*
STEAM Learning	**Technical skills learned:** How youth describe the skills they learned during the construction of the interactive mural.	***Technical skills learned:*** *How youth describe what they did technically when constructing the mural.*
		Troubleshooting challenges: *How youth describe the challenges they faced, and how they overcame them.*
	Shifting perspectives of CS: How youth's perceptions of CS (e.g., development of technology, conducting research in CS) changed after participating in the workshop.	***Shifts about how difficult CS is:*** *Youth's shift in perspectives of how they view the difficulty of CS.*
		Shifts about who can do CS: *Youth's shift in perspectives on if people that they relate to can do CS.*
		Shifts about what they can do with CS: *Youth's shift in perspectives on what they can now do with CS that they couldn't before.*
		Shifts about what you can do with CS: *Youth's shift in perspectives on the possibilities that people can work with CS.*
Cultural Expression and Community Engagement	**Youth's art histories and competencies:** How youth's previous artistic competencies and interests support their confidence in engaging and succeeding in learning the technical content.	***Youth's art expterise:*** *How youth bring their art expertise and confidence of artistry into the project.*
		Youth's art history: *How youth describe their family ties to art and desribe their own history with art.*
	Youth's cultural backgrounds and connections to the community: How youth's describe the importance of community and their culture.	***Youth's cultural expression:*** *How youth's express their cultural backgrounds to connect to their community.*
		Youth's ties to the community: *How youth's perceptions of belonging in the art community encourage their engagement.*
Fostering and Understanding Collaboration	**Layers of collaboration:** How youth worked together and with others to accomplish design goals.	***Collaboration of Youth With Each Other:*** *How youth worked together to accomplish design goals.*
		Collaboration of Youth With Research Team: *How youth worked together with Research Team members to accomplish design goals.*
		Collaboration of Youth With Partner Organization: *How youth described their experience working with partner organization.*
	Interactive Mural Driven Collaboration: How the mural scale and design of the interactive mural shapes the nature of collaboration.	***Scale of Murals:*** *How painting murals provides natural collaboration.*
		Troubleshooting Electrical Components: *How students had to work together to troubleshoot electrical components due to the large areas the components covered.*

Table 1: An outline of the themes, focus codes, and sub-codes extracted from the initial coding process and evaluation.