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NEGOTIATING ENGAGEMENT IN STEAM EDUCATION: A LONGITUDINAL INVESTIGATION OF PARTICIPANTS' EXPERIENCES IN AN ART-SCIENCE PROGRAM

Dissertation by

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Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

February 2022

Abstract

NEGOTIATING ENGAGEMENT IN STEAM EDUCATION: A LONGITUDINAL INVESTIGATION OF PARTICIPANTS' EXPERIENCES IN AN ART-SCIENCE PROGRAM

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Practitioners and scholars have begun to recognize the need to fracture disciplinary boundaries in K-12 learning settings in favor of more holistic approaches. STEAM (science, technology, engineering, arts, and mathematics) education, in particular, has been proposed as a means to reimagine science education based on youths' widespread interest in art, design, and making, and the encouragement of multiple forms of expression in these endeavors. This dissertation documents the development of an art-science program and research on the experiences of middle-school-aged participants, who predominantly identified as Latinx and bilingual, in three papers.

In the first paper, I used design-based research to investigate how an art-science program evolved to support youths' interests and disciplinary integration from a teacher perspective. A cross-case analysis of two program iterations yielded two design guidelines. First, it is important to create opportunities for youth to engage in STEAM education in ways that allow them to build on their interests while also cultivating desirable social images. Second, ongoing teacher collaboration and foregrounding youths' development of project artifacts supported disciplinary integration.

In the second paper, I draw on a longitudinal case study approach to investigate two focal youths' enactment of art-science thinking practices—or practices common to artistic and scientific fields—over three program iterations. Results highlight three insights: (1) the program's approach to disciplinary integration played a key role in which art-science thinking practices youth enacted and how; (2) the incorporation of multiple STEAM disciplines encouraged youth to build on a wide range of interests; and (3) developing artifacts supported youth to engage in STEAM projects while maintaining their social standing.

The third paper is a practitioner study documenting the program design and outcomes regarding case study youths' perspectives of art-science thinking practices. Results demonstrate how STEAM education can support youth to appreciate imagining and creating in the context of science. I conclude with the program's successes and challenges and implications for in- and out-of-school STEAM practitioners and program designers.

Dedication

For my father, Robert.

Acknowledgements

This project would not have been possible without the support from my family, friends, and valued members of my learning communities over the past six years. I would first and foremost like to thank my dissertation committee members for your thoughtful insight, support, and mentorship throughout the dissertation process. Mike, I am incredibly grateful to have worked with and learned from you. You have been a wonderful mentor to me as a researcher and educator. Thank you for your guidance and for having faith in me. Jon, your ongoing support and optimism brought me joy during my time at BC. Thank you for extending my thinking about qualitative research and for reminding me to take risks. Beth, thank you for supporting me to imagine expansive possibilities for education. I am grateful to have learned from you.

I thank all whom were a part of the project that was central to this dissertation, including the students, teachers, and researchers. Thank you for your energy and for contributing to my thinking. I have learned so much from each of you. I specifically would like to thank Ariella for her hard work and dedication to this project. I am grateful to have collaborated with you.

I thank members of the Boston College community who have shaped my journey. Thank you, Helen and Annie, for your guidance and mentorship. Helen, thank you for your steadfast kindness, attention, and support. Your feedback has pushed my thinking and made my work as a researcher and educator stronger. Annie, thank you for supporting me during my time teaching at BC. I am grateful to have worked with and learned from you. I thank my BC friends and doctoral cohort for their support and kindness—particularly Haerin, my dear friend and dissertation partner.

I would like to thank the family members and friends who supported me to pursue a doctorate and write this dissertation. I would like to thank my father for always believing in me and for being a wonderful role model. You will forever be the voice of wisdom and compassion inside my head. Thank you to my mother for being my most enthusiastic and vocal supporter. I thank my sister, Bettie, for her ongoing encouragement. I thank my friends in Charlottesville, D.C., Los Angeles, New York, Philadelphia, and Boston for your love and kindness. Our friendships mean the world to me.

I thank my life partner and best friend, Jeff, for your love and encouragement. None of this would have been possible had you not been by my side. Thank you for helping me to keep everything in perspective. You and Brayden are the greatest joys in my life. I cannot wait for our next chapter together.

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Introduction

With the current global interest in integrated approaches to education, disciplinary boundaries are increasingly becoming blurred (Finch, Moreno, & Shapiro, 2020, 2021; Kang, 2019; NRC, 2014; Takeuchi, Sengupta, Shanahan, Adams, & Hachem, 2020). These approaches recognize that individuals draw on knowledge from a range of disciplines and experiences when understanding and addressing questions encountered in their lives (Finch et al., 2020). Schooling, however, has historically relied on dividing knowledge and practices along disciplinary boundaries (Finch et al., 2020; Oleson & Voss, 1979). Scholarship documents how disciplinary thinking can constrain ways of knowing, doing, and being (Bevan et al., 2019; Connor, Karmokar, & Whittington, 2015; Finch et al., 2021; Marshall, 2014; Mejias et al., 2021). When learning in silos, youth receive explicit and implicit messages that there are exclusive practices and identities that are "legitimate" within a discipline (Bevan et al., 2019; Finch et al., 2020).

Challenging our understandings of what practices and identities are legitimate through discipline integration may be especially fruitful in science education, which has historically appreciated a narrow range of epistemologies, axiologies, and ontologies (Archer et al., 2017; Carlone, Scott, & Lowder, 2014; Rosebery, Ogonowski, DiSchino, & Warren, 2010; Rudolph, 2000). That said, it is also critical to recognize that the individuals performing and interpreting practices in STEM classrooms are inhabiting bodies that are raced, gendered, and classed (Carlone et al., 2014; Gutiérrez, 2013), social ascriptions that have histories in and of themselves. Further, the topics studied and the artifacts and tools used in science education carry their own histories, many of which remain affiliated with White males (e.g., computer science, robotics, physics) (Archer et al., 2017; Kafai, Fields, & Searle, 2014; Medin & Bang, 2014; Peppler & Wohlwend, 2018). The interactions among individuals and artifacts in science education manifest in concrete ways, perpetuating unequal power dynamics and the ongoing "underrepresentation" of individuals identifying as Black, Latinx, Native American, and/or female in science, technology, and engineering fields (National Science Foundation, 2021). This phenomenon begins as early as middle school when many of these youth begin to experience distanced relationships with science (Calabrese Barton et al., 2013; King & Pringle, 2019). With these concerns in mind, previous scholarship demonstrates that leveraging art with STEM (science, technology, engineering and mathematics) subjects (e.g., STEAM, maker spaces) can support the developing interests and identities of Black and Latinx youth, and those who identify as female in particular (Bevan et al., 2019; Carsten Conner et al., 2019; Kafai et al., 2014; Kang, 2019; Magerko et al., 2016; Peppler & Wohlwend, 2018).

Purpose

Although there are hopeful conversations about the potential of STEAM (science, technology, engineering, arts, and mathematics) education to expand learning opportunities, STEAM is still relatively new (Bush, Cook, Edelen, & Cox, 2020; Quigley, Herro, King, & Plank, 2020; Takeuchi et al., 2020). As such, empirical studies are limited, particularly regarding the design of these environments and participant youths' experiences and perspectives in these environments (Bush et al., 2020; Finch et al., 2020; Kang, 2019). To contribute to the emerging scholarship in this field, this dissertation documents the iterative design of an art-science program and longitudinal research on the experiences of middle school youth participants in three papers. Each paper is structured around a different set of questions to address each of the following purposes:

- Paper 1: The purpose of this design-based research study is to highlight the trajectory of the program over two consecutive iterations (2018-2019 School Year and Summer 2019) through an investigation of how the program evolved to support youths' interests and disciplinary integration from a teacher perspective.

- Paper 2: This paper utilizes a longitudinal ethnographic case study approach to understand the emergent art-science thinking practices of two focal youth, the roles they negotiated in group projects, and how their perspectives of art-science thinking practices shifted (if at all) over the course of three program iterations (Summer 2018, 2018-2019 School Year, and Summer 2019);
- Paper 3: This practitioner study documents the program design and outcomes generated during the third iteration (Summer 2019) and connections between the program design and science and performing arts standards.

The longitudinal case study (Paper 2) builds on the DBR study (Paper 1) by highlighting the experiences of two focal youth who participated in Dramatic Science during the program iterations highlighted in Paper 1. Similar to the DBR study (Paper 1), the practitioner study (Paper 3) also focuses on the program design, enactment, and youths' interactions with the enacted design. What is different about these two papers is the focal audience and scope of the research. More specifically, the DBR study (Paper 1) will be designed for a researcher audience and include data from two project iterations (2018-2019 School Year and Summer 2019) while the practitioner study (Paper 3) will be written for practitioners and include the design and a subset of findings generated during the third project iteration only (Summer 2019). (It is important to note that a new group teachers joined our project team at the beginning of the second program iteration (2018-2019 School Year). Given that the DBR study (Paper 1) focuses on these teachers' views of youths' engagement in the program and if/how the program integrated disciplines, this study included data from the second and third program iterations only, after these teachers joined our team.)

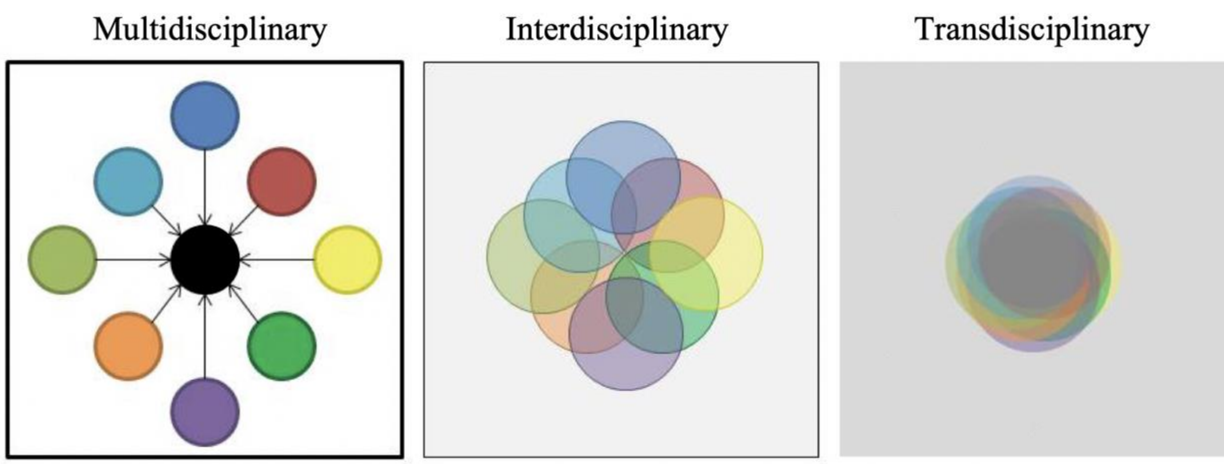
The remainder of the introduction section of this dissertation proposal includes the theoretical background and an overview of the program and curricular context for *Dramatic Science* (pseudonym), the out-of-school art-science program central to this study. Following the introduction, the literature, research questions, and methods for each of the three papers will be discussed. Last, the educational significance of this work and the relationships between the three articles will be summarized.

Theoretical Background: Art-Science Education

Rather than foregrounding a discipline, designers of STEAM education settings aim to support learners to address open-ended challenges through integrating knowledge and skills from STEAM disciplines (Finch et al., 2020, 2021; Kafai et al., 2014; Quigley, Herro, & Jamil, 2017). Although not always explicitly described, there is much variation in how the component disciplines are positioned and leveraged (or not) in STEAM learning environments depending on the level of discipline integration (Mejias et al., 2021; Quigley & Herro, 2016). Figure 0.1 depicts three approaches to discipline integration prevalent in the literature: multidisciplinary, interdisciplinary, and transdisciplinary (Quigley & Herro, 2016).

Figure 0.1

Approaches to Discipline Integration (Colakoglu, 2018)



Approaches to Discipline Integration

In multidisciplinary education settings, learners engage in multiple disciplines to address a focal challenge *without* integrating knowledge or processes from these disciplines (Quigley & Herro, 2016). During a field investigation, for example, learners could engage in mathematics to calculate the biodiversity of a habitat, science to learn about the ecological niche of focal species in this habitat, and visual art to illustrate a focal species in its habitat. Through this process, youth would utilize all three disciplines, albeit separately, to make sense of their observations and findings.

Interdisciplinary approaches differ from multidisciplinary approaches in that knowledge and processes from multiple disciplines are combined and interrelated (Quigley & Herro, 2016). For example, learners could engage in science to learn about water quality indicators in a local river while also engaging in engineering to design and test a water filter to improve these indicators. While interdisciplinarity is more integrated than multidisciplinarity, it has still been critiqued as an "additive" approach (Takeuchi et al., 2020, p. 11) because the ways of thinking and doing characteristic of these disciplines are not transformed.

Transdisciplinarity—which is considered the most integrated STEAM approach—goes beyond interdisciplinarity to support a "synergistic and reflexive relationship achieved through dialogues among people, practices, and constructs from multiple disciplines" (Takeuchi et al., 2020, p. 27). This relationship is characterized by convergence, transcendence, and emergence (Bevan et al., 2019; Mejias et al., 2021; Takeuchi et al., 2020). In terms of *convergence*, transdisciplinary education highlights the value that each discipline contributes while viewing these disciplines in light of their commonalities (Bevan et al., 2019; Marshall, 2014; Mejias et al., 2021). For example, in art and science disciplines, participants engage in common strategies and habits of thought—such as observing, imagining, and critiquing—many of which are not capitalized upon in traditional science education settings (Bevan et al., 2019; Hadzigeorgiou, 2016; Mishra, Koehler, & Henriksen, 2011; Winner, Hetland, Veenema, Sheridan, & Palmer, 2006).

When youth engage with perspectives and practices characteristic of multiple disciplines to address a question or problem, their learning *transcends* the component disciplines as well as traditional academic achievements (Bevan et al., 2019; Liao, 2016; Mejias et al., 2021; Mishra et al., 2011; Peppler & Wohlwend, 2018). In such a space, youth no longer readily distinguish their learning along disciplinary boundaries, blurring the distinctions between when they are "doing art" and "doing science" (Finch et al., 2020; Liao, 2016). Guerrilla Science's *Intergalactic Travel Bureau* provides an example of a transdisciplinary project focusing on theatrical space tourism (Mejias et al., 2021). In this exhibition, audience members are invited to interact with actors and space scientists for a space-travel consultation that highlights content, dialogue, and narrative revolving around space-science research (Mejias et al., 2021). In transdisciplinary education spaces, new epistemologies, methods, and practices can *emerge*, supporting youth to reimagine what practices and identities are legitimate in the learning environment (Finch et al., 2020; Marshall, 2014; Mejias et al., 2021; Mishra et al., 2011; Peppler & Wohlwend, 2018).

Conceptual Framework: Art-Science Thinking Practices

Building on the work of scholars who foreground common cognitive practices across art and science disciplines (e.g., Bevan et al., 2019; Henriksen & Deep-Play Research Group, 2018; Mishra et al., 2011; Peppler & Wohlwend, 2018; Root-Bernstein, Siler, Brown, & Snelson, 2011), our project team created a framework on *art-science thinking practices* fundamental to science and performing arts fields (Table 0.1). Designing art-science education settings through the lens of convergent thinking practices—rather than concepts—found in artistic and scientific fields represents an especially promising approach to STEAM education (Bevan et al., 2019; Mejias et al., 2021). Not only does this approach resonate with the practice turn in recent science education reform (NRC, 2012), but it also has the potential to support teachers and students in making meaningful connections across STEAM disciplines (Bevan et al., 2019; Mejias et al., 2021). By engaging in artistic and scientific practices—and recognizing the commonalities of these seemingly disparate domains—participants may challenge and reframe what is valued in these disciplines (Bevan et al., 2019; Finch et al., 2020, 2021; Mejias et al., 2021).

Table 0.1

Art-Science Thinking Practices

Preliminary Art-Science Thinking Practices Generated by the Researcher-Practitioner Team	Art-Science Thinking Practices Case Study Youth Reported to Enact During Their Projects
Exercising curiosity Making observations Identifying problems Empathizing Imagining and creating (e.g., solutions and representations) Learning through making mistakes Collaborating	Learning through making mistakes Critiquing Imagining and creating Collaborating

Communicating Advocating for change Getting feedback and revising	

The members of our project team engaged in ongoing discussions of practices common among these fields, resulting in a preliminary list of conjectured art-science practices depicted in the left column of Table 0.1. This preliminary list was revised based on youths' emergent art-science thinking practices and their recognition of which practices they enacted during their projects (Table 0.1, right column). In the following section, the design features of STEAM education programs that support the enacted art-science thinking practices are discussed.

Art-Science Thinking Practices

Learning through Making Mistakes and Critiquing

Foregrounding the iterative nature of STEAM education projects can encourage youth to learn from *making mistakes* and *critiquing*, art-science thinking practices that promote self-efficacy and self-compassion. When STEAM practitioners design with this goal in mind, they can support youth to engage in problem solving as an ongoing process in which several drafts must be developed, critiqued, and refined (Kang, 2019). The emphasis on ideas and processes over products can provide opportunities for youth to make mistakes and address them in subsequent drafts (Vossoughi, Hooper, & Escudé, 2016). Normalizing mistakes as a necessary part of learning during this iterative process fosters youths' development of compassionate mindsets to critiquing and refining their work and confidence in their abilities to continue in these tasks (Carsten Conner et al., 2017).

Imagining and Creating

STEAM education is especially well suited to foster *imagining and creating* through engaging youth in (1) personal expression; (2) leveraging multiple disciplinary practices and perspectives; and (3) tackling open-ended challenges with multiple outcomes. STEAM education settings can support youth to engage in imaginative and creative thinking practices through projects that encourage personal expression. The "added personalization of the artifact to a learner's own purposes or identities" (Carsten Conner et al., 2017, p. 2225) differentiates this process from making a model or prototype in traditional STEM education. Engineering and technology fields, for example, prioritize functionality and often ignore aesthetics and personalization, qualities that play a central role in the arts (Kafai et al., 2014). Creating personally-meaningful products promotes learners' sense of ownership and identification with STEAM disciplines (Bush et al., 2020; Carsten Conner et al., 2017).

STEAM projects that rely on the deep integration of multiple disciplines can further support imagining and creating by encouraging youth to employ multiple disciplinary practices and perspectives to solve problems. This intermingling of disciplines expands possibilities for youth to understand and address the challenge of interest in ways that could not necessarily be done in discipline-based learning environments (Mejias et al., 2021). Moreover, the open-ended nature of STEAM education projects privileges imagining and creating over pursuing pre-determined answers or solutions (Carsten Conner et al., 2019; Quigley et al., 2017, 2020). By foregrounding a challenge with multiple outcomes, STEAM practitioners can encourage learners to explore and leverage different approaches to generate a solution or product (Kim & Chae, 2016).

Collaborating

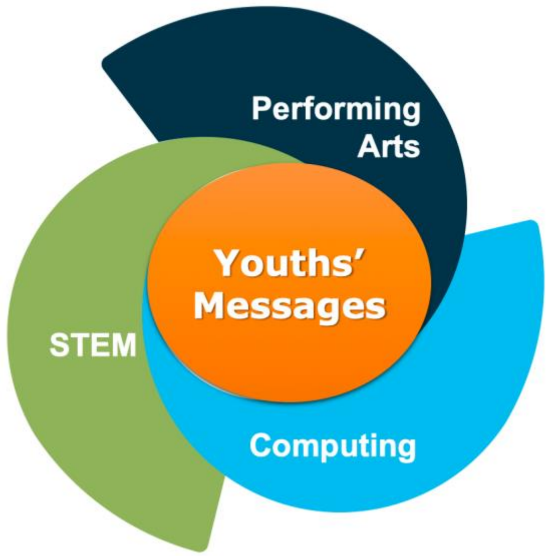
In addition to imagining and creating, the open-endedness and complexity of the challenge posed can foster *collaborating*. Open-ended STEAM projects necessitate that youth collaborate with their peers through multiple disciplinary practices and perspectives to generate a solution or product (Keane & Keane, 2016; Quigley et al., 2017, 2020). The inclusion of the arts, in particular, opens up opportunities for a broader range of ways of thinking, knowing, and doing to be valued than STEM-based projects alone (Quigley, Herro, Shekell, Cian, & Jacques, 2019). In STEAM projects, students who embrace arts disciplines have more opportunities to make meaningful contributions. Together, the STEAM project features of open-ended problem solving and the reliance on multiple disciplines can foster youths' collaboration skills as they coordinate with group members toward a common goal.

Curricular Context

Dramatic Science (pseudonym), the out-of-school art-science program that is central to this study, leveraged performing arts, STEM, and computing to engage middle school youth in creating messages about local social and environmental justice issues (Figure 0.2). As a part of this process, we aimed to support youth in engaging in art-science thinking practices and recognizing them as essential to performing arts and science disciplines and life in general. The remainder of this section describes the curricular context for the program iterations included in this dissertation. As will be discussed in the DBR study (Paper 1), the program underwent substantial revision between the second (2018-2019 School Year) and third (Summer 2019) program iterations. Given this substantial shift, both curricular contexts are described below. (Note: One of these programmatic shifts is reflected in the language used by the project team members and youth in the program, namely the shift from *theater* to *performing arts*. The descriptions of the curricular contexts and findings, including interview data, reflect this shift.)

Figure 0.2

Program Framework



Initial Curricular Context (Summer 2018 and 2018-2019 School Year)

During the first and second program iterations, each session was divided according to discipline, with students engaging in science-based lessons followed by theater-based lessons. As part of the science instruction, youth explored and investigated environmental justice issues related to an overarching theme, including climate change (Summer 2018) and water quality and distribution (2018-2019 School Year). For example, learners investigated the health of a local river by analyzing data from various water quality indicators (e.g., pH, turbidity, nitrite, lead). In another lesson, students designed and tested a water filter to improve these indicators. Each of these experiences was followed by a theater-based component in which students engaged in theater to make sense of and communicate their understanding of scientific concepts from the science-based lesson. During one theater lesson, for example, students enacted and filmed a mock news show that highlighted student-written segments on local issues about water quality and distribution. (Please see Appendix A for lesson examples.)

For their culminating project, youth engaged in theater as a means to communicate their messages about a specific, localized environmental justice issue related to the overarching theme (e.g., water quality and distribution). During the second program iteration, student groups were provided with multiple options for their project format, including creating a news show videoclip, a Public Service Announcement (PSA) poster, a PSA commercial, a TED Talk presentation, a play, or a board game. Youth presented their work to their families, peers, and teachers at a showcase event on the last day of the program.

Revised Curricular Context (Summer 2019)

As will be described in the DBR study (Paper 1), Dramatic Science was redesigned based on feedback from youth and teachers. The curricular features outlined below were implemented during the third program iteration (Summer 2019). For this iteration, the teachers collaboratively planned and taught a project-based learning unit, with the following question guiding youths' projects: *What would you like your community to be like in 10 years?* With this question in mind, groups of youth brainstormed and developed projects that highlighted messages about local social and environmental justice issues (e.g., housing rights, food rights). This process was ongoing throughout the three-week summer program. Importantly, all program sessions during this iteration were co-taught by both performing arts and science teachers, rather than being divided according to disciplinary expertise as was done previously. As discussed below, youth engaged in a process of brainstorming, creating, critiquing, and sharing their projects. (For details on lessons, please see Appendix B.)

Youth-Driven Brainstorming Phase

To support youth engagement in the Dramatic Science program sessions, we created opportunities for youth to make choices throughout their projects. Providing youth with meaningful choices on what and how they learn not only supports youths' developing interests and identities, but also improves learning outcomes (Basu & Calabrese Barton 2010; Pinkard, Martin, & McKinney de Royston, 2017). In collaboration with their group members, youth chose (1) an issue to highlight in their project's message; (2) types of media for their project; and (3) artifacts to develop for their project.

First Choice: Focal Issue. Working with a group of four to six peers, youth created projects about various local social and environmental justice issues, such as climate change, water quality and distribution, and voting rights and activism. Scholarship demonstrates that social and environmental justice issues can serve as strong motivators for youth to learn and apply artistic and scientific concepts and practices to address inequities (Liao, 2016; Madden, Wong, Vera Cruz, Olle, Barnett, 2017). Maintaining space for youth to choose a social or environmental justice issue that is locally and personally meaningful served to encourage empathetic problem solving (Bush et al., 2020).

Second Choice: Media. After choosing a focal issue, youth decided how to showcase their project. During this stage, youth were encouraged to draw on performing arts to communicate their message. We leveraged Halverson and Barker's (2017) conceptualization of performing arts, the "use of voice, movement, and/or other tools (instruments, props, puppets) to create metaphorical representations of events and experiences intended to be performed for a live audience or a future, digital audience" (p. 587). While some performing arts activities are disciplinary (e.g., a concert choir is in the music domain), others incorporate multiple artistic disciplines (Halverson & Barker, 2017). For example, a performance may include dancing, costume design, visual art projections, music, and spoken word, thereby representing the disciplines of music, dance, theater, and visual arts. Due to its interdisciplinary and audience-oriented nature, we focused on performing arts in the program design, rather than a disciplinary-arts approach (e.g., visual art, music, dance). To support youth in choosing an art form related to their interests and resources, the project team generated and proposed preliminary options, which were then revised by youth.

Third Choice: Artifacts. After selecting media to communicate their messages, youth determined what artifacts to create for their group's performance and which group members would develop those artifacts. Youth were given several choices to develop their projects, including coding lights or sound, designing and constructing props, designing models for a set, designing wearable technology, and working as an ensemble to enact ideas. For example, to produce a dance performance that highlighted a message about local climate change, youth could create costumes, mood lighting, poetry, and choreography. Within each group of four to six students, youth divided into two subgroups, each taking the lead to develop specific artifact(s) for their group's project (e.g., coding LED lights, costume design).

Creating, Critiquing, and Sharing Their Projects

When developing their art-science projects, youth engaged in iterative cycles of construction and critique (Ford, 2008; Halverson & Sheridan, 2014). In addition to collaborating with their group members to create and refine their projects, youth shared and critiqued their project drafts with the rest of their peers and instructors. From initially conceptualizing their messages to sharing their fully-developed performances, youth frequently engaged in critique that aimed to be supportive and nonjudgmental (Lerman & Borstel, 2003). Insights and questions that emerged during these critique sessions could then be addressed by group members in subsequent revisions. At the end of the program, youth presented their final projects at a showcase event. This event provided youth with an opportunity to share their projects with a broader audience, including their family members, friends, peers, and teachers.

Critique of Performing Arts and Science Disciplines

In addition to developing, producing, and sharing their messages, youth reflected on and critiqued science and performing arts disciplines (Marshall, 2014; Takeuchi et al., 2020). Youth reflected on these disciplines through various learning activities, including a graffiti activity on the "6 W's" for science and performing arts, which is revisited and revised over the cycle (What is science/performing arts? Why do people engage with science/performing arts? Who does science/performing arts? When does science/performing arts happen? Where does science/performing arts happen? How does science/performing arts happen?). The purpose of this reflection and critique was to support youth in recognizing the commonalities among performing arts and science disciplines (Marshall, 2014).

Program Context and Participants

Project Team Participants

Dramatic Science was created by an interdisciplinary team comprised of a children's theater director, science education researchers, performing arts and science educators, and graduate student researchers, who were also former public-school science and theater educators. Program sessions during the second and third program iterations were taught by a science educator, Gemma (pseudonym), and two performing arts educators, Kingston and Leah (pseudonyms), all of whom had experience teaching in the local public school district attended by program participants. Project team members were involved in iteratively designing and developing the learning environment and curricular materials. Additionally, I and another research team member also participated in all program sessions as participant observers (Glesne,

2016) and shared research insights with the project team to support program refinement in response to youths' emergent voices and practices.

In studies such as this one, it is crucial to recognize that the researcher's identity and position in relation to the individuals around them influences how they experience and interpret events (Acevedo et al., 2015; Takacs, 2002). My experience working with youth from range of cultural backgrounds in STEM learning environments over the past 10 years as a public-school science teacher, researcher, and teacher educator has profoundly shaped my understanding of equity and my interest in this research. Students with whom I have worked have supported me to grow as an educator and as a human being. I remain forever grateful for their kindness and patience and I continue to be humbled by their determination, wit, and brilliance. That said, it is essential to note that I identify with sociohistorical categories that differ systematically from the individuals with and from whom I am learning as a white, middle class, college-educated female working in an institution of higher education. Because these experiences and identifiers influence in which discourses one participates, and how, my positionality informed the research described here.

My positionality influenced the research included here in at least two ways. First, it is important to recognize that my disciplinary background as a science educator—rather than an arts educator— influenced all stages of my engagement in this research, from generating questions to drawing conclusions. Prior to participating in this project, I did not have experience collaborating with arts educators nor did I have experience designing and implementing STEAM education settings. In this way, I was positioned as a learner with regards to developing an art-science program. Had this study been conducted by a researcher with an arts background, it is likely different questions would have been asked and different findings highlighted. In other words, my disciplinary background and experience in science-based learning settings influenced which research questions I asked and which findings I highlighted based on these questions. Secondly, my positionality and learning experiences in school settings as a white, middle class, female, growing up in a predominantly white neighborhood, influenced the research included here. I believe this aspect of my positionality inhibited me from anticipating how youth participants' need to maintain desirable social images would interact with their engagement in an art-science program. As will be discussed in the findings of Papers 1 and 2, I came to recognize the urgency of this desire as the program evolved in response to youths' emergent needs and interests.

Youth Participants

Dramatic Science is part of a larger College Bound program (CB) taking place at a research university in a metropolitan area in the Northeastern United States. The CB program consists of youth in grades 7-12, who are recruited from a local urban public school district. Students participate in CB for one to two Saturdays per month throughout the school year (13 days, 6.5 hours per day) in addition to a consecutive three-week summer camp (12 days, 6.5 hours per day). Due to this demanding time commitment and potential familial financial obligations, students are provided monetary compensation for attending the sessions.

The goals of CB are three-fold: foster youths' interest in STEAM and social justice issues, support critical mindfulness and problem-solving skills, and increase youths' self-efficacy in applying to and continuing college. To meet these goals, CB youth participate in three sessions, including STEAM, Social Justice, and College and Career. Within the STEAM sessions, students engage in various projects, which have evolved over the years (e.g., robotics, smart greenhouse). While the larger CB program engaged students in grades 7 through 12, Dramatic Science was designed specifically with middle school students in mind, given that this is a time when youth are increasingly concerned with developing a sense of belonging or "fitting in" (Pinkard et al., 2017). Following this intention, a total of 15 middle school youth in 7th and 8th grade were invited to participate in the program at the beginning of this study (Table 0.2).

Table 0.2

Demographic Information: Dramatic Science Participants

Grouping	Subgrouping	Number of Students (N=15)
Grade	7th grade	4
	8th grade	11
Gender	Female	6
	Male	9
Home Language	Spanish	9
	English	4
	Haitian Creole	1
	Portuguese	1
Race	Hispanic	10
	Black	2
	White	1
	Asian	1
	Multiple races	1

Paper 1: The Design and Development of a Youth-Centered Art-Science Program

In the past two decades, integrated approaches to science education have gained momentum internationally in the form of STEM and, more recently, STEAM education (Bevan et al., 2019; Bequette & Bequette, 2012; NRC, 2014; Kang, 2019; Mejias et al., 2021; Ozkan & Topsakal, 2019). STEAM education, in particular, has been proposed as a means to foster life-wide skills, such as creativity, empathy, and activism (Bush et al., 2020; Jho, Hong, & Song, 2016; Kang, 2019; Kim & Chae, 2016; Ozkan & Topsakal, 2019; Quigley & Herro, 2016). Despite widespread interest in STEAM and the rise of STEAM-focused K-12 schools, limited research exists on the design and implementation of STEAM learning environments (Bevan et al., 2019; Bush et al., 2020; Kang, 2019; Carsten Conner et al., 2017; Quigley et al., 2020). Extant scholarship, while making important contributions to the STEAM education conversation, mainly focuses on teacher outcomes (e.g., Cook et al., 2020; Quigley & Herro, 2016; Jacques et al., 2019; Jho, Hong, & Song, 2016; Quigley et al., 2020). Regarding youth outcomes, the majority of research to date has taken place in K-12 settings (e.g., Kim & Chae, 2016; Magerko et al., 2016; Ozkan & Topsakal, 2019). Further, these studies typically focus on findings generated from a single iteration of design (e.g., Kim & Chae, 2016). Longitudinal research on multiple iterations of the design and implementation of STEAM education programs in out-of-school contexts, to my knowledge, does not exist, likely due, in part, to time and budgetary constraints. Nonetheless, documentation of ongoing design processes is critical to support holistic understandings of program design and development, including the challenges encountered and addressed in each iteration (Design-Based Research Collective, 2003). To address this need, the purpose of this design-based research study is to document the iterative design and implementation of Dramatic Science over two program iterations, including the 2018-2019 School Year and Summer 2019.

Theoretical Background: The Design and Implementation of STEAM Programs

Inspired by the potential of STEAM education to support youths' relationships with science, our project team began the process of designing Dramatic Science by consulting the relevant literature. Close attention was paid to the common design features and implementation challenges across STEAM education studies, which will be discussed in what follows. While this brief review includes studies from both in- and out-of-school settings, it is important to note that most of the STEAM education scholarship to date has been generated in K-12 classrooms, often with teachers' practices as the area of study (e.g., Cook, Bush, Cox, & Edelen 2020; Jho et al., 2016; Quigley & Herro, 2016; Quigley et al., 2020). Although the focus of this inquiry is youths' experiences in an out-of-school program, our project team nevertheless gained insight from studies taking place in K-12 in-school settings.

Design Features of Integrated STEAM Programs

While integrated art-science education is relatively new, it is informed by education research in maker spaces and STEAM learning environments. Two overarching design features are prevalent in this literature base, including foregrounding an open-ended challenge through *inquiry-based approaches* (e.g., project-based learning, problem-based learning) and supporting youth to address the challenge through *integrating multiple disciplinary practices and perspectives.*

Learning Through Inquiry: Project-Based and Problem-Based Learning

STEAM education settings primarily rely on project-based (e.g., Margerko et al., 2016; Tzou et al., 2019) and problem-based learning (e.g., Cook & Bush, 2018; Quigley, Herro, Shekell, Cian, & Jacques, 2019). Both approaches foreground an open-ended challenge in the form of a specific, and often locally-contextualized, scenario (problem-based learning) or driving question (project-based learning) (Barron et al., 1998). Project- and problem-based approaches aim to support youth to collaboratively engage in multiple disciplines to generate a solution or project (among many possible paths) to address the focal challenge, similar to the process that youth experience in their personal and professional lives outside of school (Barron et al., 1998; Mills & Treagust, 2003). STEAM education shares this common goal with project- and problem-based learning, namely to support youth in making meaning of and tackling real-world challenges through the authentic application of knowledge and practices from multiple disciplines (Bequette & Bequette, 2012; Bush et al., 2020; Cook et al., 2020; Kang, 2019; Ozkan & Topsakal, 2019; Quigley & Herro, 2016; Quigley et al., 2020).

Notably, the challenge posed must be both open-ended and meaningful to youth (Keane & Keane, 2016; Quigley et al., 2019). A sufficiently open-ended challenge will not only encourage the generation of creative ideas and solutions but also necessitate meaningful peer collaboration. In other words, the challenge must be complex enough so that one student is not able to complete the project individually. Further, a problem or question relevant to youth will support them in understanding the necessity of addressing the challenge through their work. Sharing this problem or question with youth in a way that encourages them to empathize with the challenge and connect it to their own lives and the real world supports learning and identity construction (Kim & Chae, 2016; Quigley et al., 2019).

Discipline Integration

Rather than foregrounding a discipline, designers of STEAM education settings aim to support learners to address open-ended challenges by drawing on knowledge and skills from multiple disciplines (Carsten Conner et al., 2019; Finch et al., 2020; Kafai et al., 2014; Quigley et al., 2017). Three approaches describe the relationships among disciplines most prevalent in the literature, including multidisciplinary, interdisciplinary, and transdisciplinary. (Please see the Introduction section for an overview of these approaches.)

Challenges to STEAM Education Design and Implementation

Designing and implementing STEAM learning environments with the aforementioned design features has proven challenging. First, there are obstacles present in the structure and organization of K-12 schooling, teacher education, and professional development programs—including the organization of education in disciplinary silos, the scarcity of teacher training on integrated instruction, and few opportunities for in-service teachers to collaborate across disciplines (Bush et al., 2020; Cook et al., 2020; Jho et al., 2016; Quigley & Herro, 2016). Beyond these structural barriers, educators who have attempted to develop and implement integrated STEAM curricula in their classrooms have encountered two main hurdles to supporting the design features outlined above, including *creating relevant challenges* and *integrating the arts in meaningful ways*.

Creating Relevant STEAM Challenges

Scholarship indicates that teachers understand the importance of generating personally- and locally-relevant challenges in STEAM education, a process that is dependent on the school's student population and context (Quigley & Herro, 2016; Quigley et al., 2020). That said, developing and implementing relevant STEAM challenges, with which youth can empathize by making personal and local connections, is an onerous task (Bush et al., 2020; Quigley et al., 2020). For example, some problems may not be grounded in real-world or local contexts, while others may be too narrow for youth to develop personal connections (Bush et al., 2020; Quigley & Herro, 2016).

To address this challenge, Bush et al. (2020) and Quigley et al. (2020) propose that educators focus on fostering student empathy during the design learning process. For example, educators could introduce the STEAM challenge with activities that support youth in considering how the problem influences the various stakeholders involved, including the youth themselves. A second implication would be to provide educators with time to collaborate with their colleagues and their own students to listen to and learn from them when formulating problems or driving questions for STEAM units (Basu, Calabrese Barton, & Tan, 2011; Quigley et al., 2020). By leveraging student voice and fostering opportunities for youth to empathize with the target audience, educators can create and implement STEAM challenges that are compelling and engaging for youth to investigate and address.

Robust Arts Integration

In addition to prioritizing relevancy, educators must consider how and to what extent youth will engage with multiple disciplines to tackle the focal challenge. Finding ways to integrate the arts with STEM subjects meaningfully has proven especially difficult for science and mathematics educators (Quigley & Herro, 2016). Although art should play an equal role to STEM subjects in these approaches (Carsten Conner et al., 2019; Finch et al., 2020; Liao, 2016), many maker spaces and STEAM education settings embed art as an "add on" to STEM learning activities, often to increase interest and engagement (Bequette & Bequette, 2012; Kafai et al., 2014; Liao, 2016; Mejias et al., 2021; Quigley et al., 2020). In fact, despite the inclusion of "art" in the STEAM acronym, there is much variation in how art is positioned and leveraged (or not) in STEAM learning environments (Bevan et al., 2019; Mejias et al., 2021; Quigley & Herro, 2016). For example, superficial connections to art may be encouraged by asking youth to complete tasks such as drawing a picture of the water cycle or an anatomical sketch of a grasshopper (Bevan et al., 2019; Cook et al., 2020). Alternatively, art may be leveraged in the service of STEM subjects (Mejias et al., 2021), such as positioning art as a “hook” or launching point for STEM learning or exclusively using art as a means of representation of students’ STEM learning.

Aside from decorative connections to art, the majority of STEAM education research conceptualizes arts integration in terms of design by relying on common practices found in design in arts, engineering, and technology fields (Kang, 2019; Keane & Keane, 2016; Mejias et al., 2021; Quigley & Herro, 2016; Quigley et al., 2020). Importantly, the emphasis on aesthetics and personal expression makes design in art markedly different from design in engineering and technology (Bequette & Bequette, 2012; Carsten Conner et al., 2017; Cook & Bush, 2018). Despite this departure, it is unclear if the unique attributes of art design are frequently encouraged in STEAM learning environments. In other words, youth may engage in design thinking practices characteristic of engineering or technology fields without designing for aesthetics or personal expression inherent to artistic design (Quigley & Herro, 2016; Quigley et al., 2020). For example, Cook and Bush (2018) cite two exemplar STEAM design challenges implemented with elementary school students, including designing a prosthetic leg for a kindergartner and designing a school playground. While these scenarios were undoubtedly engaging and challenging for participants, it is unclear how and to what extent youth had opportunities to design with aesthetics and personal expression in mind during these STEAM challenges. Engaging youth in design thinking solely as a part of the processes found in engineering and technology fields deprives youth of experiencing an authentic integration of arts, which is essential to STEAM education (Bequette & Bequette, 2012). Such oversight could inhibit youth from leveraging artistic practices and perspectives and could mislead them into thinking that arts, engineering, and technology design are synonymous.

Methods

Drawing on the literature base highlighted above, our project team created an out-of-school art-science program. This study documents the design and implementation processes taking place over two consecutive iterations. By highlighting the challenges encountered in each iteration, and how we made sense of and attempted to address these challenges, I hope that this study will provide a holistic account of the process with which our project team engaged. The following research questions guided this inquiry:

1. How did an art-science program's curriculum evolve to support the engagement of youth with a wide range of backgrounds and interests?
    a) What curricular approaches supported youth engagement in an art-science program?
2. What curricular and instructional approaches supported cohesion across disciplines from a teacher perspective?

The project team utilized design-based research (DBR) to address these questions (Brown & Campione, 1996; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003). Central goals of DBR include designing learning environments and developing "humble" learning theories as a part of this process (Cobb et al., 2003). This study documents the two consecutive cycles of program design, enactment, analysis, and redesign (Design-Based Research Collective, 2003), including a Saturday program in the 2018-2019 School Year (36.5 hours) and a three-week program in Summer 2019 (52 hours). This iterative process resulted in the evolution of design elements in response to participants' emergent practices.

While the prospective and reflective facets of DBR require researchers to serve dual roles as both proponents and critics of their work (Cobb et al., 2003; Design-Based Research Collective, 2003), this paper highlights our reflective analysis of the project. More specifically, we document how our design conjectures were refined over the two iterations based on insights from the ongoing analysis of the program implementation and the processes that emerged during program sessions (Sandoval, 2014).

Foci of Design

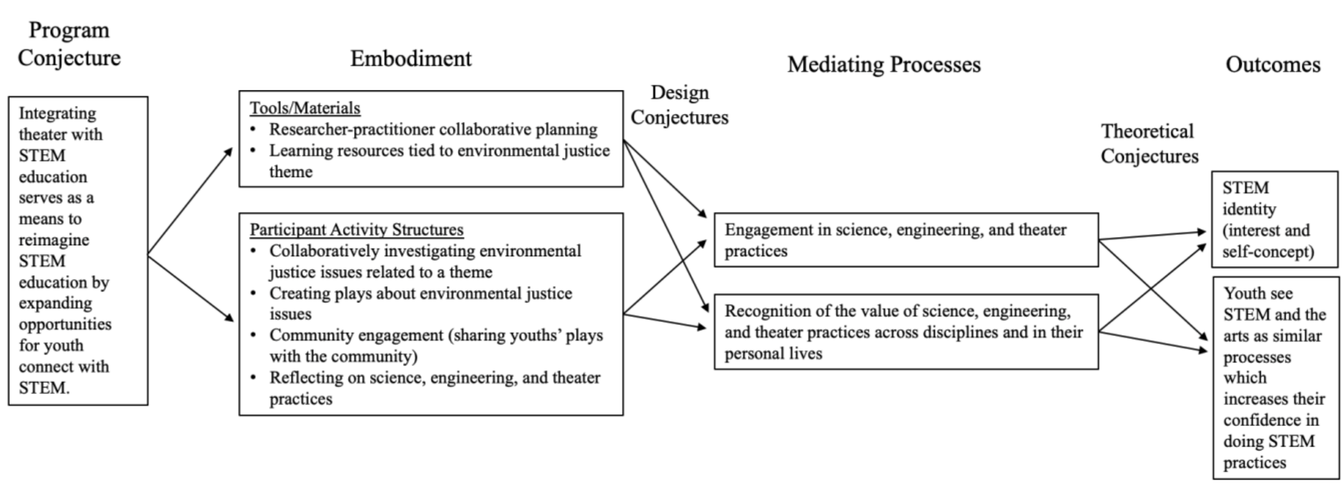
We set out on a design research journey with a researcher-practitioner team to create an out-of-school program that integrated art and science while centering youths' voices and interests. Research, as well as our own experiences working with youth from a range of cultural backgrounds, demonstrates that social and environmental justice issues can serve as strong motivators for youth to learn and apply artistic and scientific concepts and practices to address injustices (Liao, 2016). With this in mind, our approach to equity entailed privileging youths' messages about local environmental justice issues that were personally meaningful to them, which differs from the science-centered approach prevalent in schooling.

Our overarching *program conjecture* was that integrating art, specifically performing arts, with science could serve as a means to reimagine STEM education by expanding opportunities for youth to connect with STEM subjects in personally meaningful ways. This conjecture was embodied through four focal *participant activity structures*: (1) collaboratively investigating local environmental justice issues related to an overarching theme (e.g., water quality and access, climate change); (2) creating plays about environmental justice issues; (3)

sharing youths' plays with a community; and (4) reflecting on the similarities and differences among science, engineering, and performing arts practices. We believed these design elements would support youth to participate in two *mediating processes*, including engaging in art-science thinking practices and recognizing the value of these practices across disciplines. Ultimately, we hypothesized that youths' engagement in these core processes would foster two primary *outcomes*, including expanded perceptions of and identification with STEM. (Note: Our initial focus on STEM learning outcomes, rather than art-science learning outcomes, reflects the background of the main contributors of this project. In other words, most team members involved in the initial conceptualization phase (i.e., developing and writing the grant) had science backgrounds rather than arts backgrounds. As will be discussed in the findings, we now recognize the oversight of not including performing arts in our initial outcomes.) For a summary of our initial conjecture map, including our design and theoretical conjectures, please see Figure 1.1. The iterative revisions of this map based on analyses for each cycle will be discussed as a part of the findings.

Figure 1.1

Initial Conjecture Map for the Dramatic Science Program



Project Team

Our initial project team consisted of a children's theater director and four members based at a university in the Northeastern United States, including a science education researcher, a learning scientist, and two graduate student researchers, all of whom were former public-school science and theater educators. Together, we sought performing arts and science educators to join our team. We were fortunate enough to partner with two performing arts educators, Leah and Kingston (pseudonyms), and one science educator, Gemma (pseudonym), all of whom had experience teaching in the public-school district attended by College Bound students.

In light of the equity-oriented motivation of this work, it is important to acknowledge that the bodies we, as a project team, inhabit are raced, sexed, and classed. The education researchers on the project team included a Chinese female, two White females, and a White male and first-generation college student. The children's theater director and performing arts and science practitioners included a Black female, a Black male, a Jamaican female, and a White female. We include this (albeit limited) information here as a means of disclosing how the racial-ethnic aspects of our identities relate to each other and to the students with whom we work. These socio-historical ascriptions, which have shaped our own multivocal identities, undoubtedly influenced interactions amongst ourselves and the College Bound youth participating in this study. Further, the unique positionalities of our project team members influenced our conceptualization and implementation of Dramatic Science as well as the research generated from this project (Harding, 2015; Takacs, 2002). That said, we are grateful for working with and learning from a heterogeneous group of researchers and practitioners. We believe our program and the research reported here benefited from the unique backgrounds and contributions of each member during our iterative stages of program development.

Our Collaborative Design Process

Our collaborative design process began with each project team member sharing their ideas about the purposes of the program during pre-cycle planning meetings, which were held for each program iteration. Through this discussion, we generated a consensus of the goals for the upcoming cycle, including overarching program goals and discipline-specific goals. Based on these goals, a tentative curriculum was then developed for that particular cycle consisting of learning goals and activities for each program session. After these initial planning meetings, the project team met once or twice more during each program iteration to discuss our analyses of the program enactment and youths' interactions with and responses to this enactment in light of the targeted goals. Based on these discussions, we revised the programmatic structures accordingly. In addition to these project team meetings, the practitioners and graduate student researchers on the team met for 30 minutes after each program session to debrief on that day's session and adjust the plan for the following session as needed. Maintaining frequent debrief sessions allowed us to openly discuss and revise the project design based on our emergent insights (Cobb et al., 2003).

Data Sources

We employed a multiple case study approach (Yin, 2018) to analyze five data sources generated across two program cycles (cases), including conjecture maps, project team meeting logs, curricular materials, field notes from program sessions, and two rounds of interviews with teachers. The conjecture maps, meeting logs, and curricular materials, in particular, provided us with an extensive record of our ongoing design process (Cobb et al., 2003). These data, together with our observational field notes and teacher interviews, allowed us to identify and unpack the successes and challenges that emerged in each iteration by connecting salient features of design enactment to the manifested processes and outcomes (Design-Based Research Collective, 2003; Sandoval, 2014).

Retrospective Conjecture Maps

I utilized a retrospective approach to conjecture mapping as a scaffold to identify salient features of Dramatic Science's learning environment and articulate how these components evolved over time. Research team members generated an initial conjecture map before the 2018-2019 School Year program implementation (Figure 1.1). This initial map underwent three rounds of revisions based on emergent findings, resulting in four conjecture maps (Pre-School-Year, Mid-School-Year, Pre-Summer, and Post-Summer). This sequence of conjecture maps provides a visual depiction of our evolving design trajectory, which will be elaborated upon in the findings.

Project Team Meeting Logs

Over the course of the two program iterations, the project team met at approximately the beginning, middle, and end of each cycle. As mentioned previously, meetings at the beginning of each iteration were focused on goal setting and generating the curriculum, while meetings scheduled during the middle and end of each iteration were focused on debriefing emergent outcomes and redesigning the learning environment accordingly. Due to the compressed schedule of the summer program, which lasted three consecutive weeks, the project team omitted the mid-cycle meetings during this iteration, solely meeting at the beginning and end of the program. In total, the project team met eight times during this 11-month study, which includes five meetings during the (2018-2019) School Year and three meetings during the Summer (2019) program. Meeting logs with agenda items and notes generated during each meeting were compiled as an ongoing record of design for each program cycle, resulting in 18 single-spaced pages in total.

The pre-program meetings were the most time-intensive due to the task of planning for the upcoming program iteration, resulting in the need for the project team to meet two to three times prior to implementation. In general, pre-program meetings focused on the following agenda items: establishing overarching goals for the program iteration (i.e., process and product goals), identifying goals and learning activities for each program session, and generating logistical plans (e.g., materials, groupings of students). Based on the learning activities outlined during the pre-program meetings, project team members asynchronously compiled a repository with learning resources for the program iteration. These materials were reviewed during subsequent pre-program, team-wide planning meetings and also revisited and revised during the debrief meetings with practitioners and graduate student researchers after each program session.

Project team meetings taking place during the middle and end of the iteration generally focused on collectively reflecting on the program implementation in light of youths' emergent interactions and revising the design of the learning environment accordingly. More specifically, the following agenda items were discussed: revisiting our process and product goals for the cycle, discussing and generating a list of general and goal-specific successes and challenges observed during the cycle, developing action items in response to the challenges encountered, and revising our goals and the program design accordingly. Due to the scheduling needs of project team members, the end-of-program meetings were occasionally merged with the following pre-program planning meetings. The overarching goals for these combined meetings focused on debriefing the previous iteration before generating plans for the upcoming iteration per the agenda items discussed above.

Curricular Materials

Based on the learning goals and activities outlined in the pre-program planning meetings with the project team, the three practitioners and two graduate student researchers collectively created curricular materials for each program session. During this process, we aimed to build upon the teachers' curricular and pedagogical expertise by centering the teachers' voices and ideas. Graduate student researchers aimed to serve as facilitators during curriculum development meetings and then developed curricular materials after these meetings. In other words, we aimed to utilized a practitioner-driven approach to curriculum development and implementation rather than a researcher-driven approach.

Curricular materials were developed and revised throughout the program iteration based on our observations of youths' emergent interactions with the enacted design elements and informal discussions with youth. Immediately after each program session, we discussed our observations and insights about that particular session during a 30-minute debrief meeting. 12 debrief meetings occurred during each program cycle for a total of 24 meetings, or 12 hours, across the two iterations. The curricular materials developed as a result of these discussions provide insight into our evolving design decisions in response to youths' emergent interactions. These materials include brief plans for each session (i.e., targeted learning goals, guiding questions, learning activities, materials for each activity) and related resources (e.g., slides, graphic organizers, reflection questions, articles, videos, images).

Field Notes

While the data sources detailed above provided evidence on the developing design features of the program, it was equally essential to document the enactment of the program design and the learning processes that arose (Design-Based Research Collective, 2003; Sandoval, 2014). Recording observable interactions during program sessions allowed us to determine if/how aspects of the designed environment facilitated participants' interactions and, in turn, learning (Sandoval, 2014). With this goal in mind, we employed an ethnographic approach following an observation protocol agreed upon by the research team.

Field notes, generated by myself and another research team member, were based on participant observations and informal ethnographic conversations with youth during program sessions over the two iterations. Both researchers were present during all program sessions for the 2018-2019 School Year program. During this time, we alternated between taking field notes as participant observers and supporting the instructors and students as co-instructors and co-learners as needed. During the next program iteration (Summer 2019), I was the only researcher present during the program sessions. Due to more limited personnel support during this time, my role shifted to supporting the instructors and students. Instead of taking fieldnotes during program sessions as was done in the previous iteration, I relied on jotting down brief notes and recording audio-files of student discussion, upon which I further elaborated immediately after each daily program session.

Interviews with Teachers

Two rounds of semi-structured interviews were completed individually with each teacher, with the first interview occurring early in cycle two (Fall 2018) and the last occurring after this study ended (Fall 2020). (Due to a long-term commitment to traveling for a performance tour, one of the two performing arts teachers could not participate in the final interview.) Interviews, which lasted approximately 30 to 40 minutes each, were conducted either in-person or virtually based on which format was most convenient for the interviewee. Teachers were interviewed by one of the two graduate student researchers on the team.

The first round of interview questions pertained to the teacher's goals for youth participating in the program, anticipation of potential benefits and challenges for youth during the upcoming program iteration, and anticipation of essential programmatic structures to support the aforementioned goals. The questions included in the second round of interviews complemented the initial interview with a shifted focus of reflecting on the previous program implementations (2018-2019 School Year and Summer 2019) rather than anticipating the upcoming program iteration. Interviewees were asked to discuss their views on three main areas: the program goals, implementation approach, and perceived outcomes; how the program goals, implementation, and outcomes from these two iterations compared with each other; and their perceptions of youths' experiences during these iterations. Additionally, at the end of the interview, I shared preliminary themes with the teachers as a form of member checking (Thomas, 2017). More specifically, I noted program changes over the course of the two program iterations and asked them to what extent these changes resonated with their experiences in the program. Collectively, the early-late interviews highlight how each teacher's conceptualization of the goals and essential design features of Dramatic Science evolved based on insights generated from their extended immersion in the program.

Data Analysis

The purpose of data analysis was to unpack the relationships among the design elements and the interactional processes that arose during program sessions. Initial analyses were performed by the first author, followed by secondary analyses conducted by all project team members. Starting with the 2018-2019 School Year program, I began a process of going back and forth between data featuring elements of the designed learning environment (i.e., conjecture maps, project team meeting logs, curricular materials) and data featuring the processes that manifested in the learning environment (i.e., field notes for program sessions). Four questions were asked during this iterative process:

1. What were the central design elements for that particular program iteration?
2. In what ways were design elements enacted in program sessions during that iteration, if at all?
3. How did these enactments influence youths' interactions with the design elements and with participants?
4. How did youths' interactions inform the redesign of the learning environment?

When analyzing the data for each program iteration, I first reviewed the conjecture map and pre-program project team meeting logs for the most salient design aspects of the learning environment. Based on these data and the relevant STEAM education literature, I used a mixed inductive-deductive approach to generate a codebook of targeted design elements for that particular cycle. This provisional codebook, with excerpts or examples for each code, was revised based on discussion with the research team members. Using the revised codebook, I concurrently analyzed the curricular materials and field notes for each program session to examine the embedded design elements in the curriculum and the corresponding enactment of design elements during program sessions, as well as youths' interactions with and responses to these enactments. When coding the curricular materials and corresponding field notes for each session, I noted how and to what extent design elements were embedded in learning activities as well as moments of divergence between the learning environment as designed and as implemented.

After analyzing the curricular materials and field notes generated during the program iteration, end-of-program project team meeting notes were examined. Close attention was paid to insights from team members on the successes and challenges that arose during that iteration, which components and processes might have contributed to these outcomes and proposed changes to the program design based on these insights. Collectively, analyses of the mid- and end-of-program meeting logs for each cycle were used to develop a revised conjecture map for the following program iteration. During this process, codes were added to the initial codebook based on emergent design elements, the enactment of design elements during program sessions, and youths' interactions with and responses to these enactments. (Please see Appendix D for the final codebook.)

Case summaries were developed for each program iteration based on these analyses. Each case summary included the following sections: (1) central design features for the iteration (examples from conjecture map and pre-program project team meeting logs); (2) the enactment of the design and the interactional processes that emerged during program sessions (examples from curricular materials and field notes); and (3) the project team's reflection on the previous iteration and proposed design changes (examples from mid- and post-cycle project team meeting logs and revised conjecture map). Early-late interviews with all project team members served as supplemental data for corroboration of findings included in each case summary. Case summaries were shared with the project team for discussion and critique before establishing themes for each case (i.e., program iteration).

After repeating this process of analysis for each program iteration, the project team examined the long-term trajectory of the learning environment design through cross-case analysis. This macro-analysis of the evolution of Dramatic Science focused on the relationships among preliminary themes generated in each program iteration case summary. Themes generated from this cross-case analysis highlight the overall design trajectory of the program, specifically what curricular and instructional shifts occurred and why.

Findings

The results of this cross-case analysis are organized in accordance with the research questions. First, I discuss two main changes that were made to the program based on youths' emergent needs and interests, including a broad approach to arts integration and the incorporation of computing and technology (RQ 1). Next, I discuss how the teachers viewed ongoing teacher collaboration and foregrounding youths' development of artifacts for their STEAM projects as necessary to support disciplinary integration (RQ 2).

A Broad Approach to Arts Integration and Incorporating Multiple STEM Disciplines Supported Youth to Build on Their Diverse Interests

After getting to know and learning from student participants, our team adjusted the program based on their needs and interests. During the 2018-2019 School Year, we spent extensive time observing and informally talking with students to learn about which programmatic aspects were most interesting to them, which were challenging for them, and how they would change the program. From our interactions with students, we gained two core insights. First, the majority of participants were more interested in STEM than in theater. Second, although most participants were not interested in theater, many were interested in other forms of art. These insights informed the redesign of the program:

- To build on youths' interest in diverse forms of art, we shifted from engaging youth in playmaking—or more traditional forms of theater—to engaging them in performing arts, which can incorporate multiple artistic disciplines (Halverson & Barker, 2017).

- To build on youths' interest in STEM, we shifted from engaging youth in science to investigate environmental justice issues to engaging youth in computing and technology to develop artifacts for their projects.

These changes were made to support youth to build on their diverse interests and pursue multiple pathways. In the remainder of this section, the rationales for these curricular and pedagogical changes and their implementation are discussed.

Broadening Our Approach to Arts Integration: Shifting from Theater to Performing Arts

Teacher interview and field note data indicated that the majority of student participants were not interested in engaging in theater. Leah, one of the performing arts teachers, articulated how youths' general disinterest in theater made the experience challenging for the few students who were interested in theater. She made an analogy between Dramatic Science and an elective introductory theater course in high school, which many students take to fulfill their arts elective. She stated,

> I think for a student like Kamron (pseudonym) and students like him who might actually have an interest in theater, like, a deep interest in it already. A course like [Dramatic Science] is hard when you have a bunch of students who could care less about [theater]… And so, I think [intro theater in high school is] a similar parallel to how I think students like Kamron, who might actually have a deep interest in performing arts, might find it difficult to stay engaged in a classroom with people who are not as deeply interested in it as they are… And if they're all in the same class together for this type of course, it may prove difficult if you don't have the time to meet the needs of those students. (Fall 2020 interview)

Teachers' perceptions of students' overall aversion to theater echo youths' voices and interactions during program sessions. For example, students expressed low interest in theater during a movement-based, arts-interest inventory (2/2/19 field notes). During this activity, students were asked a series of questions about their interests in various art forms, including theater, visual arts, dance, music, animation, and film. Questions included:

- Which is your favorite?
- Which is your least favorite?
- Which would you like to learn more about?
- Which would you do for a job?

Based on their answers for each question, students moved to designated locations in the room, which were marked with signage (e.g., "music"). Among the 10 students present for this activity, most students (40%) indicated that theater was their least favorite art form, only one student expressed she would do theater for a job, and no students indicated they wanted to learn more about theater.

Based on youths' feedback, the teachers shifted their focus from engaging students in playmaking, or forms of traditional theater, to broader forms of performing arts, which incorporate multiple artistic disciplines (e.g., music, visual arts, film) (Halverson & Barker, 2017). Leah explained the rationale behind this transition, stating:

> I think we really tried to meet [the students] where they were and to introduce things to them that weren't just your traditional playmaking, but that were just things that we thought would engage them based on who we came to know the students to be. (Fall 2020 interview)

Leah and Gemma both emphasized how important it was to get to know the students during the 2018-2019 School Year program in order to adjust the program based on their needs and interests (Fall 2020 interviews). Broadening our team's approach to arts-integration was reflected in the shift from engaging youth in creating plays to engaging them in creating art-science projects that could take many different forms. This approach was implemented during the mid-to-late sessions of the 2018-2019 School Year. For that cycle's culminating project, students were given multiple format options, including creating a news show videoclip, a PSA poster, a PSA commercial, a TED Talk presentation, a play, or a board game. Students voted on which type of project they wanted to create and then teachers assigned them to groups based on their preferences. Almost all of the students selected board games and posters as their top choices (4/6/19 field notes). (One student wanted to create a play; however, she could not convince her peers to create a play with her.) For their culminating projects, two student groups created board games while a third group created a poster (4/27/19 and 5/4/19 field notes).

To support youths' interests and needs, our team continued to cultivate and refine a broad implementation of performing arts during the Summer 2019 program iteration. Project format choices for this program iteration included: a short film or skit, a commercial, a speech, a poem, a song, or something else (7/15/19 field notes). Based on these options, students developed a range of projects, including a cartoon about local food rights, a model of the greenhouse effect, an app vision board, a documentary about the local effects of gentrification, and a play about the local effects of climate change. The diversity of youths' projects, particularly during the Summer 2019 program, reflects how the program structure evolved to become more differentiated based on youths' interests and needs.

Leveraging Multiple STEM Disciplines: Incorporating Computing and Technology

Upon learning about youths' widespread interest in STEM, computing and technology were integrated into the curriculum for the Summer 2019 program. In an interest form completed at the beginning of the Summer 2019 program, 64% of students (7 out of 11) ranked coding as their top preference among the following options: coding lights and/or sound, prop design and construction, set design/model-making (e.g., creating 3D-printed models), wearable technology/costume design, and ensemble work (7/10/19 field notes). Gemma's conversations with youth corroborated student survey data. She explained that many students expressed interest in doing more coding: "They're, like, 'can we do more coding?' It's, like, oh, OK, we'll try to make sure we squeeze it in" (Fall 2020 teacher interview). Informed by youths' voices, multiple computing workshops were included into the summer curriculum (e.g., coding LED lights to change colors, coding LED lights to change colors based on sound frequencies or air temperature).

With youths' general preference for STEM over theater in mind, it is important to note that Dramatic Science represented a first attempt at incorporating art into a historically STEM-focused program. As such, students may have expected a STEM-rich experience due to the program's reputation. Furthermore, students were not able to select in which College Bound STEAM strand they participated during the program iterations included in this study. Instead, students were grouped into STEAM strands based on their grade levels, with students in the younger grade levels assigned to participate in Dramatic Science. These factors likely influenced youths' engagement in Dramatic Science, particularly their preference for engaging in STEM over theater. Gemma, the science teacher, articulated this tension, stating:

> We just kind of shuffled all middle schoolers into this program. And then we didn't really give them a sense of, like, OK, you're doing theater. Because a lot of the reputation of

> College Bound is that it's a science program and you're doing all these science things. You may get to fly a drone or you may get to build a robot or something [in the other strands]. And then all of a sudden, it's bam, it's theater. What am I doing with this?... Which, in the school year, I think [this] led to a lot of engagement issues. Just because [the students] were, like, theater? Why am I doing theater? I thought this was a science program? (Fall 2020 interview)

Because students did not self-select into the Dramatic Science program, it is possible that many were surprised that theater was part of the curriculum. Many students—particularly the rising 8th graders who had previously participated in the College Bound STEM program as 7th graders—likely expected to participate in a STEM-focused strand based on their prior College Bound experience. To better support youths' interests and expectations, STEM and computing were integrated into the Summer 2019 program curriculum. Gemma explained, "Using more technology allowed [the students] to kind of do the things that attracted them to College Bound that they weren't able to do at first" (Fall 2020 teacher interview). Overall, the teachers viewed the Summer 2019 program as a more engaging experience for youth, largely due to the integration of STEM and computing (Fall 2020 teacher interviews).

In addition to youths' general interest in engaging in STEM over theater, another reason for youths' preference for coding and technology was that these disciplines supported youth to engage in art-science projects through behind-the-scenes endeavors, rather than more performance-based aspects. Students mainly associated theater with audience-oriented performances, in which they were not interested or comfortable (Fall 2020 teacher interviews). In the Summer of 2019, students continued to express tensions with the performative aspects of performing arts. For example, when completing the interest survey mentioned previously, the majority of students (55%, or 6 out of 11) ranked ensemble work, or collaborating with others to perform an idea, as their least favorite option for their project work (7/10/19 field notes). Gemma echoed youths' preference to engage in background work rather than performing in front of others. She stated,

> If you weren't used to performing or being in front of people, it gets really scary, really fast and they get really nervous…A handful of students were trying to kind of lay back. And I think Kingston and Leah did a really good job of, like, all right, maybe you're the background guy, maybe you're the video guy, maybe this, maybe that; like, coming up with ideas to still include them. And so, I think giving them the inroads of having a topic to care about or having different ways of expressing it was really helpful (Fall 2020 interview)

Gemma expressed how fostering student choice in the topic for the project, the project format ("different ways of expressing"), and group members' roles (e.g., "background guy," "video guy") supported students to engage in their projects in ways that were comfortable for them, in this case, in ways that did not involve performing. To support students who wanted to engage in "background" work, Kingston and Leah worked with students to create alternative project options that resonated with them. For example, during the Summer 2019 program, one group of students chose to create and produce a play for their project but were not comfortable performing their play. Instead, the instructors offered alternative options for their project presentation, including audio-recording a read-aloud of the script, creating a stop-motion animation, or asking instructors and interns to perform the play (7/16/19). Among these options, this group of students decided to ask their instructors to perform their play. Due, in part, to this decision, youth were able to focus their efforts on behind-the-scenes work. In this case, youth were most interested in designing and constructing costumes and coding LED light accessories for the costumes, which would be worn by the instructors performing their play.

Supporting Disciplinary Integration from a Teacher Perspective

Regarding the second research question (What curricular and instructional approaches supported cohesion across disciplines from a teacher perspective?), generating curricular and pedagogical approaches to support discipline integration proved challenging, especially during the early stages of program development. The disciplinary-based structure of the program sessions during the 2018-2019 School Year did not necessitate teachers to co-plan and co-teach across disciplines, resulting in the teachers' perception of a siloed approach to the program during this iteration. In large part due to this approach, lessons were presented to students as a series of disciplinary-based activities. We aimed to address these shortcomings during the Summer 2019 program. For this iteration, teachers co-planned and co-taught a project-based learning unit that integrated multiple STEAM disciplines. The remainder of this section describes the motivations for these shifts.

Disciplinary-Based Sessions Taught Based on Teacher Expertise Resulted in a "Disjointed" Approach (2018-2019 School Year)

The teachers viewed the 2018-2019 School Year program as siloed largely due to the disciplinary-based structure of the program sessions. During this iteration, sessions were divided according to discipline, with half of each session devoted to science and the other half devoted to theater. Not only were the disciplines separated in terms of time but also in terms of who was teaching, with the science and performing arts educators solely teaching their respective disciplines (i.e., science educator teaches the science-designated time only). Gemma explained how this compartmentalized approach resulted in a "disjointed" feeling between the science and theater sessions:

> I think we were kind of recognizing that [the school year program] was really disjointed. It felt, like, theater is doing this and then the next week we do science. And we weren't collaborating as much. And because we weren't collaborating, I don't think it came across [as integrated] for the students. (Fall 2020 teacher interview)

Gemma articulated how limited teacher collaboration across disciplines likely resulted in youth viewing theater and science fields as siloed, rather than making connections among similar processes in these fields. Leah's interview data echoed this challenge:

> [If I redid the school year program] I would have wanted to know that I was going to do it like six months in advance so that I could really collaborate with the adult teaching the science course—in a way that I don't think we truly collaborated—to really make it feel totally integrated. It always felt like we were on parallel tracks. And then sometimes, like, the trains are running on the same parallel tracks but they're not always side-by-side; versus being on the same train and on the same track at the same time. And I think that that comes from having the resources to truly team plan out week-to-week, like, what does this look like. (Fall 2020 interview)

Leah largely attributed this compartmentalized approach to limited time for co-planning, which made the science and theater sessions feel disconnected (e.g., "not always side-by-side"). In her interview, Gemma elaborated upon how the disciplinary-based structure of the teacher planning sessions encouraged a siloed approach to program implementation. Gemma explained,

> Even when we started our planning, the theater group had their planning session, the science group had their planning session, and then we were trying to integrate at the end.

> Whereas if we had done a little bit of that and then a little bit of, OK, here's what we were doing and demonstrating it for each other that we can actively participate. And then, oh, this reminds me of this. So that you're going through that journey before the students are embarking on the journey with you. (Fall 2020 teacher interview)

To support disciplinary integration, Gemma advocated for teacher engagement in co-planning across disciplines, particularly demonstrating lesson components for each other as part of the curriculum development process. In Gemma's view, this approach could support the teachers to "actively participate" in learning processes outside of their disciplinary expertise when implementing the program with youth.

Largely because of a disciplinary approach to planning and teaching, the teachers perceived that the 2018-2019 School Year sessions were presented to students as a series of disciplinary-based activities. Gemma explained, "It might have kind of come across as like a series of activities, like you do this activity for this and that" (Fall 2020 teacher interview). This activity-based approach was further evident by the structure and timing of youths' culminating projects. Youth began creating their projects during the last two program sessions (4/27/19 and 5/4/19), rather than working on their projects continually throughout the school year. As a result of this structure, youths' projects did not drive the learning activities in which they engaged.

Ongoing Teacher Collaboration and Foregrounding Youths' Development of Artifacts for their STEAM Projects Supported Disciplinary Integration (Summer 2019)

During the Summer 2019 program, several curricular and pedagogical changes were implemented to support a more integrated approach to STEAM education. These changes included: (1) teachers ongoing engagement in co-planning and co-teaching all program sessions; and (2) utilizing a project-based learning approach, specifically focusing on youths' development of artifacts for their STEAM projects. For this iteration, the teachers collaboratively planned and taught a project-based learning unit, with the following question guiding youths' projects: *What would you like your community to be like in 10 years?* With this question in mind, groups of youth brainstormed and developed projects that highlighted messages about local social and environmental justice issues (e.g., housing rights, food rights). This process was ongoing throughout the three-week summer program. Youth began by brainstorming their initial project ideas during the first week of the program followed by creating and refining artifacts for their projects during the second and third weeks of the program. Throughout this process, developing artifacts for youths' projects served to drive learning in program sessions. For example, a series of coding workshops were implemented based on youths' decisions to code LED lights for their project artifacts. In one session, for example, youth engaged in a wearable-technology design challenge by coding LED light accessories for their model's costume. In another coding workshop, youth coded LED lights to change color based on sound frequencies. The project-based nature of the curriculum supported youth to intentionally build upon what they learned during the sessions when developing their project artifacts. Gemma explained,

> We were able to build on projects [in the summer] so [the students] had a longer time to dig into different activities. It wasn't just, like, activity, activity, activity [as it was during the school year]. We were able to dig in a little bit better…[T]he purpose and what we were trying to do was a little bit more cohesive. (Fall 2020 interview)

Here, Gemma suggested that the School Year sessions were presented as a series of activities, which did not require youth to deeply engage in the material nor build upon it for their projects. In contrast, youth had time to "dig into" the content during 2019 Summer program because the lessons were driven by youths' projects. In other words, youth were compelled to build upon what they learned during these lessons to create their projects.

Discussion

I discuss two main points that speak directly to the research questions. First, I argue that the two central programmatic shifts—broadening our approach to arts integration and incorporating technology and computing—were complementary of one another. Together these supported youths' engagement in behind-the-scenes STEAM pathways through foregrounding artifact development. Prioritizing youths' development of artifacts created opportunities for youth to build on their interest in STEM while cultivating desirable social images. Second, I argue that a practice-oriented approach to STEAM education—rather than a concept-oriented approach—is more conducive to disciplinary integration from a teacher perspective. More specifically, the shift from focusing on developing youths' understanding of scientific concepts for their projects (concept-oriented approach) to engaging youth in developing artifacts for their projects (practice-oriented approach) as more supportive of disciplinary integration.

Developing Artifacts for Art-Science Projects Enabled Middle School Youth to Build on Their Interest in STEM While Maintaining Desirable Social Images

Findings from this study suggest that it is essential to provide youth with opportunities to engage in STEAM education in ways that allow them to build on their interests while also maintaining their social standing. Cultivating a desirable social image is particularly important for middle-school-aged youth, given that the pressure to "fit in" amongst peers is especially strong during this period (Pinkard et al., 2017). Furthermore, prior studies indicate that the need to maintain desirable social images is especially compelling for people of color, which often results in the negotiation of multiple (sometimes competing) identities in various contexts (e.g., DiSalvo, Guzdial, Bruckman, & McKlin, 2014; Johnson, Brown, Carlone, & Cuevas, 2011). Given that youth participants ascribed to both of these categories—identifying as middle-school-aged and Black or Latinx—it is likely that they experienced a strong urgency to maintain their social standing while participating in Dramatic Science.

Youths' need to cultivate desirable social images manifested as ongoing tensions between appearing "cool" in front of their peers and pursuing their interests. Teacher interview and field note data suggested that the majority of youth presented a "tough," "too cool" exterior during program sessions. Gemma explained, "It kind of felt like the overall atmosphere was, like, 'Yeah, I am too cool for any of this. But I kind of like it, but I won't quite tell you which one I like'" (Fall 2020 interview). Gemma articulated how many students presented themselves as "too cool" during program sessions, which compelled them to purposefully and strategically hide their interests. Leah echoed this sentiment when reflecting on her perception of a particular student's experience, who identified as a Latina female, in the 2018-2019 School Year program. She stated,

> [T]here was always this, like, tough, I'm-not-interested exterior [about her]. But that's not really true. You're actually very interested. You're just being a typical middle schooler who, if your friends aren't doing it, then you don't want to do it. That type of thing. But I do remember around this culminating project [during the school year] that she—that light, you can sort of see it behind that tough exterior—that she actually was interested in what we were doing, and she actually did learn a lot. And so, you saw that little flame inside of her. (Fall 2020 interview)

In this utterance, Leah explained her perception of how this student experienced pressure to fit in with their peers. This pressure compelled her to hide her interest behind a "tough" exterior by only engaging in activities in which her friends were interested and willing to participate. Leah went on the discuss the tensions that she perceived this particular student to experience in Dramatic Science. She stated,

> I think that exterior was there for a very particular reason that we don't know. And I think when you are kind of interested, but you're not quite sure. And you're not sure that you feel safe, and you're not sure that you want to be perceived a certain way. And even if you have that light inside—it's like she's probably dealing with a real tug of war between what she truly wants to do, and what she wants to learn, and how she wants to be in the classroom, and how she wants to evolve, and what she feels like she has to do in the world. (Fall 2020 interview)

Leah perceived this student to experience a "tug of war" among competing desires that were often at odds with one another. For example, Leah ventured that the student had to wrestle with "what she truly wants to do [and] learn" and "what she feels like she has to do" in order to feel safe and maintain a desirable image ("perception") in front of her peers.

The need to cultivate a "tough," "cool" image by hiding one's interests was not unique to this particular student. Field notes corroborate teacher interview data regarding this finding. In general, students rarely volunteered to share their work in front of the whole class during share-out circles. Instead, the teachers asked particular students or groups of students to share their work or teachers shared student work anonymously (e.g., 2/2/19 field notes, 7/17/19 field notes). When student work was shared anonymously, the authors of the work rarely admitted that it was their work, especially when other students asked (e.g., 2/2/19 field notes). Field notes documenting the work of students who developed a play for their Summer 2019 project further echo this finding. These students decided to ask the instructors to act out their play rather than enacting it themselves or creating an audio-recording of themselves reading the script aloud. These data indicate that students' need to protect their social standing was an equally—if not more compelling—force compared to their disinterest in theater. Together, these factors caused students to withdraw from the performative aspects of theater, resulting in the programmatic shifts described earlier (i.e., a broader approach to performing arts and the integration of computing and technology).

Previous studies with youth of color echo the tensions, or "tug of wars," that Leah and Gemma perceived youth participants to experience during Dramatic Science. DiSalvo and colleagues (2014), for example, illustrated how African American male adolescents participating in a computer science program negotiated conflicting identities—in this case, wanting to learn while also maintaining a "cool pose" in front of their peers. As a result of this tension, youth engaged in "face-saving" tactics to preserve their presentations of self while protecting themselves from embarrassment in front of their peers (DiSalvo et al., 2014). Johnson and colleagues' (2011) study puts forth a similar argument. In a retrospective study of the STEM career trajectories of three women of color, Johnson et al. (2011) argue that women of color can sometimes find themselves in settings where the authoring of certain identities is more urgent than others. Their findings indicate how authoring identities can be a survival strategy, rather than a form of self-expression (Johnson et al., 2011). Drawing on Anzaldúa's (1999) work, Johnson et al. (2011) argue that women of color's frequent experiences with fending off negative ascriptions supports them to develop "la facultad" (p. 60), or the capacity to quickly read and respond to a situation. While Anzaldúa (1999) explains that this ability is "latent" (p. 61) in everyone, she argues that:

> Those who are pounced on the most have it the strongest—the females, the homosexuals of all races, the darkskinned, the outcast, the persecuted, the marginalized, the foreign ... It's a kind of survival tactic that people, caught between the worlds, unknowingly cultivate. (pp. 60-61)

Given that the youth participating in Dramatic Science identified with at least one of these social categories, it is likely that many of them already had experiences that required them to cultivate this survival tactic by the time they reached middle school. With this in mind, participants' disinterest in and avoidance of performing arts is unsurprising. The performance-based and audience-oriented aspects of performing arts underscore how performers must collectively work outside of their comfort zones through taking risks and making mistakes (Neelands, 2009), processes that highlight vulnerability. Given that youth appeared to feel an urgency to maintain a "tough," "cool" exterior, it makes sense that they would avoid engaging in more vulnerable aspects of performing arts. As a result, our team shifted our curricular and instructional approaches to better meet youths' needs and interests. More specifically, we shifted our focus to engage youth in developing artifacts for their projects through behind-the-scenes pathways. Developing artifacts for their STEAM projects, rather than engaging in performance-based work, created opportunities for youth to maintain a desirable social image, while simultaneously building on their interest in STEM, particularly coding.

Foregrounding Youths' Engagement in Artifact Development for STEAM Projects Through a Practice-Oriented Lens Supported Disciplinary Integration from a Teacher Perspective

A central goal of STEAM education is to support learners to draw on knowledge and skills from multiple disciplines (Carsten Conner et al., 2019; Finch et al., 2020; Kafai et al., 2014; Quigley et al., 2017). With this overarching goal in mind, how and to what extent our program engaged youth in artistic and scientific disciplines evolved over the course of this study. More specifically, we shifted from a concept-oriented to a practice-oriented approach. Based on findings from this study and previous scholarship (e.g., Bevan et al., 2019; Mishra et al., 2011; Peppler & Wohlwend, 2018; Root-Bernstein et al., 2011), I argue that a practice-oriented approach to STEAM education—rather than a concept-oriented approach—is more conducive to disciplinary integration.

For the first program iteration included in this study (2018-2019 School Year), our program team subconsciously utilized a concept-oriented approach to STEAM education. During this iteration, youth engaged in science to investigate underlying concepts around local environmental justice issues, which served as content for youths' projects. Meanwhile, youth engaged in theater as a means to synthesize and communicate their understandings of scientific concepts. Through this approach, we foregrounded developing youths' understanding of disciplinary concepts. In this case, youth investigated and made sense of scientific concepts around local issues of water quality and distribution. Teacher interview and field note data indicated that this concept-oriented approach manifested as a series of disciplinary-based activities, rather than an integrated STEAM experience ("It might have kind of come across as like a series of activities, like you do this activity for this and that," Fall 2020 interview, Gemma).

Despite our project team's intention to partner science and performing arts as disciplinary equals when designing the program, this intention did not come to fruition during the first and second program iterations. By initially utilizing a concept-oriented approach, our project team experienced a design challenge that is well-documented in STEAM education research, namely utilizing the arts in the service of STEM subjects (e.g., Bevan et al., 2019; Mejias et al., 2021; Quigley et al., 2017). Although art should play an equal role to STEM subjects in STEAM education settings (Carsten Conner et al., 2019; Finch et al., 2020; Liao, 2016), prior scholarship indicates that finding ways to meaningfully integrate the arts with STEM subjects has proven especially difficult for science and mathematics educators (Quigley & Herro, 2016). Our project team fell into this pitfall mainly by using a concept-oriented approach to STEAM education, specifically by leveraging performing arts as a means of representation of students' learning of scientific concepts.

During the Summer 2019 program, we shifted away from a concept-oriented approach to a practice-oriented approach to STEAM education. During this iteration, we prioritized engaging youth in developing artifacts for their STEAM projects. This shift supported us to foreground youths' engagement in STEAM practices, rather than youths' understanding of disciplinary concepts (Bevan et al., 2019). Through this approach, STEAM disciplines were partnered as a vehicle to create projects that highlighted youths' messages about local social and environmental justice issues. Importantly, youths' artifact-development processes were not compartmentalized according to discipline. Program sessions were co-planned and co-taught by the teachers, rather than dividing these sessions based on disciplinary expertise as was done in the previous iteration. Collectively, these changes supported teachers to view the Summer 2019 program sessions as more integrated than the 2018-2019 School Year sessions.

Findings from this study indicate that a practice-oriented approach to STEAM education —specifically the shift to focusing on youths' engagement in developing artifacts for their STEAM projects—is more conducive to disciplinary integration, from a teacher perspective, compared to a concept-oriented approach. Focusing on engaging youth in STEAM practices, rather than understanding disciplinary concepts, supported the teachers to meaningfully integrate STEAM disciplines in ways that positioned artistic and scientific disciplines as equal partners (Bevan et al., 2019). This finding resonates with theoretical frameworks put forth by STEAM education scholars who foreground common epistemic practices across artistic and scientific disciplines (e.g., Bevan et al., 2019; Henriksen & Deep-Play Research Group, 2018; Mishra et al., 2011; Peppler & Wohlwend, 2018; Root-Bernstein et al., 2011). (It is important to note that emerging scholarship on practices common to artistic and scientific disciplines is mainly theoretical. Empirical studies on learners' enactment of convergent art-science practices, to my knowledge, does not yet exist.)

Conclusions and Implications

This study explored how an art-science program evolved based on youths' emergent needs and interests (RQ 1) and teachers' views on how to support disciplinary integration (RQ 2). Findings from this study suggest two central implications. First, it essential for STEAM educators and program designers to create opportunities for youth to engage in STEAM education in ways that allow them to build on their interests while also cultivating desirable social images. Providing educators and program designers with ongoing opportunities to learn from their students—specifically about their needs and interests—when designing and developing a STEAM program is especially important. Second, I argue that supporting ongoing teacher collaboration across disciplines through a practice-oriented lens—rather than a concept-oriented lens—may better serve educators and students in STEAM learning settings through integrating STEAM disciplines in meaningful ways. The teachers participating in this study viewed engaging youth in STEAM practices to develop artifacts for their projects as a means to integrate disciplines.

With these conclusions and implications in mind, it is important to recognize the limitations of this study. First, it is important to recognize that findings were influenced by the program context. Dramatic Science's out-of-school learning setting allow for substantial flexibility for youths' STEAM projects, particularly during the third program iteration (i.e., flexibility in terms of project topic, format, and artifacts). Second, this study speaks to teachers' and researchers' *perceptions* of youths' experiences in the program. Although the second paper included in this dissertation highlights the experiences of two case study youth, more research is needed to understand youths' self-reported experiences. Third, these findings are influenced by the project team members who participated in this project and iteratively designed the program. Had other individuals been involved in this process, it is likely that a different set of findings would have been generated. Nonetheless, it is my hope that other STEAM educators and program designers can learn from the experiences highlighted in this study.

Creating Opportunities for Youth to Maintain Desirable Social Images in STEAM Education Settings

Based on findings from this study, I argue that it essential for STEAM educators and program designers to create opportunities for youth to engage in STEAM education in ways that allow them to build on their interests while maintaining their social standing. Previous scholarship on the experiences of middle-school-aged youth, particularly youth of color, indicate how important it is for youth fit in with their peers (DiSalvo et al., 2014; Johnson et al., 2011; Pinkard et al., 2017). During the early stages of program design and implementation, it was difficult to fully grasp how this desire would interact with youths' engagement in an art-science program. Youth participants' need to cultivate desirable social images manifested as ongoing tensions between wanting to appear "cool" and "tough" in front of their peers and pursuing their interest in learning. These tensions were most prominent when youth engaged in performance-based aspects of performing arts during program sessions, which resulted in youths' engagement in "face-saving" tactics (DiSalvo et al., 2014).

This finding complicates a prevalent argument for integrating the arts with STEM disciplines as a means to broaden participation in STEM. On the one hand, integrating the arts with STEM disciplines can foster more opportunities for personal expression, which can support learners' interest and identity construction (Bequette & Bequette, 2012; Carsten Conner et al., 2017; Cook & Bush, 2018; Quigley & Herro, 2016; Quigley et al., 2020). At the same time, engaging in personal expression through artistic disciplines can be a vulnerable endeavor. The performance-based and audience-oriented aspects of performing arts, in particular, highlight the potential of experiencing vulnerability (Neelands, 2009). Engaging in processes that highlight potential vulnerability would be challenging for many people of all ages and races. Coupled with a desire to "save face," (DiSalvo et al., 2014) engaging in performing arts may be especially difficult for many middle-school-aged youth of color if they do not have a strong prior interest in or experience with performing arts. Therefore, it is essential for educators and program designers to develop STEAM education settings that account for youths' need to cultivate desirable social images while building on their interest in artistic and scientific disciplines. Providing educators and program designers with ongoing opportunities to learn from their students—specifically about their needs and interests—when designing and developing a STEAM program is especially important.

Utilizing A Practice-Oriented Approach to STEAM Education to Support Disciplinary Integration

Designing and implementing learning settings that integrate STEAM disciplines is a challenging endeavor (Mejias et al., 2020; NRC, 2014). Findings from this study suggest that a practice-oriented approach to STEAM education, rather than a concept-oriented approach, has potential to support meaningful disciplinary integration (Bevan et al., 2019; Henriksen & Deep-Play Research Group, 2018; Mishra et al., 2011; Peppler & Wohlwend, 2018; Root-Bernstein et al., 2011). More specifically, the teachers participating in this study viewed engaging youth in STEAM practices to develop artifacts for their projects as a means to integrate disciplines. In contrast, a concept-oriented approach to STEAM education, which was implemented in the initial program iterations, resulted in program development and implementation that was siloed by the disciplines.

Designing STEAM education settings through a practice-oriented lens may provide teachers with a framework to reflect on and improve their practice (Bevan et al., 2019). A practice-oriented approach to STEAM education focuses on supporting learners' engagement in practices common to artistic and scientific fields. In this particular study, the teachers utilized a practice-oriented approach through foregrounding youths' development of artifacts for their projects. To develop wearable technology, for example, youth participants engaged in computing and costume design and construction. Another practice-oriented example of STEAM education is supporting learners to develop a script that highlights their engagement in narrative and argumentation practices around a question or idea. Not only does a practice-oriented approach to STEAM education resonate with the practice turn in recent science education reform (NRC, 2012), but it also has the potential to support teachers to co-plan and co-teach across disciplines. Foregrounding practices, rather than concepts, could liberate teachers to collaboratively plan and teach across disciplines in which do not consider themselves to be experts, given that a deep understanding of disciplinary concepts is not required in this approach. Supporting ongoing teacher collaboration across disciplines through a practice-oriented lens may better serve educators and students in STEAM learning settings through integrating STEAM disciplines in meaningful ways.

Paper 2: A Longitudinal Study of Middle School Youths' Emergent Art-Science Thinking Practices in an Art-Science Program

Despite prevalent assumptions that the arts and sciences are incompatible, these disciplines have been entangled throughout history (Peppler & Wohlwend, 2018; Root-Bernstein & Root-Bernstein, 1999; Strosberg, 2015). Performing artists, scientists, and engineers demonstrate many common thinking practices, which are not only critical to their disciplinary fields but also life in general (Carsten Conner et al., 2019; Mishra et al., 2011; Peppler & Wohlwend, 2018; Winner et al., 2006). Fostering art-science thinking practices, such as empathizing and collaborating, is especially crucial in the current era of accountability and high-stakes testing, which has resulted in the narrowing of the curriculum, particularly in urban schools (Achinstein & Ogawa, 2011; Winner & Hetland, 2008). By engaging in science and art, and recognizing the commonalities of these seemingly disparate domains, participants may challenge and reframe what is valued in STEM disciplines (Finch et al., 2020). This convergent space has the potential to enable youth to develop and embrace expansive discourses and practices that may better support their relationships with science and art (Carsten Conner et al., 2019; Henriksen et al., 2015; Marshall, 2014; Mishra et al., 2011; Peppler & Wohlwend, 2018).

Despite prevalent international interest in art-science education and the rise of STEAM-focused K-12 schools, there is limited research in the context of STEAM education settings (Bevan et al., 2019; Finch et al., 2020; Kang, 2019; Quigley et al., 2020). In particular, there is a paucity of research on youth participants' experiences in art-science education settings (Bush et al., 2020; Kang, 2019; Quigley et al., 2020). Extant scholarship, while making important contributions to the STEAM education conversation, mainly focuses on teacher outcomes (e.g., Cook et al., 2020; Jho et al., 2016; Quigley et al., 2020). Regarding youth outcomes, the majority of research to date has taken place in K-12 settings (e.g., Kim & Chae, 2016; Ozkan & Topsakal, 2019). Further, these studies typically focus on findings generated from a single iteration of design. Longitudinal research on youths' experiences in out-of-school STEAM education contexts over the course of multiple iterations, to our knowledge, does not exist. In light of this need, this study investigates the experiences of two middle school youth, Lara and Jayda (pseudonyms), who identify as Latina and Dominican American, respectively, in an out-of-school art-science program over three program iterations. Given that STEAM education has been proposed as a means to reimagine and expand what it means to be an author of science (Finch et al., 2020; Mejias et al., 2021; Quigley et al., 2019), investigating the evolving experiences of female youth of color in these spaces is especially important.

Methods

This inquiry will add to the STEAM education conversation by documenting Lara's and Jayda's emergent of art-science thinking practices; any shifts in how they position themselves in group projects as related to their enactment in these practices; and any shifts in their perspectives of art-science thinking practices. It is important to note that the framework on art-science thinking practices included in this study is still in-process. I expect that it will continue to evolve as more is learned about which practices resonate most with teachers and students in STEAM education contexts. The findings from this study will support future STEAM education program design and research regarding convergent practices across artistic and scientific fields. The research questions that guide this inquiry are as follows.

1. What art-science thinking practices emerge for two middle-school-aged youth during their participation in an art-science program, and how does the program design relate to youths' engagement in these practices?

a) How does youths' engagement in art-science thinking practices relate to the roles they negotiate in group projects?

2. How do youths' perspectives on art-science thinking practices shift, if at all?

Drawing from a larger design-based research (DBR) study (Brown & Campione, 1996), a longitudinal ethnographic case study approach was utilized to understand the complex nature of two middle-school-aged youths' experiences throughout their participation in Dramatic Science over three program iterations from early July of 2018 to late July of 2019 (140.5 program hours).

Youth Participants

Participant selection for this study was based on three criteria: self-reported gender (female), ethnicity (Black and/or Latina/x), and grade level when entering the program (7th). As members of the youngest grade band in the program, youth in 7th grade were selected under the assumption that they would be a part of the Dramatic Science program for the remainder of their middle school years. Among the 15 youth participating in Dramatic Science at the beginning of this study, three met the inclusion criteria, two of whom identified as Latina and one of whom identified as Dominican American. Due to inconsistent attendance and the eventual attrition of one youth, this inquiry includes case studies of the two remaining youth, Lara and Jayda, who were part of the same project groups for all three program cycles included in this study. Lara and Jayda were demographically comparable to the remaining youth participating in Dramatic Science, who predominantly identified as Latina/o (67%) and multilingual (73%). Consistent attendance for all three program iterations (13 months) allowed for the generation of robust data sets for each youth. Investigating the experiences of a small number of youth supports the employed methodological approach of longitudinal ethnographic research, which requires engaging in "thick description" (Geertz, 1973, p. 6) to interpret the complexities of participants' ways of living, being, and knowing. Developing rich case studies of two youth through this approach will support researchers and practitioners to interpret the complexity and nuance of the findings, supporting them to glean insights for their work (Stake & Trumbull, 1982).

Data Sources

Data were generated during program sessions over three program cycles, including a consecutive three-week session in July of 2018 (12 sessions, 52 hours), Saturday sessions during the 2018-2019 school year (13 sessions, 36.5 hours), and another consecutive three-week session in July of 2019 (12 sessions, 52 hours), for a total of 140.5 program hours. Primary data sources include field notes from participant observation during program sessions (75 pages total) and seven rounds of semi-structured interviews (20-40 minutes each) with each youth (50-105 pages each), which took place near the beginning and end of each program cycle in addition to a final follow-up interview in the fall of 2019. Two rounds of semi-structured interviews with the teachers and drafts of youths' projects served as secondary data to further corroborate findings.

Observational Data

Field notes, generated by myself and another research team member, were based on participant observations and informal ethnographic conversations with youth during program sessions over the three program cycles. We alternated between taking field notes as participant observers and supporting the instructors and students as co-instructors as needed. For observations, an ethnographic approach was used, following an observation guideline agreed upon by the research team. Guided by our conceptual framework, we paid close attention to youths' actions and utterances related to their emergent art-science thinking practices and the roles they negotiated during group projects.

Interview Data

Interview data highlighted youths' feelings and views about performing arts and science, experiences during Dramatic Science sessions, and visions of their futures (e.g., goals, career aspirations). All interviews were conducted and transcribed by the first author. When developing the interview protocols for the semi-structured interviews, graphic elicitation (Bagnoli, 2009), specifically in the form of a relational map, was utilized to understand youths' perspectives of art-science thinking practices. Given the complex and dynamic nature of participants' views of art and science, graphic elicitation may illuminate aspects of youths' perspectives that may have otherwise gone unsaid (Rodriguez & Kerrigan, 2016). As described below, participants completed three relational maps, which were revisited and revised during subsequent interviews. Youths' utterances about these relational maps highlighted their evolving perspectives of the art-science thinking practices in the contexts of their personal lives, science, and performing arts (RQ 2).

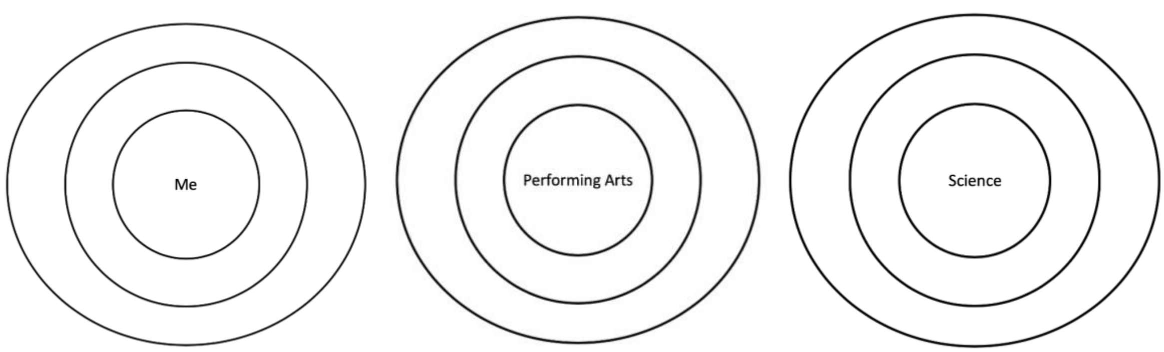
Regarding how youths' engagement in art-science thinking practices influenced their roles in their group projects (RQ 1a), late-summer and late-school-year interviews included questions on each youth's group project for the showcase event. More specifically, each participant was asked to describe her group project and her role in the project. Additionally, she was asked which skills she utilized in her group project before marking in which of the 10 focal art-science thinking practices her group engaged and how. Lara and Jayda, the focal youth included in this study, were part of the same project groups for all three program cycles. During this time, their groups developed a public service announcement (PSA) about the local effects of climate change (Summer 2018), an interactive board game on water quality, access, and equity (2018-2019 School Year), and a play about the local effects of climate change (Summer 2019). (Note: As discussed in the DBR study (Paper 1), the programmatic language shifted from “theater” to “performing arts” after the second program iteration. Youths’ utterances in the interview data reflect this shift.)

Artifact Data: Relational Maps

Research participants created three relational maps to document the importance of art-science thinking practices (see Table 0.1) in their personal lives (map 1) and in the disciplines of science and performing arts (maps 2 and 3). These original maps (Figure 2.1) were then revisited and adjusted by youth in subsequent interviews. The purpose of engaging in this process was to understand youths’ perspectives of the relevance of the art-science thinking practices in performing arts and science fields, and how these perspectives evolved (if at all) throughout their long-term participation in Dramatic Science. Also, it was equally, if not more important, to understand how youth perceived these thinking practices—which the project team deemed vital to both science and performing arts domains—as relating to themselves and their lives (if at all). Thus, youths’ discussions about the three relational maps supported a holistic understanding of each youth’s perceptions of art-science thinking practices within various contexts (i.e., youth’s personal life, science, performing arts), and how these views shifted (or not) in relation to one another over time.

Figure 2.1

Images of Blank Relational Maps for Initial Interviews



During individual interviews, participants were asked to place 10 cards, each with one art-science thinking practice (as conceptualized by the project team), on the map according to how important they thought these practices were to themselves and their lives. In other words, the more critical the student deemed the thinking practice to be in the area of interest (e.g., my personal life), the closer to the center they placed the card. Students placed cards with practices viewed to have lesser importance to the area of interest farther away from the center circle. After placing the pre-determined cards on the map, participants were asked to write or draw any additional practices or ideas they felt were important to the area of interest. Each participant first created the personal life ("Me") map before going through the same process to create relational maps for performing arts and science during the following Dramatic Science program session.

During the interviews, the personal life ("Me") map was discussed by youth before the science and performing arts relational maps near the beginning of cycle 2 (2018-2019 School Year). The purpose of starting with the personal life map was to foreground the role of art-science thinking practices in youths' lives before discussing the roles of these practices in science and performing arts disciplines. After discussing their personal life maps, youth were then asked to choose which relational map to discuss next, science or performing arts. When discussing each of these maps, each youth was first reminded of the purpose of the maps and then asked to explain why she placed each card in the given location on the map, starting with the center circle and moving outwards.

The original maps were revisited and adjusted by youth in subsequent interviews. When each map was revisited, the youth participant was asked if she wanted to move, add, or remove any cards on her map by drawing or writing before explaining her decisions. The science and performing arts relational maps were revisited at the end of the second and third program cycles

(May 2019 and late Summer 2019), while the personal life map was revisited at the end of the third program cycle (late Summer 2019). The science and performing arts maps were revisited more frequently to prompt youth to reflect on the roles of art-science thinking practices, which the program aimed to support, in performing arts and science and how they related to each other, if at all.

Data Analysis

Data analysis focused on youths' engagement in art-science thinking practices, roles in group projects, and views of art-science thinking practices. The initial analysis of the interview transcripts and field notes was performed by myself, followed by a secondary analysis by research team members. I developed a coding framework for the interview and field note data through a mixed deductive and inductive approach (Miles, Huberman, & Saldaña, 2014). This approach afforded the analysis of participant data in light of existing theory while also allowing the researcher to highlight nuances and alternative findings that are specific to the participants in the study, which may be absent from existing theory. Deductive codes were informed by salient themes from extant literature on convergent epistemic practices in STEAM education (e.g., Bevan et al., 2019; Liao, 2016; Marshall, 2014; Mejia et al., 2021; Mishra et al., 2011; Peppler & Wohlwend, 2018; Quigley et al., 2020), while inductive codes were generated through descriptive and in vivo coding. This provisional codebook was revised based on discussion with the research team. As a result of this process, subcodes were refined and condensed into eight overarching categories: (1) general views of doing science and doing performing arts, (2) views of art-science thinking practices in science and performing arts, (3) previous experience with science and performing arts, (4) emotional connections with science and performing arts, (5) hopes for future self (e.g., goals, hobbies, careers), (6) self-reported experiences in Dramatic

Science, (7) engagement in art-science thinking practices during program sessions, and (8) participant's roles and interactions during learning activities and group project during program sessions. (Please see Appendix E for the final codebook.)

To organize the field note and interview data for each youth, case summaries were generated and arranged by overarching categories from the codebook. These case summaries were shared with the research team for discussion and critique before establishing themes for each case in light of the concepts included in the research questions. To develop analytic reliability, themes were examined regarding their prevalence, with both convergent and divergent examples sought within and across the interview and field note data.

Findings

The results for each case study participant are organized in accordance with the research questions. A main art-science thinking practice enacted by the youth, the relationships between this practice and the program design, and any shifts in the youth's role in her group project are described for each program cycle (RQ 1). Next, shifts in the youth's perspectives on art-science thinking practices in the context of science, performing arts, or her personal life are described (RQ 2). Each case concludes with a summary of the youth's evolving interest in and identification with science and performing arts. This discussion relates to an overarching goal of the program, namely to foster youths' interest and identity construction with STEAM. To contextualize the findings for each case, I begin by introducing the youth.

The Case of Lara

Introducing Lara

Lara is a Latina cisgender female who grew up in a bilingual Spanish- and English-speaking household with her mother, father, and older sister. Her hobbies included hip-hop dance, gymnastics, and soccer. When discussing influences in her life, Lara referred to her family as her support system and education as vital to her future (7/12/18 and 10/26/19). School was especially critical for Lara as she consistently referred to her schooling habits throughout interviews. Lara prided herself on becoming a "straight-A student," an identity that was entangled with her hard-work ethic (7/12/18). She explained,

> I used to be one of those students who copied but now I'm just, like, I'm not learning anything. And I would rather get bad grades and work my way up than get good grades and get carried by someone. (3/16/19)

As a result of her hard work, Lara reported that her peers considered her to be one of the "smart" people in the class, often going to her for help to figure out answers (7/12/18 and 3/16/19). Lara expressed that working hard and maintaining high grades were important in all of her classes, regardless of her interest in the subject. She explained, "I'll just do the work even though I don't like the work. Or I feel like I'm forced to do the work because I don't want to bring my grades down" (7/12/18). Lara reiterated this sentiment when speaking about her first memory of doing science in which she created a model of the sun, Earth, and moon for a school project. She described this project as "easy" and "boring" due to her familiarity with the phenomenon. Again, despite her disinterest in the project, she prided herself on getting her work done (7/12/18).

Lara's affiliation with a "good student" identity (Archer et al., 2017; Carlone et al., 2014) was related to her enculturation as a passive consumer of knowledge in formal school settings (Achinstein & Ogawa, 2011; Basu & Calabrese Barton, 2010). When describing her experience with science in school, Lara referred to her science teacher's pedagogy, whom she had from 4th through 6th grade: "Mr. Arnold (pseudonym) was, like, okay, I'm gonna say this. You have to memorize it. And then we'll do this packet and you have to get it right" (7/12/18). Lara further highlighted her position as a passive consumer in school science when explaining what skills were valuable in science, including getting the “right” answers, closely following directions, fixing mistakes, always doing homework, and asking the teacher questions to understand the topic (7/24/18, 11/03/18, 03/16/19, and 10/26/19). These “good student” identity practices fostered Lara’s self-efficacy in science class, supporting her to feel proud and competent for staying focused, getting her work done, and maintaining high grades.

This case demonstrates Lara’s journey in exercising and grappling with art-science thinking practices that conflicted with her school-oriented practices and perceptions of science. More specifically, Lara went from depreciating and experiencing discomfort with collaborating, imagining, and creating to successfully collaborating with her peers in a group project. In what follows, we describe Lara’s journey in leveraging the practice of collaborating, and how this enactment related to her role in her group project.

From “Carrying the Team” to Becoming a Team Player: Collaborating by building on her interest in coding

Lara’s main art-science thinking practice arose during the third program cycle when she was able to collaborate with her group members to develop and produce a play about the local effects of climate change. For this project, Lara was able to create a niche for herself as her group’s coding lead by building on her interest in coding.

Cycle 1: “Carrying the team” by getting close-ended activities done efficiently and independently. During the first program cycle, Lara consistently expressed and enacted a diligent work ethic, which encouraged her preference for close-ended tasks that could be completed individually. For example, during the first week of the program, youth explored an interactive model of predicted rising sea levels in their surrounding communities. During this activity, Lara expressed frustration from working with Jayda and another peer, both of whom were looking up the predicted rising sea levels at their home addresses, rather than following the directions. This interaction prompted Lara to ask one of her teachers if she could work alone because her peers were “not focused” and she would rather finish her work before “messing around” (field notes, 07/10/2018). Although her group members were exercising curiosity by looking up their home addresses, Lara interpreted their actions as conflicting with her vision of how to engage in learning (i.e., stay on task by following the directions).

Lara demonstrated and expressed similar frustrations from working with her peers during three investigations that summer, including an experiment on the effect of carbon dioxide on water temperature and an experiment on the effect of filtration material on water clarity. She explained that she would rather have done these activities individually or with people who shared similar work habits:

> I would rather do [those activities by] myself next time because sometimes my friends don't—one of them does no work and the other one tries to go along [with her]. And then I'm just here doing all the work…I’d rather work with different people who actually want to do the work. (07/24/18)

Again, Lara expressed frustration with her peers’ ways of engaging in activities, which were different from her “get-it-done” approach.

Because of these experiences in Dramatic Science, Lara described herself as “carrying the team” that summer (07/24/18). Likewise, when creating her and Jayda’s project, namely a public service announcement (PSA) poster on climate change, Lara reported that she did the majority of the work on the project. She prided herself on putting a lot of time and effort into the poster, qualifying it as her biggest success in Dramatic Science that summer:

> I really researched all the details on how climate change is really affecting us. And I didn't see anybody explain their poster while I'm actually explaining my poster [during the showcase event]…I spent a lot of my time [on it and] I feel proud of it. (07/24/18)

This statement alludes to how Lara's enactment of "good student" identity practices in Dramatic Science enabled her to maintain her self-efficacy (e.g., "I feel proud"), similar to her experience in school science. She further explained that she found enjoyment and confidence in the act of completing work, stating, "Just doing the work and having a feeling that you actually completed the work and stuff like that [makes it fun]…[It makes me] feel proud" (07/24/2018). Lara's sense of pride for completing her work efficiently was entangled with her relationship with science, given that it bolstered her self-efficacy with the discipline.

The aforementioned activities—which Lara reported to successfully complete and expressed an interest in working individually—were close-ended, involving directions and encouraging a narrow range of outcomes. In a similar vein, Lara experienced frustration with open-ended tasks, in which there was no one right answer or solution. For example, Lara expressed discomfort with an open-ended activity on designing an architectural solution to climate-change-induced flooding of the local city. She stated,

> [T]he activity we did, like, what's a solution to the [our] city and how it's gonna be flooded. How [are] we supposed to do that?…How [are] we supposed to do that? But when we did the activity with the two bottles [to measure the effect of carbon dioxide on water temperature], I was, like, okay, I can do that, that, and that. Easy. (07/10/2018)

In this statement, Lara suggests a preference for close-ended activities, specifically an experiment on the effect of carbon dioxide on water temperature, over open-ended activities like the design challenge. When working on activities in Dramatic Science during Cycle 1, most of which were close-ended, Lara was able to enact her individualistic and diligent work ethic, resulting in her role as “carrying her team.”

Cycle 2: Peripheral participation in a group project and a continued preference for close-ended activities. During Cycle 2, Lara continued to experience comfort with close-ended activities and frustration with those that were more open-ended. Unlike the PSA poster project, the group project during Cycle 2 was more open-ended, stemming Lara’s peripheral involvement in the project and reported lack of success. For her group project, Lara and a group of three peers, including Jayda, designed and created an interactive board game on issues of water quality and access. Lara’s group members conceptualized the goal and components of the game (e.g., game design, cards with prompts), while Lara used modeling clay to create the dice for the game. When reflecting on her experience with this project, Lara reported playing a minimal role (i.e, only making the dice) and expressed that the overall project was unsuccessful: “[W]e didn't really play [the game]. And I think when they played it, it didn't make sense. No one knew how to win. I don't think we were really good at that” (07/09/19). Lara’s peripheral involvement in this group project and her absence from the symposium event, in which youth played their board game with audience members, likely influenced her view that the project was unsuccessful.

Different from her experience with her group project that cycle, Lara experienced success on an activity with a defined outcome, namely designing, creating, and testing a water filter (07/09/19). During the design stage of this activity, participants could make choices on which materials to use, the amount of materials to use, and the configuration of the materials. After designing and creating their water filters, the youth used local river water samples to test their effectiveness in improving various water quality indicators (e.g., pH, nitrite, pesticides, bacteria). Even though the design of the filter was fairly open-ended, Lara and her partner used limited materials in their design, specifically one coffee filter and one cotton ball (field notes, 12/8/18). Upon reviewing Lara and her partner's design, an instructor asked if they wanted to use any other materials (e.g., three types of sediment, activated carbon, coffee filters, cotton balls). Lara declined, stating that she remembered doing a similar water filter activity previously and that these materials worked best. Still, Lara considered her experience a success: "I think it was only the filter—that was the only [success I had] because that was easy. It took like one or two tries" (07/09/19). Rather than justifying her success based on the effectiveness of their water filter, Lara explained that she felt successful because the challenge was "easy" and only took "one or two tries." Coupled with her utterances about her group's lack of success with the board game ("no one knew how to win"), these statements suggest that Lara prefers activities in which there is a clearly-defined outcome (e.g., creation of a water filter) from those that are more ambiguous.

Cycle 3: Becoming a team player by building on her interest in coding. During the third and final program iteration included in this study, there was a noticeable shift in Lara's role in her group's project. Rather than "carrying the team" in the PSA poster project (Cycle 1) or peripherally participating in the board game project (Cycle 2), Lara collaborated with her group members—all of whom made meaningful contributions to their project.

For this project, a group of five, including Lara and Jayda, created, produced, and directed a play about the future effects of climate change on their local community. During this process, group members engaged in (1) conceptualizing and developing the characters and script for their play, (2) designing and creating costumes for the characters; (3) coding LED light accessories for the costumes, and (4) casting and directing staff members to act out their play. During the costume design process, the team of five divided into two specialized groups. In one group, Jayda and two peers worked on costume design and construction while in the other group, Lara and one peer, worked on coding LED light accessories for the costumes. More specifically, the first group sketched out two sets of costumes for each of the five characters, which would be worn at different times during the play, and then constructed the costumes using materials requested by the youth (e.g., t-shirts, sewing materials, ribbon). Based on the costume sketches, the second group used Python programming to code LED light strips to turn two different colors by using an on/off switch the actors could push during the play.

This was the first time that Lara reported to experience success with an open-ended group project during Dramatic Science. She explained:

> [M]y group was actually focusing and it was actually fun because we had the teachers involved, not just the students, in the play. And everyone spacing out—two people doing coding, and then three other people working on the script and the clothes [that] involved coding with the LED lights. It was fun. (07/25/19)

In this utterance, Lara attributes the success of her group's project to three factors. First, she recognized that her group members were "focused," which stands in contrast to her perception of her peers during previous projects and activities, particularly during the first program cycle. Second, she recognized that everyone in the group contributed to the project through their specialized roles and tasks. Third, she enjoyed casting and directing the teachers to act out their play, rather than solely involving the student group members.

Lara further explained that her group's project was more creative than projects in past program iterations. She stated, "I felt like we were more creative—a lot more creative this year. And we actually included science, performing arts, and coding. [The other College Bound groups] just did one topic" (07/25/19). Here Lara attributed her group's creativity during Cycle 3 to their ability to combine science, performing arts, and coding in their project. This project contrasted with previous program iterations as well as with other College Bound STEM program groups, in which youth were only working on "one topic."

While multiple factors influenced Lara's experience that summer, she later highlighted her interest in coding as a primary reason for her success and enjoyment with her group project:

> [A]ll I wanted to do was coding. I didn't care what the play was [about]. I just wanted to do the coding part because I know that [my peers] wanted to include coding. So, it was, like, I don't care whatever you guys do, I am doing the coding part. (07/25/19)

She went on to explain that "the coding part" was her most memorable experience (07/25/19) and later reframed her biggest success that summer as coding in a follow-up interview, stating, "I liked [coding] because it's just interesting. And you're working with computer science and you learn so much, especially for today." (10/26/19). Collectively, these utterances demonstrate that Lara was able to successfully collaborate with her peers on an open-ended project by building on her interest in coding. In doing so, she was able to create a niche for herself as her group's coding lead, while her group members offered other contributions. This experience stands in stark contrast to her experience in group projects in the previous two cycles, in which she was either "carrying the team" (PSA poster) or peripherally involved (board game).

Lara's Shifting Perspectives on Art-Science Thinking Practices

Lara's successful experience with her group's project during the third program cycle corresponded with shifts in her perspective on the value of art-science thinking practices in her personal life and in science. (No shifting perspectives were articulated in the context of performing arts.) In her personal life, Lara articulated the value of collaborating, imagining, and creating (Figure 2.2). In science, she recognized the value of imagining, creating, and storytelling (Figure 2.3). Interestingly, she viewed collaborating, imagining, and creating as entangled with one another and referred to her experience in Dramatic Science in Cycle 3 as contributing to her emergent perspectives on these practices. In what follows, we describe Lara's shifting perspectives concerning these practices in the context of her personal life and science.

Figure 2.2

Shifts in Lara's Views of Collaborating, Imagining, and Creating in Her Personal Life

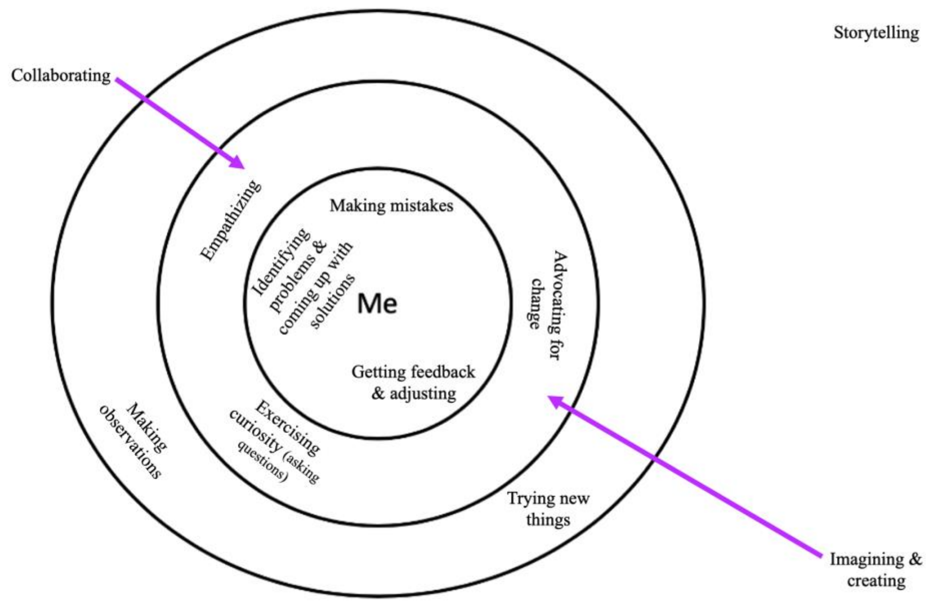
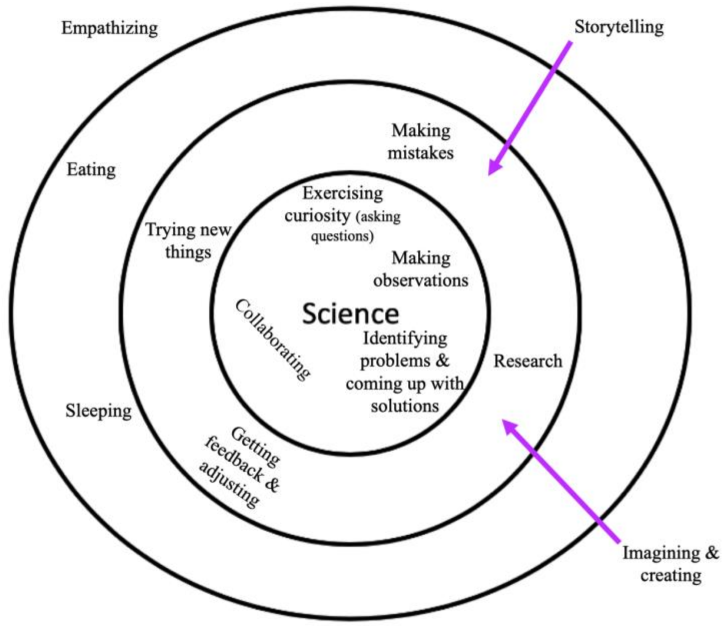


Figure 2.3

Shifts in Lara's Views of Imagining, Creating, and Storytelling in Science



Shifts in Lara's Views of Art-Science Thinking Practices in Her Personal Life: A newfound appreciation for collaborating, imagining, and creating. During an initial artifact-based interview, Lara explained that collaborating, or working as a team, was not important in her personal life. She stated,

> I don't really like working as a team because I realize when I work alone, I get stuff completed faster. It's way better to be working alone because you could focus more and rather than everyone talking to you about drama...The only time I'll work in a group is if it's for a project. If it's mandatory, then, yeah, sure, why not. (03/16/19)

This statement echoes Lara's enacted practices and utterances around staying focused and getting her work done efficiently in Dramatic Science sessions, particularly during the first and second program cycles (Summer 2018 and 2018-2019 School Year), rather than getting involved in discussions that were peripheral or unrelated to learning activities.

Lara’s view of collaborating—as well as many other art-science thinking practices on her map—was framed through her experience with school, in which she was enculturated to get her work done efficiently and often independently. Furthermore, her preference for working individually was influenced by macro-pressures including state-mandated testing and obtaining a degree in higher education. She explained,

> Me focusing on another person is not going to help me succeed in life…I do not like working as a team. Because if you're getting so used to working as a team—if you're going to college, you're not going to have a whole team with you. It's just gonna be you... [Even] if you want to work as a team, you can't really work as a team. Education-wise you should at least work independently, because if you're taking the [state-mandated test], are you going to have the whole team with you? (03/16/19)

Here Lara recognized a narrative circulating in the United States about individualism as vital to success in education and life in general. Unfortunately, Lara’s association of individualism with education is a pervasive reality experienced in formal education across the United States, given the current era of individual accountability and high-stakes testing in K-20 school settings (Achinstein & Ogawa, 2011; Varelas, Martin, & Kane, 2013). Lara’s experience in formal school settings supported this narrative, given the focus on completing work efficiently and independently in an effort to maintain high grades. As a result, Lara viewed collaborating as an obstacle to her own success.

Like collaborating, Lara viewed imagining and creating as irrelevant to her personal life. She stated,

> Imagining and creating—that sounds like theater to me because I don't like being creative. Theater is not my thing or storytelling. I don't like either of them. But, like, imagining stuff, nah. I'm only imagining stuff when I'm reading a book. (03/16/19)

Lara depreciated imagining and creating, which she associated with theater or performing arts rather than science, stating that she only imagined when reading a book (e.g., generating mental images and scenarios). Lara's marginalization of these art-science thinking practices in her personal life aligned with her enacted "good student" identity practices and utterances. In other words, Lara's discomfort with imagining and creating complemented her preference for close-ended activities with directions and well-defined outcomes, activities that limit youths' creativity.

After experiencing success and enjoyment during her group's climate-change-play project in Cycle 3 (Summer 2019), Lara voiced a shift in her views of collaborating, imagining, and creating in her personal life, moving these art-science thinking practices closer to the center of her map (Figure 2.2). She explained her decision, stating,

> I moved imagining and creating to the second circle because if you're working as a team, you guys don't want to do the same project someone else did. You want to do something different, something that'll get other people inspired. Honestly, [imagining and creating is the] same thing as working as a team. (07/25/19)

Lara referred to her experience in her group project that summer as the primary reason for her newfound appreciation of these art-science thinking practices. Interestingly, she equated collaborating with imagining and creating, stating that they were the "same thing." She linked these practices again later in the interview, stating that "With more people involved in the group [for our play project], we could have more ideas on what to do" (07/25/19). In other words, Lara recognized that collaborating with multiple people sparked her group members' imagination and creativity when developing their project.

Lara's shifted perceptions of collaborating, imagining, and creating were further supported by her reflection on her group's experience during that cycle. She stated, "I felt like we were more creative—a lot more creative this year. And we actually included science, theater, and coding. [The other STEM groups in College Bound] just did one topic" (07/25/19). Here Lara attributed her group's creativity during Cycle 3 to their ability to combine science, theater, and coding in their project. This project contrasted with previous program iterations, which only included science and performing arts, as well as with other College Bound STEM program groups, in which youth were only working on "one topic" (e.g., 3D printing, laser cutting). During an electronic-fashion design challenge that summer, Lara articulated a similar sentiment, exclaiming to one of her instructors and a small group of peers, "We're being so creative! And we're doing coding and theater!" (07/11/19). In this particular activity, Lara volunteered to model a costume for her group, while her group members coded LED lights to accessorize her costume. Immediately after the fashion challenge presentations and group discussion, Lara and her group were eager to show off Lara's costume to youth in the other College Bound STEM classes.

Collectively, these data indicate that the incorporation of coding during Cycle 3 was particularly important to create a meaningful and enjoyable experience for Lara, which encouraged a newfound appreciation for art-science thinking practices she might have otherwise continued to dismiss. If coding had not been part of the curriculum and her group's project that summer, it is possible that Lara may have peripherally participated in her group, as she did during the board game project in Cycle 2, which would have led to a very different experience.

Shifts in Lara's Views of Art-Science Thinking Practices in Science: A newfound appreciation for imagining, creating, and storytelling. In addition to expressing shifting views of art-science thinking practices in her personal life, Lara also articulated a shift in her perspective on imagining and creating in the context of science, moving these practices closer to the center of her map (Figure 2.3). When she initially created this map, Lara explained that imagining and creating were irrelevant to science, stating,

> Because you're not gonna—I mean you could create a project but you're not going to imagine. Why [are] you gonna imagine. [Pause]. I don't know. If you have a solution to a problem, you're not going to keep imagining it. You're gonna want to make something, prove some point, or whatever. Creativity. How [are] you gonna be creative. (03/16/19)

Lara's utterances allude to the role of creativity and imagination in science. For example, one could "create a project" or "make something." She also stated that "if you have a solution to a problem, you're not going to *keep* imagining it" (italics added), implying that one must initially imagine a solution. At the same time, however, Lara explicitly rejected the notion that science involves imagining and creating ("why [are] you gonna imagine," "how [are] you gonna be creative"), and implicitly associated science with more concrete processes (i.e., "make something, prove some point").

Lara's experience in her group's play project during Cycle 3 fostered a new perspective, encouraging her to see the value of these practices in science. In contrast with her previous statement, she explained that imagining and creating were important in science: "because—like I said last time, you don't want to do the same stuff as anybody else did. Then you wouldn't be your own person" (07/25/19). Here Lara referenced her earlier discussion of the role of imagining and creating in her personal life ("if you're working as a team, you guys don't want to do like the same project someone else did”), further emphasizing that imagining and creating were vital for being “your own person.”

Like imagining and creating, Lara also moved “storytelling” closer to the center of her science relational map at the end of the third cycle (Figure 2.3). Lara initially stated that storytelling did not play a role in science:

> It’s not really important because you can't really story-tell your claim and then do a solution for it. It's gonna be boring. If you have a problem that you need to fix, you can just tell it right there. You're not going to make a whole story about it. Unless you want to include background information which is gonna be way bad. (03/16/19)

When proposing solutions to problems in science, Lara makes an argument for the importance of getting straight to the point (“just tell it right there”), rather than storytelling, which she refers to as “boring” and “bad.” This sentiment echoes her previous discussion on the value of taking action in science rather than engaging in imagining (i.e., “if you have a solution to a problem, you're not going to keep imagining it. You’re gonna want to make something, prove some point”).

After her experience creating and producing a play about climate change during Cycle 3, Lara articulates a shift in her thinking, stating,

> I'm moving storytelling because there's a lot of stuff on climate change—that’s one of the topics that we're doing—and people really need to know what's going on in this world and how this planet is not doing good and getting warmer by each day. (07/25/19)

Lara recognized storytelling as a means of communicating important scientific issues with an audience, similar to the process that she and her group members engaged in when creating a play about climate change. While Lara acknowledged a shift in her thinking about storytelling in science, it is important to note that she did not experience the enactment of this art-science thinking practice directly, given that she was not involved in creating the script for her group's play (07/25/19).

In a follow-up interview, Lara associated performing arts with storytelling and expressed low self-efficacy in this art-science thinking practice, stating, "I understand [performing arts] tells a story but how are you supposed to do that. I don't understand" (10/26/19). She further explained that storytelling through her group's play during Cycle 3 was an ineffective means of communication: "We were trying to get a point across to the whole world. Nah...If you're trying to get a point across to somebody—we need data—like, information—or you need an explanation of why you think this" (10/26/19). Here Lara highlighted the value of data, information, and explanations as more compelling means of communication compared to storytelling. This statement also implicitly acknowledges that the program design could have better supported Lara's group to research explanations and data to support their storyline on the effects of climate change, rather than relying primarily on their background knowledge and experience with climate-change-related phenomena.

While Lara's perspectives of imagining and creating in the context of science shifted at the end of the third cycle, her view of the role of collaborating did not shift. Different from her personal life map, Lara initially placed collaborating at the center of her science map and did not move this card in subsequent interviews. The tension Lara experienced with the role of collaborating in her personal life, however, was echoed during her initial discussion of this practice in the context of science. She stated,

> I put teamwork here?! That's going all the way out. [Lara begins to draw an arrow to move "teamwork" away from the center of the map]. It's not important anymore—

> [pause]—actually it is [important] because if you have a group and if you're working on a particular issue, especially global warming—that needs a lot of research—you can't do that all by yourself. You need a whole team to do that. So that's going to stay there, sadly. (03/16/19)

Lara initially acted surprised that she had placed teamwork (i.e., collaborating) in the center of her map ("I put teamwork here?!") and expressed that she wanted move it "all the way out." Given this reaction, it appeared that Lara's discomfort with collaborating in her personal life, which was largely affiliated with her school-oriented practices, influenced her perception of the role of this practice in science. Upon further reflection, Lara reconsidered her stance, explicitly recognizing the fundamental role of collaboration on researching important environmental justice issues like global warming. Still, Lara concludes with the sentiment that teamwork is "sadly" going to stay in the center, reflecting her continued tension with this practice.

Evolving Interest in and Identification with Performing Arts and Science

By engaging in art-science thinking practices and recognizing the value of these practices, we anticipated that these processes would support youths' interest in and identification with performing arts and science fields. However, Lara's case highlights a different story. While Lara's participation in Dramatic Science fostered her interest in and identification with coding, it simultaneously reaffirmed her disinterest in performing arts, leading her to pursue more coding-related programs in the future.

Throughout the duration of this study, Lara consistently communicated a preference for science and coding over performing arts. Regarding science, Lara reported a high interest in and identification with the discipline. She consistently ranked her interest in science as an 8 of out 10 (07/12/18, 07/24/18, and 10/26/19), explaining that science "could be fun" and was especially “interesting” when she learned new things (07/25/19 and 10/26/19). As far as her identification with science, Lara cited her hard-work ethic, high grades, and her peers’ tendency to seek her help for answers as validating factors that made her feel “good” about herself in science (07/12/18, 07/24/18, and 03/16/19).

Coding became a more prominent interest for Lara over the course of this study. Beginning in the first program iteration, Lara articulated that she wanted to do more coding in Dramatic Science, mainly due to her successful experience in an elective high-school-level coding class during 6th grade (07/24/18). Lara described coding as her “strength” because it was “easy to learn” (10/26/19). Once coding was incorporated into Dramatic Science during Cycle 3, Lara stated that her feelings toward science “changed but in a good way because we're finally doing something new. Not only science and performing arts—we're doing science, performing arts, and coding—and I like coding” (07/09/19). By the end of the study, Lara expressed an interest in pursuing a STEM career, specifically in becoming a computer scientist or a nurse (10/26/19), rather than running a business or becoming a translator, which she discussed previously (07/12/18 and 07/24/18). Specifically, she envisioned herself working as “part of a group doing coding and computer science to spread a message, especially about climate change” (10/26/19).

Lara consistently reported low interest in and identification with performing arts, which resulted in tensions in her participation in Dramatic Science over the course of this study. She rated her interest in performing arts as a 2 out of 10, explaining that performing arts was “boring” and something she had “never experienced” before (07/12/18, 07/24/18, and 03/16/19). After her experience with her group’s play project in Cycle 3, Lara initially expressed that her feelings toward performing arts were “better” because her group “included coding to make [the project] a little bit better and more creative rather than just doing a play" (07/25/19). In a follow-up interview, however, Lara reassessed her feelings toward performing arts, stating,

> The biggest challenge would be performing arts because—I wouldn't know how to perform or create the script or, I don't know, designing it. That's not really me. That was meant for some people but it wasn't meant for the whole group. (10/26/19)

Lara's low identification with performing arts related to her association of the discipline with creating and performing a script, as well as her low self-efficacy with these processes. As a result, she described the Dramatic Science program as "not really me."

Despite the tension that Lara experienced with performing arts, she determined that her participation in Dramatic Science allowed her to figure out her interests, specifically supporting her to pursue her passion in coding in the future. She explained,

> [I]f you don't like performing arts, that's one direction that you're not going to do. And if you like science, then you'll probably get to do more science. And if you like technology, then you'll most likely do technology in the future…[Dramatic Science] kind of shapes your direction. (10/26/19)

For Lara, participating in Dramatic Science allowed her to capitalize on her interest in coding, while simultaneously reaffirming her disinterest in performing arts processes. This experience encouraged Lara to pursue more coding-related opportunities within the larger College Bound program. Beginning in the fall of 2019, for example, Lara joined a program to create smart greenhouse systems, a project that incorporated science and technology. In this project, youth coded sensors (e.g., humidity, temperature) and LED lights for their greenhouses and collected and analyzed data generated by the sensors to support the growth of their plants (Asante et al., 2021).

Summary of the Case

Lara's role in group projects and her perspectives of art-science thinking practices shifted across the duration of this study, mainly due to her meaningful experience with her group's play project during the third iteration. Due to the incorporation of computing in the curriculum, Lara was able to build on her interest in coding and become her group's coding lead. This project marked Lara's first successful experience working on an open-ended project with multiple peers during her participation in Dramatic Science. She no longer referred to herself as "carrying the team" or playing a peripheral role as she had done in previous program iterations. Instead, she recognized that all of her group members, including herself, contributed to the success of the project. Because of this experience, Lara expressed a newfound appreciation for the art-science thinking practices of collaborating, imagining, and creating in her personal life. Lara previously expressed discomfort with these practices, which conflicted with her school-oriented practices (e.g., following directions, getting work done efficiently and independently). Similarly, Lara began to recognize the value of imagining and creating in science, which she previously deemed irrelevant to the discipline. Interestingly, Lara perceived the practices of collaborating, imagining, and creating to be entangled with one another, noting that collaboration among individuals fuels imagination and creativity.

Despite Lara's experience with her group's play project, her participation in Dramatic Science fostered her previous interests in and identification with certain disciplines, rather than inspiring new interests. In other words, Lara's participation in Dramatic Science strengthened her interest in and identification with computer science while reinforcing her low interest in and identification with performing arts. Lara nevertheless viewed her trajectory as meaningful given that participating in the program allowed her to explore multiple disciplines (e.g., coding, science, performing arts) and hone in on her interest in coding, resulting in her future enrollment in a computing-based program in College Bound.

The Case of Jayda

Introducing Jayda

Jayda is a Dominican American cisgender female growing up in a primarily Spanish-speaking household with her mother, father, and older brother. Jayda described herself as creative, curious, and confident. The art-science thinking practices of imagining and creating especially resonated with Jayda. She explained, "I just like making my own stuff. So, I feel like as a kid you could be imaginative and creative" (02/09/19). In particular, she enjoyed fashion design and drawing.

When describing how doing science related to her personal life, she explained that she often experimented by mixing nail polish with water to make different "swirled" designs (07/11/18 and 11/16/19). This utterance demonstrates that Jayda associated doing science with experimenting or tinkering with materials to unique patterns and designs, rather than habits valued in traditional school science settings (e.g., doing homework, memorizing facts, following directions). This broad and personally-relevant view of science was echoed in other interviews as well. For example, Jayda's first memory of doing science related to her personal life, specifically her hair, and took place at home. Around the age of nine she realized, "[E]very time I do my hair–when I wet it, it gets shorter because of the curls. They stretch up. And when you flatten it, it extends" (7/11/18). She explained that this experience made her "fascinated" with her hair and "how it work[ed]," prompting her to research the science behind it.

Jayda referred to science as her favorite school subject at the beginning of this study and consistently articulated a desire to become a medical doctor throughout this study (07/11/18 and

11/16/19). She expressed that she enjoyed learning about new things in science and explained that many people close to her were also interested in science (07/11/18). Her brother, for example, founded a science club at his high school. She also met most of her friends in science class partly due to their common interest in the subject.

In terms of how school influenced her view of and identification with science, Jayda highlighted the role her teacher played, who was both Jayda's and Lara's science teacher from 4th through 6th grade:

> Mr. Arnold is the one who made me focus more on science. He made me realize how science is more important to life than you really think it is...I used to get bad grades in science but not anymore. He made me realize that science is everything–that you can't run away from it. In science, there's math, science can help your life problems, and I guess get a good grade. (7/11/18)

Rather than valuing science solely as a means to an end, such as a grade or a school requirement, Mr. Arnold inspired Jayda to recognize science as an interdisciplinary domain and a way to address lived challenges.

Jayda's case demonstrates that she found space to engage in imaginative and creating thinking through personal expression in Dramatic Science. Over the course of her participation in the program, Jayda enacted art-science thinking practices that she valued in her personal life, including imagining and creating. On the one hand, Jayda's interest in imagining and creating was cultivated in Dramatic Science, which encouraged her engagement in self-expression and negotiation of a leadership role in group projects and the program as a whole. On the other hand, Jayda did not express more interest in or identification with performing arts or science over the duration of this study. Even so, this case provides insight into how art-science programs can support youth like Jayda by encouraging them to capitalize on their interest in practices that often go unrecognized in formal school settings (e.g., imagining, creating).

From Peripheral Participation to Becoming a Group Leader: Expressing herself by building on her interest in imagining and creating

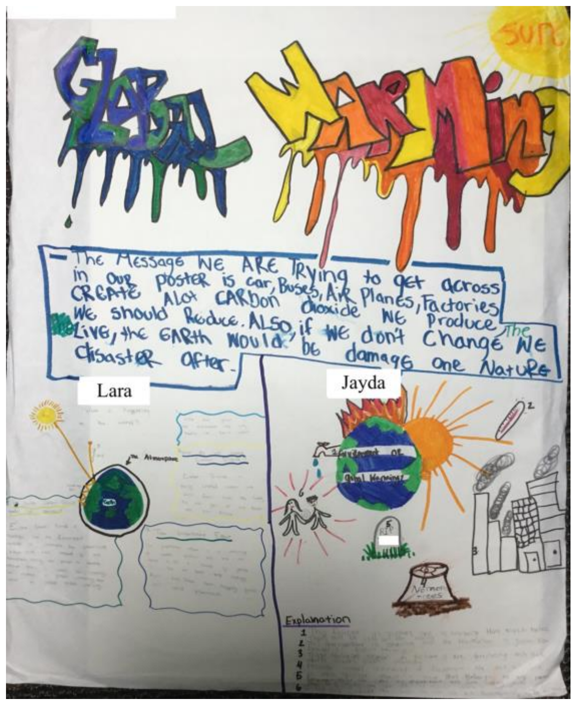
Jayda's main art-science thinking practices, imagining and creating, arose during the second and third program cycles when she was able to express herself in group projects. In both projects, Jayda took on a leadership role in her group.

Cycle 1: Peripheral participation in close-ended activities. The majority of the learning activities and the group project during the first program cycle were not engaging for Jayda, resulting in her peripheral participation in these activities. For example, during several close-ended science experiments that Lara reported enjoying (e.g., experiment on the effect of carbon dioxide on water temperature), Jayda was often observed talking with a friend or using her phone, which often frustrated her group member Lara (07/12/18, 07/17/18). On the other hand, there were occasional episodes in which Jayda exhibited curiosity with the learning activities. During an interactive model activity, for example, Jayda and another peer looked up predicted rising sea levels at their home addresses, rather than following the directions, and reacted to the results with surprise ("Damn!") (07/10/2018). Instead of staying on task and following directions regardless of her interest in the activity as Lara had done, Jayda was compelled to explore areas that piqued her interest.

Unfortunately, not many of the activities nor the group project that summer were interesting for Jayda. As mentioned previously, Lara and Jayda worked together to create a PSA poster on climate change. During this project, each youth created a representation of climate change phenomena. Lara researched and illustrated a model of the greenhouse effect, similar to many models found on the internet (Figure 2.4, left), and explained the amplification of the greenhouse effect due to human-induced rising levels of carbon dioxide. Meanwhile, Jayda made a representation of global warming by compiling a set of images to illustrate a message about the causes of global warming (e.g., pollution from factories, deforestation) (Figure 2.4, right).

Figure 2.4

Lara and Jayda's Public Service Announcement (PSA) on Global Warming (Summer 2018)



Although both participants contributed to the poster, this project was not particularly engaging for Jayda, given that she frequently talked with her friends and requested to take breaks during project work time. Because Jayda was absent for the end-of-cycle interview and showcase event, we are not able to draw on Jayda's reflection on her experience that summer. However, Lara reported that she, rather than Jayda, had completed the majority of work on the project and "carried her team" that summer (07/24/18), which corroborates field note data indicating that Jayda was not thoroughly engaged in the project. Additionally, in a follow-up interview, Jayda reflected on her past projects and specifically expressed her disinterest in creating the PSA poster that summer because “pull[ing] up “facts” was “boring” (07/23/19).

Cycle 2: Becoming a group leader by building on her interest in imagining and creating. During the second program cycle, Jayda began to demonstrate a shift in her role in her group’s project, a board game on issues of water quality and access. Jayda worked with three peers, including Lara, to conceptualize the goal and components of the board game and ultimately assumed a leadership role. At the end-of-cycle symposium event, for example, Jayda and her friend Rosalin (pseudonym) volunteered to explain the directions for their game and answered questions for an audience composed of middle-school peers, high schoolers, undergraduate mentors, instructors, and family members (Figure 2.5) (05/04/19).

Figure 2.5

Jayda and Rosalin Engage Audience Members in Playing Their Boardgame

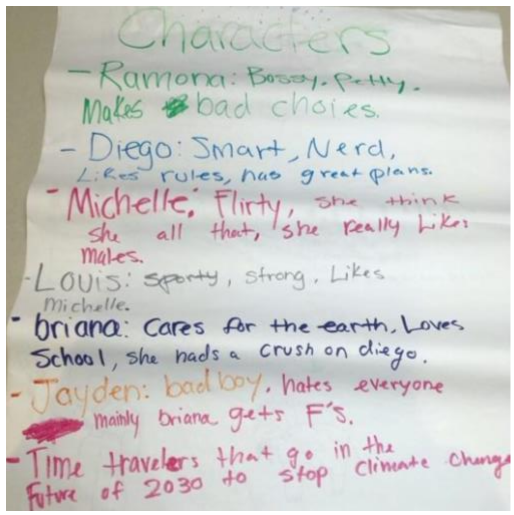
When reflecting on her project, Jayda described it as one of her two biggest successes that year. She explained, “When people were playing [our game], they were saying how it wasn’t fair [that] everybody didn’t get water…It’s like they understood [the message of the game] and were saying it was a good game” (07/10/19). Sharing their project with and receiving external recognition from an audience, in terms of the audience’s understanding of the game’s message as well as their appraisal of the game, resulted in a memorable experience for Jayda.

After her experience in Dramatic Science that year, Jayda expressed an appreciation for imagining and creating in science, practices that she reported to enact during her group's board game project. She explained that imagining and creating were important in science "[b]ecause when you're trying to make stuff in science, it's okay that you add, you know, like, your touch. It doesn't have to be plain" (07/10/19). In this statement, Jayda implicitly linked imagining and creating with self-expression (i.e., "add your touch"). Further, she explicitly noted the value of self-expression when describing the program: "It's [Dramatic Science], like, a way to express yourself. So, if you wanted to express yourself, you should probably do that. Because in performing arts you express yourself and, I guess, in science as well but, like, mostly in performing arts" (07/10/19). In this statement, Jayda grapples with whether or not self-expression is permissible in science and, in the end, associates this practice more with performing arts.

Cycle 3: Becoming a group and program leader by building on her interest in imagining and creating. Jayda's shifting role and participation in her group project were most prominent during the third program iteration, largely due to the cultivation of her interest in imagining and creating through performing arts and fashion design. As described previously, Jayda worked with Lara and three peers on this project to create, produce, and direct a play about the local effects of climate change. Jayda took on a leadership role in this project, particularly when conceptualizing and developing the characters and the script for the play as well as designing and constructing the costumes for the characters. For example, Jayda conceptualized the plot line for their play: a group of teenagers time travel to 2030 and witness the effects of climate change on their city before traveling back to present day with a warning about what lies ahead if nothing is done (07/11/19). After group members readily agreed with her idea, Jayda and her group discussed the number of characters for their story, eventually reaching a consensus to include five or six characters. When developing the characters, Jayda elicited and wrote down ideas from her group members for each of the characters' names and attributes (Figure 2.6).

Figure 2.6

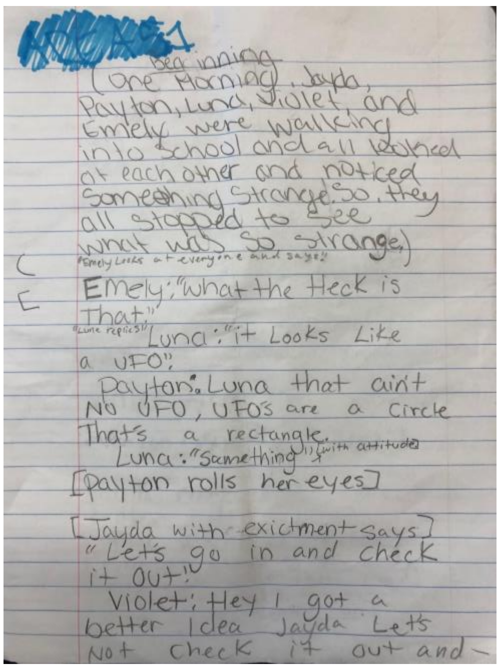
Initial Conceptualization of the Characters and Plot for Youths' Play



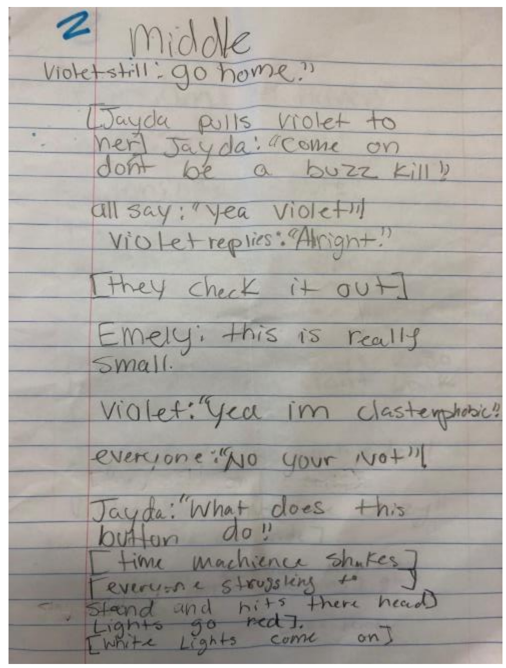
In addition to leading her group's conceptualization of the plotline and characters, Jayda assumed a leadership role when writing the script for their play and designing and creating the costumes for the characters, both of which she worked on outside of program sessions (07/17/19, 07/18/19). When creating the script for their play, Jayda and her group members reported communicating with each other via text outside of program sessions to support Jayda's writing of the script (Figure 2.7) (07/18/19). Additionally, Jayda sketched two sets of costumes for each of the characters, which would be worn at different times during the play (07/17/19) (Figure 2.8). She shared these sketches with her group members—including the coding group members, Lara and another peer—and coordinated with her instructors to request and obtain materials for the construction of the costumes (i.e., t-shirts, ribbons, sewing materials). Building on her prior experience with sewing, Jayda played a central role in all aspects of the costume construction process and communicated with the coding group regarding the LED light accessories for the costumes (07/24/19, 07/25/19). Due to youths' interest in costume construction and coding (Figures 2.8 and 2.9), they focused their efforts on these activities for the remaining program sessions, rather than further developing their initial script.

Figure 2.7

An Excerpt from Youths' Script



Beginning
[One Morning, Jayda, Payton, Luna, Violet, and Emely were walking into school and all looked at each other and noticed something strange so, they all stopped to see what was so strange.)
(Emely looks at everyone and says)
Emely: "what the Heck is That"
("Luna replies") Luna: "it Looks Like a UFO".
Payton: Luna that ain't No UFO, UFO's are a Circle That's a rectangle.
Luna: "Something" (with attitude)
[Payton rolls her eyes]
[Jayda with exictment says]
"Let's go in and check it out!"
Violet: Hey I got a better Idea Jayda Let's Not check it out and -



2 Middle
Violet still: go home."
[Jayda pulls Violet to her] Jayda: "come on don't be a buzz kill!"
all say: "Yea Violet!!"
Violet replies: "Alright."
[They check it out]
Emely: this is really small.
Violet: "Yea im clastephobic!"
everyone: "No your Not"!
Jayda: "What does this button do!"
[time machience shakes]
[everyone struggling to stand and hits there head]
Lights go red].
[White Lights come on]

Figure 2.8

Costume Design Artifacts Generated by Jayda

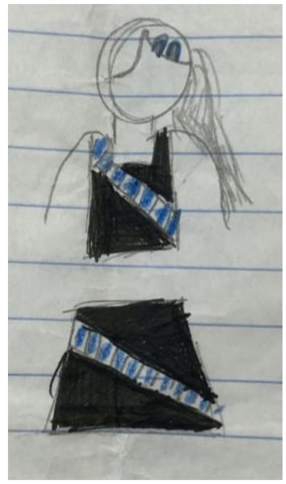


Figure 2.9

Youth Engaging in Python Programming to Code LED Lights for Costumes

Jayda's investment in her group's play project was readily apparent. Jayda was the only group member to work on her project outside of program sessions, an action that she had not demonstrated in previous projects. She also demonstrated an eagerness to work on costume construction on several occasions. For example, during a session in which participants shared and critiqued their peers' project drafts, Jayda seemed frustrated that this process was time-consuming, eventually asking one of her teachers if she and her group could start working on their projects (07/18/19). In another session, Jayda and her group members asked their instructors if they could work on their projects instead of participating in the check-in circle

(07/24/19). Compared to the previous two projects, the play project created a range of opportunities for youth to engage in imagining and creating, allowing Jayda to flourish.

Jayda's success with and leadership role in her group's project was recognized by both herself and her instructors that summer. When reflecting on her experience, Jayda was most proud of sharing her group's play at the symposium event (11/16/19). Similar to her reflection on her group's success with their board game in the previous program iteration, Jayda recognized that her group's hard work resulted in a meaningful experience, sharing their play and its message—which was enacted by program instructors and narrated by youth—with the larger College Bound audience. When asked about her role in her group's project that summer, Jayda stated, "[My role was] leadership, I guess. I was doing the most work...I don't know [why]. I can't really explain it" (07/23/19). Jayda recognized that she was the main contributor to her group's project, yet she was hesitant to articulate why she had come to this role.

Jayda's initiative and leadership in her group's project did not go unnoticed by her teachers that summer. At the symposium event, Jayda's teachers presented her with the "Butterfly" award to recognize her metaphorical metamorphosis into a program leader (07/25/19). Additionally, Jayda was one of two participants nominated by her instructors to serve on the program's Youth Advisory Board for the following school year (07/25/19). When reflecting on their perceptions of students' experiences in Dramatic Science, two Dramatic Science instructors independently remarked that Jayda was a student who most benefitted from participating in the program. Both instructors expressed that they noticed an evolution in Jayda's engagement in her group's projects and in the program as a whole (10/15/2020 & 11/11/2020). For example, one instructor stated:

> When Jayda started, she was a little shy. She didn't really want to talk. She didn't really want to be seen. But over time, as she was advocating for what she wanted to do, I think she found her voice. Then, in getting more comfortable with that, she was also able to express herself more artistically. And in the culminating project that summer…she was excited to be the fashion designer. So that was really great to see. (10/15/2020)

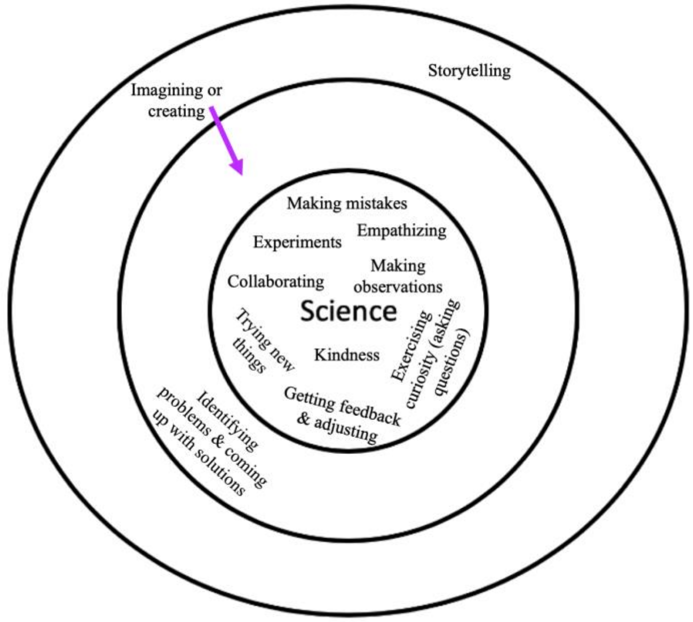
Over the course of this study, Jayda's instructors witnessed her transition from a "shy" and peripheral participant to a vocal and confident leader, who was excited to express herself artistically (10/15/2020 & 11/11/2020). While this shift likely relates to a variety of factors—such as Jayda's increasing comfort level with her peers and instructors and her growth outside of Dramatic Science—the program's cultivation of Jayda's interest in imagining and creating, and fashion design, in particular, played a prominent role in supporting Jayda's transformation.

Jayda's Shifting Perspectives on Art-Science Thinking Practices

Although the play project (Cycle 3, Summer 2019) allowed more opportunities for Jayda to build on her interest in imagining and creating compared to her group's board game project (Cycle 2, 2018-2019 School Year), she nevertheless expressed a shift in her perspective on the role of these art-science thinking practices in the context of science after the second program iteration (Figure 2.10). (No shifts were articulated in Jayda's perspectives of art-science thinking practices in the contexts of her personal life or performing arts.) Dissimilar from Lara, imagining and creating played a central role in Jayda's personal life. Jayda reported that she enjoyed "making" her own "stuff," including designs with nail polish and water, drawing, and fashion (02/09/19, 05/04/19). Only later, however, did Jayda come to recognize the value of these practices in science (02/09/19).

Figure 2.10

Shifts in Jayda's Views of Imagining and Creating in Science



Shifts in Jayda's Views of Art-Science Thinking Practices in Science: A newfound appreciation for imagining and creating. Although Jayda foregrounded the importance of imagining and creating in her personal life, she initially rejected the idea that these practices were valuable in science, stating: "[Y]ou don't imagine in science, you *do* in science" (02/09/19). Jayda implied that science is a discipline that relies on concrete practices ("doing"), rather than abstract practices like imagining. After participating in Cycle 2, however, Jayda articulated a shift in her thinking. She explained that imagining and creating were important in science "[b]ecause when you're trying to make stuff in science, it's okay that you add, you know, like, your touch. It doesn't have to be plain" (07/10/19). In this statement, Jayda implicitly linked imagining and creating with self-expression (i.e., "add your touch"). Further, she explicitly noted the value of self-expression when describing the program: "It's [Dramatic Science], like, a way to express yourself. So, if you wanted to express yourself, you should probably do that. Because in theater you express yourself and, I guess, in science as well but, like, mostly in theater" (07/10/19). In this statement, Jayda grapples with whether or not self-expression is permissible in science and, in the end, associates this practice more with theater. Yet, Jayda was able to create space to express herself by adding her own "touch" to group projects in Dramatic Science, including a board game (Cycle 2) and a play (Cycle 3). When reflecting on these projects, Jayda explained that she and her group members engaged in imagining and creating when creating their board game (Cycle 2) and when imagining the story for the play (Cycle 3). Interestingly, Jayda did not refer to the costume design and construction process—the part of her project in which she was most invested—when referring to the practices of imagining and creating.

While Jayda did not explicitly associate imagining and creating with collaborating, she implicitly linked these practices (07/10/19 & 07/23/19). She explained that collaborating was vital for her group's project, stating:

> [Y]ou could do [the project] by yourself, but I feel like it wouldn't be as good as it would be if we did it with a team…because it wasn't just my idea. It was a lot of other people's ideas. (07/10/19)

Similar to Lara, Jayda implied that collaborating, imagining, and creating were entangled, (i.e., teamwork results in more ideas and better projects). Unlike Lara, Jayda did not articulate a shift in her thinking regarding the practice of collaborating, given that she initially positioned this practice as central to science (Figure 2.10), performing arts, and her personal life.

Evolving Interest in and Identification with Performing Arts and Science

While Jayda's participation in Dramatic Science supported her enactment of imagining and creating, this experience did not foster her interest in and identification with performing arts or science. During the first and second program iterations, Jayda articulated low interest and identification with theater. She explained, "[Theater] just doesn't equal my personality" (07/11/18), plays are "cheesy" and "boring," and "Shakespeare's not really my thing"

(07/10/19). In these statements, Jayda mainly associated theater with staged plays, an impression echoed by many other youth participants in Dramatic Science, particularly during the first and second program iterations. After her experience creating a play in Cycle 3, however, Jayda expressed a slight shift in her feelings toward performing arts due to her experience with costume design and construction. She explained, “I'm just interested in the costume part. Storytelling is way too much. Cuz you have to write a script. Then you’ve got to get feedback. And then you might have to adjust it. And it's a lot” (07/23/19). Despite her positive experience with costume design—and her broader perspective of performing arts that included behind-the-scenes activities (e.g., costumes, scriptwriting), rather than solely on-stage activities—Jayda articulated a tense relationship with performing arts during a follow-up interview. She explained, “In front of people, I can’t do it. I get too scared. I could do it without people looking at me. Off-the-stage stuff” (11/16/19). Rather than foregrounding the behind-the-scenes work, which most resonated with her interests (e.g., fashion design), Jayda reverted to primarily associating performing arts with on-stage theater performances and expressed vulnerability with this aspect.

Regarding science, Jayda’s utterances suggested that participating in Dramatic Science was not expansive for her interest in and identification with science. Despite her initial high interest in and personally-relevant conceptualization of science (07/11/18), Jayda consistently described herself as “not good” in science throughout the duration of this study (07/11/18 and 07/10/19). Rather than articulating identification with science in terms of her interests or enacted practices, Jayda associated being “good” in science with intelligence (i.e., you have to be “very smart,” 07/11/18) and getting the “best” grades (“I have a B plus in science. It’s okay, but it’s not the best,” 07/10/19). Over the course of her participation in Dramatic Science, Jayda slowly disaffiliated with science (12/08/18, 07/10/19, 07/23/19). While she enjoyed learning new things in science, she also explained that science could be boring and specifically associated it with doing “paperwork” and watching videos (07/23/19). Further, she added that she did not “get” coding (07/23/19). Jayda’s participation in science education settings, including Dramatic Science, played a role in her of view science as “boring” and coding as something she did not “get.” Informed by these experiences, Jayda narrated tension with science, as further evidenced when she grappled with whether or not she could add her “touch” in science (07/10/19).

Although her interest in and identification with performing arts and science was not fostered throughout her participation in this study, Jayda consistently described Dramatic Science as a program that encouraged self-expression and creativity, practices that were also important in her personal life. After the second and third program cycles, Jayda explained that Dramatic Science was a way to “express yourself” (07/10/19) and “be yourself and no one will judge you” (07/23/19). In a follow-up interview, she explained that Dramatic Science is “a really good way to be creative, especially if you’re a person that likes art. It just mixes different things like science, performing arts, and visual arts. I think it’d be a good program for somebody who likes arts” (11/16/19). In this statement, Jayda foregrounded the role of the arts in Dramatic Science, rather than science, and implicitly attributed creativity with the combination of multiple disciplines (i.e., science, performing arts, and visual arts). Further, she explained that her participation in the program fostered her creativity, stating:

> I feel like it changed my view of what I can do. Instead of being comfortable with things I already know I feel like I can expand my mind more…like art, like creative stuff. It helped me find my creative side. (11/16/19)

Although imagining and creating had always been important practices in Jayda's personal life (07/11/18, 02/09/19), Jayda described the program as helping her "find" her "creative side" and supporting her self-efficacy in trying things outside of her comfort zone.

Summary of the Case

Due to her experiences building on her interest in imagining and creating in the second and third program iterations, Jayda's role in her group projects and her perspective of the art-science thinking practices of imagining and creating shifted across the duration of this study. The play project during Cycle 3 (Summer 2019), in particular, created multiple pathways for Jayda to cultivate these practices through character development, script writing, and costume design and construction. As a result, Jayda thrived in this setting, resulting in her peers' and her instructors' recognition of Jayda as a project and program leader. In part due to her experiences enacting the practices of imagining and creating in the context of her group projects during the second and third program cycles, Jayda expressed a new perspective on the role of imagining and creating in science, coming to recognize that it's "okay that you add…your touch" in science (07/10/19). Furthermore, she explained that her participation in the program allowed her to "find" her "creative side" (02/08/2020). Even with these experiences, Jayda did not express a stronger interest in and identification with performing arts or science over the course of her participation in Dramatic Science.

Discussion

Reflecting the nature of the larger DBR study from which this inquiry stems, this discussion documents my reflective analysis of this project. In what follows, I examine how the design features of the program related to youths' engagement in art-science thinking practices and their shifting roles in group projects for each program cycle (RQ 1). Next, I discuss how youths' perspectives of art-science thinking practices shifted over the course of this study (RQ 2).

Relationships Between the Program Design and Youths' Engagement in Art-Science Thinking Practices

A Concept-Oriented Approach to STEAM Education: Youths' Projects and Project-Development Processes Maintain Disciplinary Boundaries

The level of discipline integration in the program sessions—and the relationships amongst the component disciplines—played a large role in which art-science thinking practices youth enacted during each program cycle and how. Our project team subconsciously utilized a concept-based approach to STEAM education during the first two program cycles (Summer 2018 and 2018-2019 School Year). During these iterations, youth engaged in science to investigate underlying concepts around local environmental justice issues, which served as content for youths' projects. Meanwhile, youth engaged in theater as a means to synthesize and communicate their understandings of scientific concepts. During each program cycle, youth investigated and made sense of scientific concepts around local environmental justice issues, including climate change (Summer 2018) and water quality and distribution (2018-2019 School Year). This concept-oriented approach manifested as a series of disciplinary-based activities, rather than an integrated STEAM experience. As such, youths' projects largely remained disciplinary.

Cycle 1 Project: A PSA Poster that Foregrounded Science Concepts. Lara and Jayda's Cycle 1 project foregrounded science concepts while excluding performing arts, which reflected the prioritization of students' understanding of science concepts in the program. More specifically, they made a PSA poster about climate change by researching and documenting concepts on their poster along with drawings to illustrate these concepts. Unsurprisingly, this project did not provide opportunities for youth to engage in art-science thinking practices in robust ways. For example, collaborating was not fostered given that the PSA project could have been completed individually, prompting Lara to "carry the team" that summer. Meanwhile, the PSA poster provided limited room for imagining and creating—leading to Jayda's peripheral participation in the project.

This project highlights two design shortcomings at odds with design features central to STEAM education projects, namely the open-endedness of the question posed and the necessity of multiple disciplinary practices and perspectives to address the question (Bush et al., 2020; Cook et al., 2020; Kang, 2019; Quigley et al., 2020). First, this project did not engage youth in addressing an open-ended question or challenge through many possible paths. A sufficiently open-ended STEAM project—in which there is no one right answer or solution—maintains space for youth to make meaningful choices while collaborating with their peers throughout the learning process (Quigley et al., 2019). Lara and Jayda's PSA poster, however, had a clearly-defined outcome (i.e., a poster with facts) and did not necessitate collaboration.

Second, the PSA poster did not require youth to engage in multiple disciplinary practices and perspectives. In this project, scientific concepts were foregrounded while performing arts was omitted. The exclusion of performing arts from this project reflects a common challenge encountered by science and mathematics educators in STEAM education, namely how to meaningfully integrate the arts with STEM subjects (Bequette & Bequette, 2012; Kafai et al., 2014; Liao, 2016; Mejias et al., 2021; Quigley et al., 2020). During our first program iteration, our program enactment fell into this pitfall by utilizing a concept-based approach to STEAM education, specifically foregrounding students' understanding of scientific concepts over performing arts. As a result, Lara and Jayda were able to create a project that reflected this unequal dynamic. Art played a decorative role in their project, requiring youth to engage with art by drawing science concepts (Bevan et al., 2019; Cook et al., 2020). Although science was featured more centrally in this project, the project format did not require youth to deeply engage in scientific practices (Cherbow, McKinley, McNeill, & Lowenhaupt, 2020), given that the youth were able to complete the project by reporting and illustrating scientific facts and concepts. Comparable projects are prevalent in traditional science classrooms where there is an emphasis on memorization of canonical facts (Varelas, Martin, & Kane, 2013).

Cycle 2 Project: A Boardgame That Foregrounded Performing Arts. During the second cycle, our project team continued to subconsciously utilize a concept-oriented approach to STEAM education. Different from the first cycle, however, we began implementing a broader approach to arts integration during this cycle. This design shift better supported youth to incorporate performing arts into their projects, unlike the previous program iteration.

For their Cycle 2 project, Lara and Jayda created a boardgame about water quality and distribution. Largely due to the inclusion of performing arts in this project, Jayda was able to build on her interest in imagining and creating. Jayda, for example, collaboratively created cards for players to draw as they landed on certain spaces on the boardgame path. When played, this boardgame illustrated a narrative about water quality and access and the roles of various stakeholders in this narrative. For example, corporations like Nestlé were depicted as essentially stealing water from residents through the privatization of water (Cummins, 2018). While a project that emphasized performing arts resonated with Jayda's creative side, these design aspects conflicted with Lara's "good student" identity practices (Archer et al., 2017; Carlone et al., 2014; Varelas et al., 2011)—such as, getting the right answers, closely following directions, finishing work quickly, and asking the teacher questions to understand the topic—which historically supported her self-efficacy in science class in school. This tension nudged Lara to play a peripheral role in the project (i.e., making the dice) and report a lack of success.

Different from the last program iteration, the program design better supported youth to incorporate performing arts and science in their project. However, this time performing arts, rather than science, played a dominant role through the emphasis on narrative development and role-playing (Halverson & Sheridan, 2014). In fact, when reflecting on their group's project, neither Lara nor Jayda strongly associated their board game with science. For example, Lara reported that the topic was about science while Jayda reported that the project was "not really" related to science because it did not include facts. Although science played a minimal role in this project, Jayda nevertheless began to make connections between science and performing arts after participating in this project. By building on her interest in imagining and creating—mainly through performing arts practices (e.g., narrative development)—Jayda came to recognize that it was "okay that you add…your touch" in science.

A Practice-Oriented Approach to STEAM Education: Projects Reflect Disciplinary Integration but Youths' Project-Development Processes Maintained Disciplinary Boundaries

During the third program cycle, our project team shifted away from a concept-oriented approach to a practice-oriented approach to STEAM education. During this iteration, we prioritized engaging youth in developing artifacts for their STEAM projects. This shift supported us to foreground youths' engagement in STEAM practices, rather than youths' understanding of disciplinary concepts (Bevan et al., 2019). Through this approach, STEAM disciplines were partnered as a vehicle to create projects that highlighted youths' messages about local social and environmental justice issues. While youths' final projects integrated multiple disciplines, Lara's and Jayda's processes for developing their project artifacts remained disciplinary.

Cycle 3 Project: A Play That Foregrounded Performing Arts and Computing. The programmatic design shifts in the third program cycle created compelling opportunities for Lara and Jayda to engage in art-science thinking practices when developing their play project. More specifically, Lara was able to collaborate with her peers by building on her interest in computing while Jayda was able to enact imaginative and creative thinking practices by mainly building on her interest in fashion design. Several program design elements were central to supporting youths' engagement in these practices for their project, including (1) a project-based learning unit that foregrounded youths' development of artifacts for their STEAM projects; and (2) the encouragement of personal expression through artifact development.

For this iteration, the teachers collaboratively planned and taught a project-based learning unit, with the following question guiding youths' projects: *What would you like your community to be like in 10 years?* With this question in mind, groups of youth brainstormed and developed projects that highlighted messages about local social and environmental justice issues (e.g., housing rights, food rights). This process was ongoing throughout the three-week summer program. Youth began by brainstorming their initial project ideas during the first week of the program followed by creating and refining artifacts for their projects during the second and third weeks of the program. Throughout this process, developing artifacts for youths' projects served to drive learning in program sessions.

Open-ended STEAM projects, such as this one, necessitate that youth collaborate with their peers through multiple disciplinary practices and perspectives to generate a project (Keane & Keane, 2016; Quigley et al., 2017, 2020). These design aspects—particularly the inclusion of computing—supported Lara to collaborate with her peers by becoming her group's coding lead. Rather than "carrying the team" as she had done during the PSA poster project (Cycle 1) or minimally participating as she had done during the boardgame project (Cycle 2), Lara collaborated with her peers in pursuit of a common goal. When reflecting on her group's project that cycle, Lara attributed part of her group's success to members' specialized roles in coding, script-writing, and costume design. Based on this experience, Lara recognized that the incorporation of multiple disciplines in her group's project fostered creativity ("[W]e were a lot more creative this year. And we actually included science, theater, and coding").

Jayda's case highlights the importance of cultivating imagining and creating through personal expression in art-science learning spaces (Bequette & Bequette, 2012; Bush et al., 2020; Carsten Conner et al., 2017). Jayda had extensive opportunities to deeply enact imagining and creating during her Cycle 3 project, specifically through character development, scriptwriting, and fashion design and construction. Because Jayda was able to express herself by developing a personally meaningful project, her sense of ownership in her project was enriched (Kafai et al., 2014), supporting her to become a project and program leader. Jayda's interest in imagining and creating—and fashion design, in particular—would likely go unnoticed in most science classrooms, where there is often little room for imaginative and creative thinking (Hadzigeorgiou, 2016; Kafai et al., 2014). Integrating the arts with science may support youth like Jayda, who might otherwise slowly "opt-out" of STEM learning contexts, in coming to understand that adding one's "touch" in science can be permissible and even celebrated (Shanahan & Nieswandt, 2009).

Although their play project integrated multiple disciplines at the level of the final project, it is important to reiterate that the art-science thinking practices youth engaged in to create artifacts for their project remained disciplinary. Lara collaborated with her group members by coding the LED lights for the costumes. Meanwhile, Jayda engaged in imaginative and creating thinking practices primarily through performing arts, specifically fashion design (i.e., costume design and construction) and theater (e.g., character development, scriptwriting). Similar to the last cycle, the youth reported that their project included minimal science. Although the play was related to a science topic (i.e., climate change), it did not necessitate youth to deeply engage in scientific practices to create their project. In future iterations, we would engage youth in researching the phenomenon of interest (e.g., local climate change) in addition to relying on their prior knowledge and experience when developing their script. We would also scaffold the script-writing process to encourage youth to formulate a robust dialogue around local climate change in their narrative (Reiser & Tabak, 2014). These strategies would have better facilitated youths' engagement in scientific and performing arts practices simultaneously.

Cultivating Appreciation for Imagining, Creating, and Collaborating in STEAM Education Settings

Regarding youths' views of arts-science thinking practices (RQ 2), case study youth were able to cultivate new perspectives of imagining, creating, and collaborating over the course of this study. In the context of science, both Lara and Jayda cultivated new appreciations for imagining and creating. In the context of her personal life, Lara articulated new appreciations for imagining, creating, and collaborating—practices that she viewed as entangled. (Jayda's experiences in Dramatic Science reinforced her views of these practices in her personal life, which she deemed central.) By engaging in STEAM education projects that relied on imagining, creating, and collaborating, youth developed new perspectives on these practices.

Jayda was able to build on her interest in imagining and creating by engaging in endeavors that fostered personal expression, such as costume design, script-writing, and creating a boardgame. Encouraging imaginative and creative thinking and explicitly recognizing these practices as valuable in STEM fields may support youth, like Jayda, whose creative identity might otherwise go unnoticed in traditional STEM learning spaces (Calabrese Barton et al., 2013). Because she was able to leverage and capitalize on her creative identity, Jayda was able to recognize the value of imagining and creating in science as well as position herself as a leader in the Dramatic Science program.

For Lara, the emergent practice of collaborating—specifically by building on her interest in coding—was pivotal to her development of new perspectives of imagining, creating, and collaborating, which she viewed as entangled. Lara did not initially view these practices as important in her life, unlike Jayda. Lara's self-reported disinterest in these practices, coupled with her utterances and enacted practices during the program sessions, relates to her demonstration of practices of a “good student” identity, which are typically encouraged and praised in schooling (Archer et al., 2017). Lara, for example, expressed an interest in maintaining straight A’s, working hard and efficiently regardless of her interest in the task, and completing close-ended procedural tasks. These utterances and practices are likely crucial to Lara’s development of self-efficacy in science (Aschbacher, Li, & Roth, 2010).

Given that students are often required to complete close-ended procedural tasks in science classrooms as efficiently as possible (Calabrese Barton et al., 2013), it is not surprising that youth like Lara find comfort and success with these types of tasks, which can often be done independently. Science and engineering processes in the field, however, are open-ended, messy, and collaborative (Ødegaard, 2003). Because of the nature of these endeavors, student engagement in open-ended STEAM projects can support youth like Lara in building self-efficacy with more ambiguous endeavors, which are prevalent in science fields and life in general, as well as in recognizing the value of collaboration. Lara experienced success and enjoyment with an open-ended project for the first time during her participation in Dramatic Science when her group was able to leverage computing and performing arts to create a play about climate change.

Importantly, both Lara and Jayda were able to leverage their knowledge and resources in the context of Dramatic Science. Lara was able to build on her interest in coding and create a niche for herself as an expert coder when creating technology-enhanced costumes for her group's play (Cycle 3). Meanwhile, Jayda was able to embrace her creative identity in the design and development of her group's projects, including a board game (Cycle 2) and a play (Cycle 3). Previous scholarship demonstrates that youth are more likely to develop meaningful relationships with science when their practices and resources are valued in the learning environment (Calabrese Barton et al., 2013). Education spaces that leverage arts and science fields provide more opportunities for youth to embrace their practices and identities while simultaneously positioning themselves as meaningful contributors and doers of art and science.

Conclusions and Implications

This study traced case study youths' enactment of art-science thinking practices, roles in group projects, and reflections on art-science thinking practices over three program iterations. Lara's and Jayda's cases illustrate that designing STEAM education programs that deeply integrate multiple disciplines—and engage youth in hybrid practices that transcend disciplines—is a complex and onerous task. Our project team directly felt the gravity of this challenge as we grappled with tensions among program design, enactment, and youths' interactions during program sessions.

Based on findings from this study, I discuss three implications. First, I argue that a practice-oriented approach to STEAM education is necessary but not sufficient to support youths' engagement in hybrid practices that transcend disciplines. To better support this goal, leveraging a practice-oriented lens in conjunction with an inter- or trans-disciplinary approach to STEAM education may have more potential to support youth in making connections across disciplines. Second, youths' engagement in an art-science education program created opportunities for youth to build on a wider range of interests compared to disciplinary-based learning settings. Even though youth participants' practices remained disciplinary, youth could pursue multiple project pathways based on their (albeit disciplinary) interests. Third, creating opportunities for middle-school-aged to engage in STEAM education in ways that allow them to build on their artistic interests while also preserving their social standing is especially important. STEAM educators and program designers can learn from student participants to understand which artistic disciplines resonate with them (e.g., visual arts, music, dance) and how these approaches might be implemented in ways that allow youth to preserve their social standing.

With these conclusions and implications in mind, it is important to recognize the limitations of this study, particularly the limited number of students participating in this study. As with any qualitative study, no two students' experiences in Dramatic Science were the same. Furthermore, it is important to note that no two student groups engaged in the same processes due to the open-ended nature of the projects, particularly during the third program cycle, specifically the embedded choices in the project format (e.g., animation, cartoon) and artifacts to create for their projects (e.g., 3-D printed model, LED light accessories, script). Had other student participants been involved in this research, it is possible that a different set of findings would have been generated. Although the nuances of these findings are specific to the youth participants, I believe that the findings and overarching implications echo many of these experiences of students in the larger program. (Please see Paper 1 for details on how this paper's findings applied to the evolution of the program.)

Toward Practice-Based, Inter- or Trans-disciplinary Approaches to STEAM Education

Our program utilized a concept-based approach to STEAM education during the first and second cycles, which resulted in the youths' creation of disciplinary-based projects, rather than projects that deeply integrated multiple STEAM disciplines. During the third program cycle, we shifted to focus on youths' development of artifacts for their STEAM projects (practice-oriented lens), rather than their understanding of science concepts (concept-oriented lens). As a result, youths' Cycle 3 project incorporated multiple disciplines, namely computing and performing arts (e.g., fashion design, theater). As described in the DBR study (Paper 1), the teachers viewed this practice-oriented approach to better support disciplinary integration. However, upon analyzing data on Lara's and Jayda's development of their play project as a part of this inquiry, it was clear that the processes that youth engaged in to create their project artifacts remained disciplinary. In other words, Lara was able to specialize in computing while Jayda was able to specialize in fashion design when creating their project.

Based on these findings, I argue that a practice-oriented approach to STEAM education is necessary but not sufficient to support youths' engagement in hybrid practices that transcend disciplines. To better support this goal, leveraging a practice-oriented lens in conjunction with an inter- or trans-disciplinary approach to STEAM education may have more potential to support youth in making connections across disciplines (Bevan et al., 2019; Finch et al., 2021; Mejias et al., 2021; Takeuchi et al., 2020; Quigley et al., 2016). Compared to multidisciplinary learning settings, inter- and trans-disciplinary approaches could have more potential to support youth to reimagine what it means to do science and do art (Finch et al., 2020; Liao, 2016). The youth in this study were able to distinguish their learning along disciplinary lines because the artifacts they created for their projects—and the processes that they engaged in to create these artifacts—remained disciplinary.

Another unintended consequence of maintaining disciplinary boundaries was that youths' interest and identity construction was reinforced along disciplinary lines rather than transformed. Lara, for example, became more interested in computer science as she primarily engaged in coding activities while avoiding artistic practices (e.g., scriptwriting, costume design) during Cycle 3. Meanwhile, Jayda became more interested in creative endeavors—which she continued to associate more with artistic disciplines (e.g., theater, fashion design)—while she avoided technology-based activities such as coding. Coupled with the separation of disciplines, the promotion of student choice in the projects was a design weakness in some ways, given that it reaffirmed youths' previous interests rather than sparking new interests. In other words, the youth participants were able to pursue disciplinary paths with which they were comfortable. Embedding artistic and scientific learning activities through inter- or trans-disciplinary approaches addresses this challenge by requiring youth the engage in multiple disciplines simultaneously (Mejia et al., 2021; Finch et al., 2021). Kafai and colleagues (2014), for example, leveraged this approach during an e-textile project in which youth concurrently simultaneously engaged in crafting and coding through the use of LilyPad Arduino kits. When youth engage in artistic and scientific disciplines simultaneously, then they will be more likely to expand their interest and identity construction in both disciplines (Finch et al., 2020, 2021).

Supporting Youths' Diverse Interests and Practices Through STEAM Education

Even though disciplinary boundaries were maintained, our program's approach to STEAM education nevertheless expanded possibilities for youth to build on a wider range of interests compared to disciplinary-based learning settings (Bush et al., 2020; Carsten Conner et al., 2017; Finch et al., 2020; Quigley et al., 2017). The inclusion of the performing arts, in particular, opened up opportunities for a broader range of ways of thinking, knowing, and doing to be valued than STEM-based projects alone (Quigley et al., 2019). For Jayda, the integration of performing arts, particularly fashion design, supported her to assume a leadership role during Cycles 2 and 3. Jayda became a group and program leader because she was able to build on her interest in imagining and creating during her group's board game project (Cycle 2) and play project (Cycle 3). Similarly, the integration of coding, supported Lara to successfully collaborate with her peers on their play project (Cycle 3). Building on her prior interest in coding, Lara was able to negotiate a role for herself as her team's coding lead and successfully collaborate with her group members to create and produce their play.

Given that multidisciplinary education is more attainable for in-school settings due to the maintenance of disciplinary boundaries (Quigley & Herro, 2016), we find it hopeful that even less-integrated approaches to STEAM education can support youth to build on a wider range of interests compared to discipline-specific and STEM-based learning settings. The incorporation of the arts, in particular, has the potential to support participants in reimagining which practices are valued in science (Finch et al., 2020). In art-science education settings, youth like Jayda who embrace artistic practices are more likely to negotiate central roles in the learning setting and receive external recognition from their peers and teachers (Calabrese Barton et al., 2013).

Integrating Artistic Disciplines that Resonate with Youths' Interests and Needs

Even though incorporating performing arts widened the range of valued disciplinary practices and perspectives in Dramatic Science, it is important to note that both Lara and Jayda experienced tensions with the performative aspects of this discipline. Lara, for example, avoided artistic processes while embracing STEM-related practices like coding. According to Lara, performing arts was her biggest challenge in Dramatic Science because performing and creating a script were "not really me." Even though Jayda gravitated towards performing arts activities, she remained comfortable only with the behind-the-scenes aspects (e.g., fashion design) rather than those that were performative (e.g., acting). Similar to Lara, Jayda continued to express low self-efficacy with performing arts ("In front of people, I can't do it."), even after she was recognized for her leadership role by her peers and her instructors during Cycle 3.

Reflecting on Lara's and Jayda's trajectories in light of these findings, it is not a coincidence that their projects progressively included performing arts in more robust ways over the course of the three program cycles. When they were new to the program during Cycle 1, their project was devoid of performing arts. While the omission of performing arts in this project reflects a program design flaw (Bequette & Bequette, 2012; Quigley et al., 2020), it also reflects youths' discomfort with the discipline with which they had limited prior experience. Instead, they decided to work on a science-based project that was comfortable and familiar. Although Lara and Jayda's Cycle 2 project included performing arts, it continued to reflect a tension they experienced with the performative aspect of the discipline. For this project, the youth decided to engage with performing arts through the creation of a board game that audience members could play, rather than a more performance-based piece. On the other hand, Lara and Jayda's Cycle 3 project revolved around a staged theatrical production. While Lara and Jayda's group were able to create and produce a play during Cycle 3, it is important to note that they chose this project format largely because the teachers offered to act out the play for the youth.

Based on Lara's and Jayda's cases—and our work with youth in Dramatic Science over two consecutive years—we found that it is essential to provide middle-school-aged youth with opportunities to engage with performing arts in ways that allow them to build on their artistic interests while also preserving their social standing. Performing arts, in particular, is a discipline that underscores risk-taking (Neelands, 20019) and, in turn, vulnerability. Most adolescents—particularly youth of color—try to avoid experiencing vulnerability, given the need to "fit in" (Pinkard et al., 2017) and fend off negative social ascriptions (DiSalvo et al., 2014; Johnson et al., 2011). Directing staff members to act out the play, rather than doing so themselves, was more comfortable for Lara and Jayda's group—as it would be for many other middle schoolers—given that the play was produced in front of a large audience consisting of families, peers, high school students, and instructors. Because the play was acted out by individuals other than the students who created the play, it removed the group members from the audience's gaze and externalized the group members' contributions. As a result, group members were able to deeply engage with performing arts in ways that allowed them to build on their interests while also "saving face" (DiSalvo et al., 2014, p. 276) or preserving one's presentations of self and protecting them from embarrassment. Foregrounding youths' voices, interests, and needs (Basu & Calabrese Barton, 2010) to gauge which artistic disciplines will resonate with them (e.g., visual arts, music, dance) and how these approaches might be implemented in ways that allow youth to preserve their social standing is particularly important.

Paper 3: "It's Okay That You Add Your Touch": Fostering Imagining and Creating Through STEAM Education

Practitioners and scholars around the world have begun to recognize the need to fragment disciplinary boundaries in K-12 learning settings in favor of more holistic approaches, including STEM (science, technology, engineering, and mathematics) and, more recently, STEAM (science, technology, engineering, arts, and mathematics) education (Bevan et al., 2019). Drawing on perspectives, ideas, and practices from multiple disciplines not only supports youth to understand and address challenges encountered in their lives but also expands what practices and identities are valued in a given space (Finch et al., 2020). STEAM, in particular, has been proposed as a means to reimagine science education based on youths' widespread interest in art, design, and making, and the encouragement of multiple forms and expressions in these activities (Carsten Conner et al., 2017).

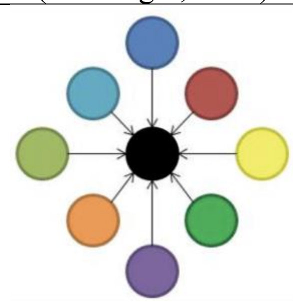
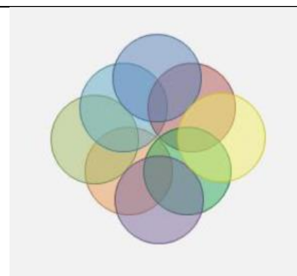
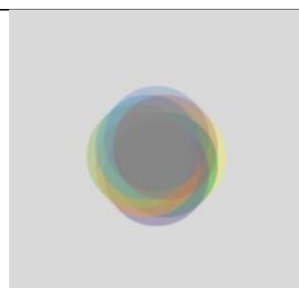
Building on the work of STEAM education scholars who foreground common practices across artistic and scientific disciplines (e.g., Bevan et al., 2019), we document the design, implementation, and outcomes of *Dramatic Science* (pseudonym), an out-of-school art-science program for middle- and high-school-aged students from an urban public school district. To illustrate the program implementation, we share a vignette of a group's development and production of a play about climate change. During this project, youth conceptualized the characters and script, designed and created costumes, coded LED light accessories for the costumes, and cast and directed staff members to perform the play. Interview data highlight focal youths' reflections on practices common to artistic and scientific fields before and after this experience. Our results demonstrate that a multidisciplinary STEAM education project supported youth to appreciate *imagining and creating* in the context of science. We conclude with the successes and challenges of multidisciplinary STEAM education and corresponding implications for in- and out-of-school practitioners and program designers.

Theoretical Background: Approaches to Discipline Integration

When designing STEAM education settings, it is important to be intentional and explicit about the relationships among disciplines, particularly regarding how learners will engage in these disciplines (Mejias et al., 2021; NRC, 2014). There are three approaches to discipline integration most prevalent in the STEAM education literature, including multidisciplinary, interdisciplinary, and transdisciplinary (Quigley & Herro, 2016). Table 3.1 includes a visual representation, definition, and example for each approach. While these approaches are ordered from least to most integrated, it is important to note that each approach has different affordances and constraints in terms of cognition and learning (NRC, 2014). The youths' STEAM project highlighted in this study utilized a *multidisciplinary approach*, primarily utilizing computing and performing arts, albeit separately.

Table 3.1

Unpacking Approaches to Discipline Integration

	Visual Representation (Colakoglu, 2018)	Definition (Quigley & Herro, 2016)	Example
Multidisciplinary		Learners engage in multiple disciplines to address a focal challenge *without* integrating knowledge or processes from these disciplines.	During a field investigation, learners engage in mathematics to calculate the biodiversity of a habitat, science to learn about the ecological niche of focal species in this habitat, and visual arts to illustrate a focal species in its habitat.
Interdisciplinary		Learners combine and interrelate knowledge and skills from multiple disciplines to address the focal challenge.	Learners engage in science to learn about water quality indicators in a local river while also engaging in engineering to design and test a water filter to improve these indicators.
Transdisciplinary		Learners engage in multiple disciplines simultaneously, blurring the distinctions between when they are “doing science” and “doing art.”	Learners engage in science and theater simultaneously by developing a script that highlights narrative and argumentation around climate change phenomena.

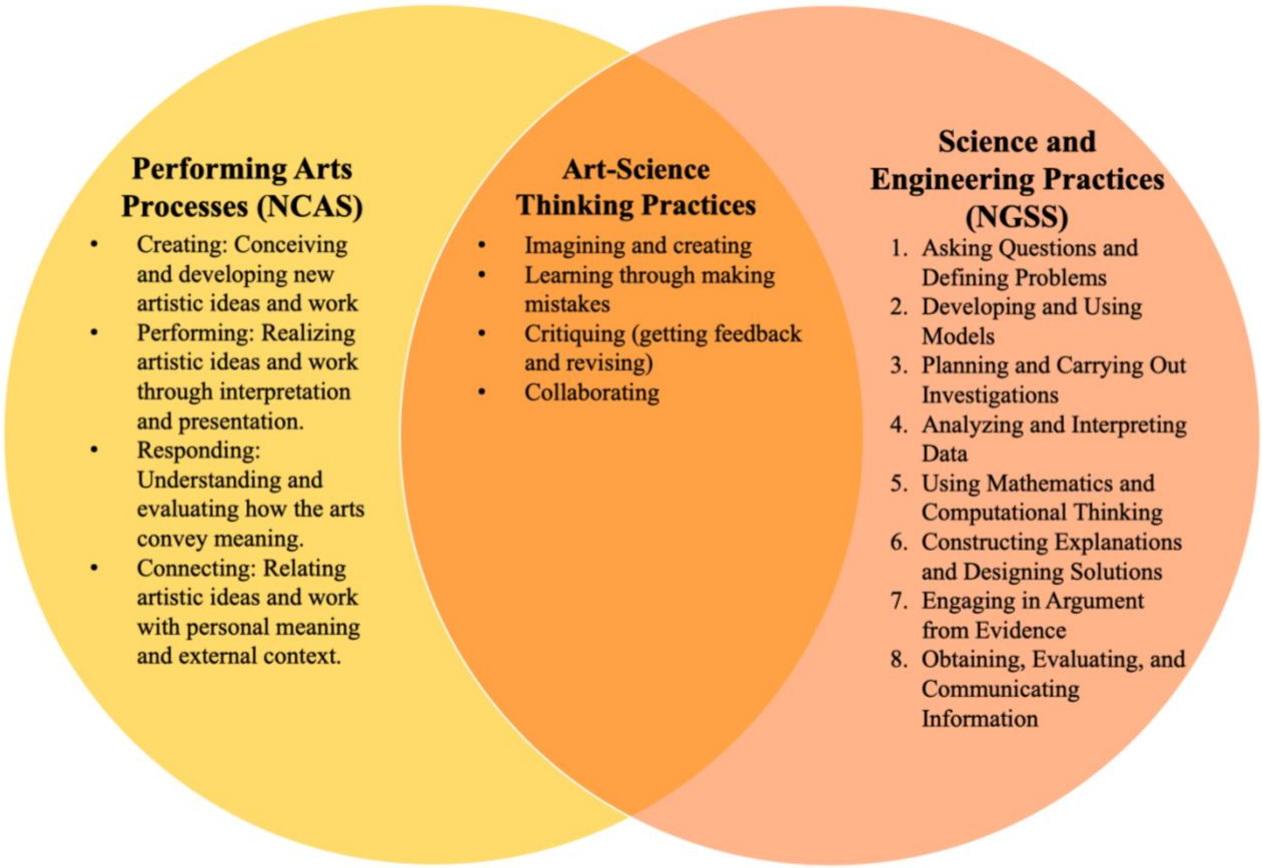
Program Background

Relationships Between Artistic and Scientific Disciplines

Dramatic Science was created by a multidisciplinary researcher-practitioner partnership among a science educator, two performing arts educators, a science education researcher, a learning scientist, and two graduate student researchers. When designing the program, we aimed to promote youths' engagement in and reflection on practices common to artistic and scientific fields. With this goal in mind, our project team brainstormed convergent *art-science thinking practices* and discussed how these practices related to those included in the national education standards, including the Next Generation Science Standards (NGSS) and the National Core Arts Standards (NCAS), if at all. Based on these ongoing discussions, we created a preliminary list of conjectured art-science thinking practices, which, we suggest, lie at the convergence of performing arts processes and STEM practices. This preliminary list was revised based on which practices youth reported to enact during their projects in Dramatic Science, resulting in the list depicted in the middle of Figure 3.1. Among the art-science thinking practices that youth reported to enact, their perspectives on the value of imagining and creating in the context of science shifted most profoundly.

Figure 3.1

Art-Science Thinking Practices: The Convergence of Performing Arts and STEM Practices



Guided by this framework, we generated the following driving question to guide youths' projects during the program iteration highlighted in this study: *What would you like your community to be like in 10 years?* With this question in mind, groups of youth selected a local social and environmental justice issue (e.g., housing rights, food rights) to highlight in their project. Youths' final projects were presented to their family, friends, peers, and instructors during a symposium event, which occurred on the last day of the program. A summary of the weekly learning activities and the corresponding design principles are included in Table 3.2. (For a detailed description of daily learning activities, please see Appendix B.) It is important to note that no two groups engaged in the same processes due to the open-ended nature of the projects, specifically the embedded choices in the project format (e.g., animation, cartoon) and artifacts to create for their projects (e.g., 3-D printed model, LED light accessories, script). For the program iteration highlighted in this study, youths' projects included a cartoon about local food rights, a model of the greenhouse effect, an app vision board, a documentary about the local effects of gentrification, and a play about the local effects of climate change. (Please see Appendix C for details on youths' projects.) By encouraging youth to choose their project format and artifacts, the program structure was differentiated based on youths' interests and identities.

Table 3.2

Summary of Weekly Learning Activities and Corresponding Design Principles

	Summary of Weekly Learning Activities	Core Design Principles
Week 1: Connecting & Exploring	• Community building • Introduction to the driving question: What would you like your community to be like in 10 years? • Introduction to potential STEAM project artifacts (e.g., coding LED lights, costume design) • Explore potential pathways for their project (e.g., skit, installation, speech, video, spoken word, animation) • Reflect on and critique the disciplines of performing arts and science	• Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 6: Reflecting on common thinking practices between performing arts and science and critiquing these disciplines.
Week 2: Envisioning & Creating	• Community building • Identify a focal social or environmental justice issue for the project • Brainstorm and storyboard the message for their project • Select a pathway for their project • Engage in performing arts and science processes to create and refine artifacts for their project • Share and critique project drafts • Reflect on and critique the disciplines of performing arts and science	• Principle 1: Privileging youths' voices through creating messages about locally-relevant social and environmental justice issues. • Principle 2: Promoting choice in the focal issue and artifacts for youths' projects. • Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects.

Week 2: Envisioning & Creating		• Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience. • Principle 6: Reflecting on common thinking practices between performing arts and science and critiquing these disciplines.
Week 3: Creating & Refining	• Community building • Engage in performing arts and science processes to create and refine artifacts for their project • Share and critique project drafts • Practice communicating stories in preparation for a symposium event • Share final projects with peers, family, friends, and instructors •	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.

Youth Participants

Dramatic Science was part of a larger college-preparation program taking place at a research university in a metropolitan area in the Northeastern United States. A total of 19 students participated in Dramatic Science during this study, including three 7th graders, ten 8th graders, and six 9th graders. These students predominantly identified as Latina/o (67%) and multilingual (73%). During the summer program examined in this study, youth attended Dramatic Science sessions on Mondays through Thursdays for four to five hours per day over three consecutive weeks (52 hours total).

The vignette below describes one group's experience creating and producing a play about climate change, and their engagement in costume design and computing in particular. This focal group was selected due to the multidisciplinary nature of their project, which foregrounded performing arts and computing. There were five middle school students in this group, including one 7th grader and four 8th graders. These students identified as bilingual Spanish- and English-speakers (100%), Latina/o (60%) or Dominican American (40%), and cisgender (80% female, 20% male). Field notes based on participant observation of this group were generated during each program session. As a part of a larger study, two students in this group, Lara and Jayda (pseudonyms), participated in two rounds of interviews, which took place near the beginning and end of the summer program. Together, the field note and interview data provide insight into the group's experience creating their play and their reflections on practices common to artistic and scientific fields in light of this experience.

Example of Implementation

The students in the case study group developed, produced, and directed a play featuring a "squad" of five middle-school-aged female characters who time-travel to the future and witness the effects of climate change on their local community. Youth developed the characters and script for their play, designed and created costumes (Figure 3.2), coded LED light accessories for the costumes, and cast and directed staff members to play the roles of the characters (Figure 3.3). Among these processes, the youth in this group were most interested in costume design and construction and coding LED light accessories for the costumes. They devoted more time to these processes than others (e.g., scriptwriting) and requested to work on these processes during multiple program sessions. Further, the interview participants consistently referred to these activities during interviews. Given that the youth spent most of their time designing and creating costumes and coding LED light accessories for the costumes, we focus on their engagement in these processes in the following section.

Figure 3.2

Costume Design Artifacts

Figure 3.3

Staff Members Performing in Costumes Created by Youth During a Symposium Event

Creating Costumes and Coding LED Light Accessories

To develop the costumes, the group divided into two specialized groups. Jayda and two peers worked on costume design and construction, while Lara and one peer coded LED light accessories for the costumes. More specifically, Jayda's group sketched two sets of costumes for each character—which were worn at different times during the play—before constructing the costumes using materials they requested (e.g., t-shirts, sewing materials, ribbon). Based on the costume sketches, Lara's group used Python programming to code LED light strips to turn two different colors by using an on/off switch the actors could push during the play.

Findings

Interview data highlight Jayda's and Lara's perspectives on the art-science thinking practices enacted during their project and the value of these practices in the context of science, performing arts, and their personal lives. Among the art-science thinking practices that both youth reported to enact (Figure 3.1, middle), their perspectives on the value of *imagining and creating* in the context of science shifted most profoundly. After participating in Dramatic Science, Jayda and Lara expressed newfound appreciations for imagining and creating in the context of science, practices that they previously associated with performing arts.

Initial Perceptions of Imagining and Creating as Irrelevant to Science

Before participating in the program, Jayda rejected the idea that imagining was valuable in science, stating: "[Y]ou don't imagine in science, you *do* in science." Jayda implied that science is a discipline that relies on concrete practices ("doing"), rather than abstract practices like imagining. Similarly, Lara explained that imagining and creating were irrelevant to science:

> [Y]ou're not gonna—I mean you could create a project but you're not going to imagine. Why [are] you gonna imagine. I don't know. If you have a solution to a problem, you're not going to keep imagining it. You're gonna want to make something, prove some point, or whatever. Creativity. How [are] you gonna be creative.

Lara's utterances allude to the role of creativity and imagination in science. For example, one could "create a project" or "make something." She also stated that "if you have a solution to a problem, you're not going to *keep* imagining it" (italics added), implying that one must initially imagine a solution. At the same time, however, Lara explicitly rejected the notion that science involves imagining and creating (e.g., "why [are] you gonna imagine"), and implicitly associated science with more concrete processes (i.e., "make something, prove some point").

Newfound Appreciations for Imagining and Creating in Science

After participating in Dramatic Science, Jayda and Lara articulated shifts in their thinking. Jayda explained that imagining and creating were important in science "[b]ecause when you're trying to make stuff in science, it's okay that you add, you know, your touch. It doesn't have to be plain." In this statement, Jayda implicitly linked imagining and creating with personal expression (i.e., "add your touch"). Further, she explicitly noted the value of personal expression when describing Dramatic Science: "It's a way to express yourself. So, if you wanted to express yourself, you should probably do that. Because in performing arts you express yourself and, I guess, in science as well but mostly in performing arts." In this statement, Jayda grapples with whether or not personal expression is permissible in science and, in the end, associates this practice more with performing arts.

Meanwhile, Lara connected her newfound appreciation for imagining and creating to multiple factors, including her group's personalization of their project, collaboration among group members, and incorporation of multiple disciplines. Lara explained that imagining and creating were important in science "because you don't want to do the same stuff as anybody else did. Then you wouldn't be your own person." Lara recognized the value of imagining and creating in science regarding doing work that is personalized to the people who are creating it, similar to Jayda's rationale ("it's okay to add your touch"). Interestingly, Lara equated collaborating with imagining and creating, stating that they were the "same thing." She linked these practices again later in the interview, stating that "With more people involved in the group [project], we could have more ideas on what to do." In other words, Lara recognized that collaborating with multiple people encouraged her group members to engage in imagining and creating when developing their project. Lastly, Lara also recognized that incorporating multiple disciplines fostered her group's creativity. When reflecting on her group's play project, she stated: "I felt like we were more creative. And we actually included science, performing arts, and coding. Not just one topic."

Discussion

Jayda's and Lara's utterances highlight how engaging in a multidisciplinary STEAM project fostered new perspectives on imagining and creating in the context of science. More specifically, the following STEAM project features supported youths' shifting perspectives, including the utilization of multiple disciplines, peer collaboration, personal expression (Carsten Conner et al., 2017; Quigley et al., 2017). Lara's utterances highlight how the commingling of STEAM disciplines and collaboration among individuals engaged in these disciplines can fuel imaginative thinking (Mejias et al., 2021). According to Lara, her group was "more creative" because they incorporated multiple disciplines and ideas from multiple people ("more people" leads to "more ideas"). In other words, an open-ended project that relied on multiple disciplines expanded possibilities for the group project in terms of what type of project and artifacts they developed and how (Carsten Conner et al., 2019).

Lastly, both Lara and Jayda recognized that creating a STEAM project that was personalized by the group members supported their newfound appreciations for imagining and creating in science. Although Jayda came to recognize that it was "okay" to add "your touch" in science, she still mainly associated personal expression with performing arts rather than science. This perspective is perhaps unsurprising given that imagination and creativity often are neglected in traditional science curricula (Hadzigeorgiou, 2016; Kafai et al., 2014).

In light of these findings, it is important to note that the art-science thinking practices youth enacted to create and produce their play remained disciplinary, rather than hybrid practices that transcended disciplines (Bevan et al., 2019). During their project, Lara primarily engaged in computing while Jayda primarily engaged in fashion design. Learners' enactment of these disciplinary practices reflected the multidisciplinary nature of their project, which maintained disciplinary boundaries (Quigley & Herro, 2016). Youths' interviews corroborated this finding, given that they were able to distinguish between when they were doing performing arts (e.g., scriptwriting, costume design) or computing (i.e., coding LED lights) when working on their project. Nevertheless, we find it hopeful that a multidisciplinary approach to STEAM education can support youth to develop more expansive perspectives of science.

Recommendations for Practitioners

Although participating in Dramatic Science encouraged Lara and Jayda to develop more expansive perspectives of science—specifically regarding the value of imagining and creating—their participation in this program reaffirmed and solidified, rather than transformed, their pre-existing interests with certain disciplines. In other words, because youth were able to engage in disciplinary processes with which they were interested, their interests were reaffirmed along disciplinary lines. For example, Jayda, who reported that she "didn't get" coding, withdrew from computing experiences that were outside of her comfort zone. Instead, she gravitated toward activities with which she had prior experience and interest (e.g., fashion design and construction). Similarly, Lara, who was interested in computer science rather than performing arts, had the freedom to primarily participate in computing activities, while avoiding artistic processes. As a result, Jayda became more interested in fashion design and Lara became more interested in computer science after participating in the program.

On the one hand, the open-ended nature of the projects—which maintained space for youth to build on their interests, experiences, and skillsets—was a strength of the program. Yet, as Lara's and Jayda's cases demonstrate, this strength was also a weakness because it did not encourage youth to pursue pathways outside of their comfort zones. To support youth in exploring novel endeavors, we recommend devoting extensive time for youth to practice activities with which they have limited experience (e.g., computing) before beginning their projects. Another approach would be to embed artistic and scientific activities within one another through interdisciplinary or transdisciplinary approaches so that youth would need to enact multiple disciplinary practices and perspectives simultaneously (Mejia et al., 2021). Kafai and colleagues (2014), for example, leveraged a similar approach during an e-textile project in which youth concurrently engaged in crafting and coding through the use of LilyPad Arduino kits.

Conclusion

In light of our findings, we argue that STEAM education offers promising approaches for learners to think about ideas and practices that cross and extend beyond disciplines (Bevan et al., 2019), particularly for the roles that imagination and creativity play in STEM fields. Encouraging imaginative and creative thinking, and recognizing these practices as valuable in scientific fields can support youth, like Jayda, whose creative identities might otherwise go unnoticed in traditional STEM learning spaces. Aspects of our program design, particularly the conceptualization of art-science thinking practices, have much potential for use in K-12 settings through partnerships between science and arts educators. Our future research will further investigate how various approaches to discipline integration (e.g., multidisciplinary, interdisciplinary, transdisciplinary) influence youths' enactment of art-science thinking practices.

Conclusion

Despite widespread interest in STEAM and the rise of STEAM-focused K-12 schools, limited research exists on the design and implementation of STEAM learning environments and the experiences of youth participants in these environments (Bush et al., 2020; Kang, 2019; Carsten Conner et al., 2017; Quigley et al., 2020). Extant scholarship, while making important contributions to the STEAM conversation, mainly focuses on teacher outcomes (e.g., Cook et al., 2020; Herro & Quigley, 2016; Jacques et al., 2020; Jho et al., 2016; Quigley et al., 2020). With regards to youth outcomes, the majority of research to date has taken place in K-12 settings (e.g., Magerko et al., 2016; Ozkan & Topsakal, 2019). Further, these studies typically focus on findings generated from a single iteration of design (e.g., Kim & Chae, 2016). Longitudinal research generated from STEAM education programs in out-of-school contexts over the course of multiple iterations, to my knowledge, does not exist. To address this paucity, this dissertation investigates the design and enactment of an art-science program over multiple program iterations while highlighting two focal youths' experiences participating in these iterations.

The DBR study (Paper 1) explored how an art-science program evolved over two consecutive program iterations. Two main changes that were made to the program based on youths' emergent needs and interests, including a broad approach to arts integration and the incorporation of computing and technology. Art-science teachers viewed ongoing teacher collaboration and foregrounding youths' development of artifacts for their STEAM projects as necessary to support disciplinary integration. Findings from this study suggest two central implications. First, it essential for STEAM educators and program designers to create opportunities for youth to engage in STEAM education in ways that allow them to build on their interests while also cultivating desirable social images. Second, I argue that supporting ongoing teacher collaboration across disciplines through a practice-oriented lens—rather than a concept-oriented lens—may better serve educators and students in STEAM learning settings through integrating STEAM disciplines in meaningful ways.

The longitudinal case study (Paper 2) builds on the DBR study (Paper 1) by highlighting the experiences of two focal youth who participated in Dramatic Science throughout the program. This study documented case study youths' engagement in art-science thinking practices, roles in group projects, and their perspectives art-science thinking practices over three program iterations. Findings illustrate the relationships between the program design and youths' enacted art-science thinking practices during group projects. Based on findings from this study, I discuss three implications. First, I argue that a practice-oriented approach to STEAM education is necessary but not sufficient to support youths' engagement in hybrid practices that transcend disciplines. Second, youths' engagement in an art-science education program created opportunities for youth to build on a wider range of interests compared to disciplinary-based learning settings. Third, creating opportunities for middle-school-aged to engage in STEAM education in ways that allow them to build on their artistic interests while also preserving their social standing is especially important.

Lastly, the practitioner study (Paper 3) documents the program design and outcomes from the third iteration (Summer 2019), while also highlighting connections between the program design and K-12 science and performing arts education standards (i.e., NCAS and NGSS). While the DBR study (Paper 1) and the practitioner study (Paper 3) both focus on the program design, enactment, and youths' interactions with the enacted design, they differ in terms of the focal audience and the scope of the research. More specifically, the DBR study (Paper 1) is designed for a researcher audience and includes data from three project iterations (Summer 2018, 2018-

2019 School Year, Summer 2019) while the practitioner study (Paper 3) is written for educators and includes the design and a subset of findings generated during the third project iteration only (Summer 2019).

With these conclusions and implications in mind, it is important to recognize the limitations of these studies. First, it is important to recognize that findings were influenced by the program context. Dramatic Science's out-of-school learning setting allow for substantial flexibility for youths' STEAM projects, particularly during the third program iteration. Second, the limited number of teacher and youth participating in these studies is important to keep in mind. As with any qualitative study, no two students' experiences in Dramatic Science were the same. Although the nuances of the youth case study (Paper 2) findings are specific to the youth participants, I believe that the findings and overarching implications echo many of these experiences of students in the larger program, as highlighted in the DBR study (Paper 1). Similarly, this dissertation's findings are influenced by the project team members who participated in this project and iteratively designed the program. Had other individuals been involved in this process, it is likely that a different set of findings would have been generated. Keeping this in mind, it is my hope that other STEAM educators and program designers can learn from the experiences highlighted in this dissertation.

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Appendix A

Summary of Lessons from Cycle 2 (2018-2019 School Year)

Summary of Science-Based Lessons

Science Lessons	Description
Investigating the quality of local water sources	• Collecting and testing water samples from a range of sources (e.g., school, home, local reservoir, local river, bottled water) • Analyzing and interpreting data for a range of water quality indicators (e.g., pH, alkalinity, nitrites, nitrates, bacteria, pesticides, chlorine, hardness, lead, copper, iron)
Investigating the effectiveness of commercial water filters	• Investigating the effectiveness of three water filters (i.e., Proctor & Gamble water purification tablets, LifeStraw, and a household Brita filter) by testing a water sample from a local river before and after filtering (same water quality tests as listed above) • Analyzing and interpreting data in relation to advertised product claims (e.g., LifeStraw removes 99.999999% of waterborne bacteria) • Deconstructing the commercial water filters to analyze and compare the materials and components in each product
Designing, creating, and testing a water filter	• Designing and creating water filters with various supplies (e.g., 2-L plastic bottles, sediment of different sizes, activated carbon, coffee filters, cotton balls, rubber bands) • Testing the effectiveness of each of the student-generated water filters on water quality indicators before and after filtering • Redesigning and recreating the first water filter iteration based on the test • Analyzing, interpreting, and comparing data generated from each group's water filter in relation to the product design
Observing, questioning, and discussing issues of water quality and distribution	• Analyzing and interpreting data from multiple sources (e.g., documentaries, news videoclips, articles, guest speakers) on local and national issues of water access and control • Discussing questions generated by both teachers and youth participants (e.g., Is water a renewable resource? Does water belong to everyone or is it a commodity? How much should water cost and who should pay?) o Data sources on local issues included lead test results for K-12 public schools, a historical timeline of events that affected the water quality of a local river, and a toxic sewage flood that disproportionally affected lower income communities. o Data sources on national issues included Nestlé bottling water in drought-hit California, historical changes in the Colorado River's water supply, water crisis in Flint, and community-based water protection and activism efforts (e.g., youth activism efforts, indigenous people protesting the Dakota Access Pipeline)

Summary of Theater Lessons

Theater Lessons	Description
Imagining and writing a scary story (took place around Halloween)	• Walked to a local reservoir and collected water samples. • Used local reservoir setting as inspiration for writing a scary story • Sharing of scary stories
Guerilla Street Theatre	• Explore power and image dynamics through theater of the oppressed games (tangles and knots, tableau tag). • Reflection: Based off of games we just did, how can we use our findings from science to impact Guerilla theatre? • Explore ways to spread awareness of health and access to clean water
Tour of a children's theater	• Tour of a children's theater • Brainstorm – PSA commercial about water equity
Rap-a-Thon Workshop	*Planned but not implemented. Instead, students worked by themselves on writing a story.* • Students will reflect on the areas of study from the past sessions • Students will explore different methods of brainstorming and drafting • Students will explore A/B rhyme scheme thru puzzle method • Students will have time to edit their 8, 12, or 16 bar verses on steam topic of choice • Students will practice over instrumentation and share • Ensure students have time to create their storylines for next semester
Exploring Examples of Arts Activists	• Presentation with activist art examples (song on water, visual art, poetry/spoken word, etc.) • Discussion – how are science and art skills embedded in these pieces?
Data Mosaics	• How to communicate scientific information • Mosaic activity (communicating stories about data)
Mock News Show	• Filmed a mock news show with two hosts, different news segments, and commercials • Students wrote different news segments and commercials and reported on them during the show
Project Work	• Board games on issues of water access and equity

Appendix B

Summary of Lessons from Cycle 3 (Summer 2019)

Weekly Theme	Daily Learning Activities	Description of Daily Learning Activities	Connection to Design Principles
Week 1: Connecting	Day 1: Community building and introduction to the program	• Community-building games (e.g., theater games, engineering challenge) • Introduction to the project driving question: What would you like your community to be like in 10 years? • Interest inventory on potential community-based issues to explore for the projects: education rights, food rights, green space rights, housing rights, natural resources rights, and transportation rights	• Principle 1: Privileging youths' voices through creating messages about local social and environmental justice issues. • Principle 2: Promoting choice in the focal issue and artifacts for youths' projects. • Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects.
	Day 2: Introduction to technical theater and critiquing the disciplines of performing arts and science	• Community-building games • Discussion – what counts as "doing performing arts"? What counts as "doing science"? • Introduction to technical theater (e.g., scenic design, lighting, sound, costumes)	• Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 6: Reflecting on common thinking practices between performing arts and science and critiquing these disciplines.
	Day 3: Coding workshop and critiquing the disciplines of performing arts and science	• Community-building games • Coding workshop: Coding LED lights • Synthesis activity: How would you introduce people to the mood of your neighborhood using lighting? • Graffiti activity and discussion: 6 W's (who, what, when, where, why, how) posters for doing science and doing performing arts	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 6: Reflecting on common thinking practices between

Week 1: Connecting			performing arts and science and critiquing these disciplines.
	Day 4: Coding workshop and exploring project pathways	• Community-building games • Continue coding workshop: Coding LED lights • Costume design challenge: Design and code wearable technology (LED light accessories) for your model's costume • Overview of possible pathways for youths' projects (e.g., interactive gameshow, art installation, murals, social practice art, multimedia performances with dance, spoken word, animation). • Begin storyboarding process: In small groups, youth began creating a message to highlight their focal issue in terms of their vision for their future community (i.e., What would you like your community to be like in 10 years?)	• Principle 1: Privileging youths' voices through creating messages about local social and environmental justice issues. • Principle 2: Promoting choice in the focal issue and artifacts for youths' projects. • Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects.
Week 2: Envisioning and Creating	Day 5: Brainstorming and sharing stories-in-the-making for their projects	• Community-building games • Gallery walk and discussion: Exploration of local social and environmental justice issues • Workshops to support artifact development for projects: Laser cutting and 3-D printing • Building on their initial storyboards, youth discussed possible pathways for the group projects (e.g., installation or model, speech, short skit or video, spoken word, song, animation). • Whole group: Sharing of initial ideas for their projects	• Principle 2: Promoting choice in the focal issue and artifacts for youths' projects. • Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.

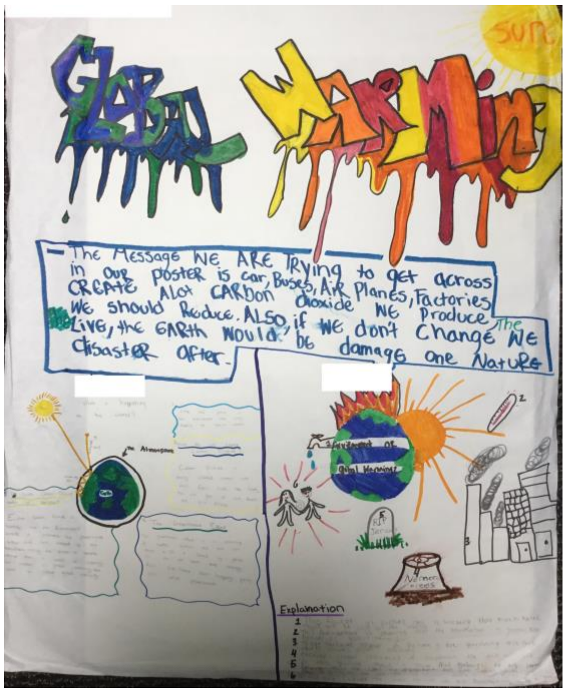
Week 2: Envisioning and Creating	Day 6: Coding workshop, and project development and critique	• Community-building games • Coding workshop: Coding LED lights to respond to music (i.e., LED lights change color based on sound) • Project worktime: Youth checked in with their project group before breaking into specialized subgroups to work on project artifacts (e.g., coding LED lights, costume design, script-writing, 3-D printing). • Presentation and critique in small groups: Youth presented their artifact drafts to peers whom were not in their group. To get feedback on specific aspects of their project drafts, the presenters posed questions for the listeners and engaged in discussion based on these questions.	• Principle 2: Promoting choice in the focal issue and artifacts for youths' projects. • Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.
	Day 7: Project development and critique	• Community-building games • Workshop: Envision what your group's performance could look like through improvisation. • Whole-group share-out of project drafts: A group of students share their project draft. Students volunteer to play roles of various characters in the story and act out the story on stage with the guidance of the performing arts instructor. • Discussion and critique of project drafts • Project group check-in • Continue working on projects	• Principle 1: Privileging youths' voices through creating messages about local social and environmental justice issues. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.
	Day 8: Project development and critique, and critiquing the disciplines of performing arts and science	• Community-building games • Graffiti activity and discussion: Revisiting and revising our 6 W's (who, what, when, where, why, how) posters for doing science and doing performing arts • Project group check-in	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific

Week 2: Envisioning and Creating		• Continue working on projects • Whole-group share-out of project work from that day	practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience. • Principle 6: Reflecting on common thinking practices between performing arts and science and critiquing these disciplines.
Week 3: Creating and Refining	Day 9: Project development and critique	• Community-building games • Whole-group share-out of project drafts: A group of students share their project draft. Students volunteer to play roles of various characters in the story and act out the story on stage with the guidance of the performing arts instructor. • Discussion and critique of project drafts • Project group check-in • Continue working on projects	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.
	Day 10: Presentation practice and critique	• Community-building games • Draft presentation talking points • Practice presentations and engage in critique sessions with peers and instructors • Project group check-in • Continue working on projects	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects. • Principle 4: Utilizing artistic and scientific practices to design and create youths' projects.
	Day 11: Presentation practice and critique	• Community-building games • Project group check-in • Continue working on projects • Practice presentations and engage in critique sessions with peers and instructors	• Principle 3: Privileging creativity and collaboration by maintaining open-endedness and flexibility in youths' projects.

Week 3: Creating and Refining			• Principle 4: Utilizing artistic and scientific practices to design and create youths' projects. • Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.
	Day 12: Symposium event	• Community check-in • Brief preparation time for upcoming presentations • Presentation of performances	• Principle 5: Building recurrent opportunities for youth to share and critique their project drafts with a meaningful audience.

Appendix C

Examples of Participants' Projects for Each Program Iteration

<table>
<tr><th>Learning Cycle</th><th colspan="2">Examples of Youths' Projects</th></tr>
<tr>
<td>Cycle 1 (Summer 2018)</td>
<td>


Public Service Announcement: The local effects of climate change* (*Jayda and Lara's project)
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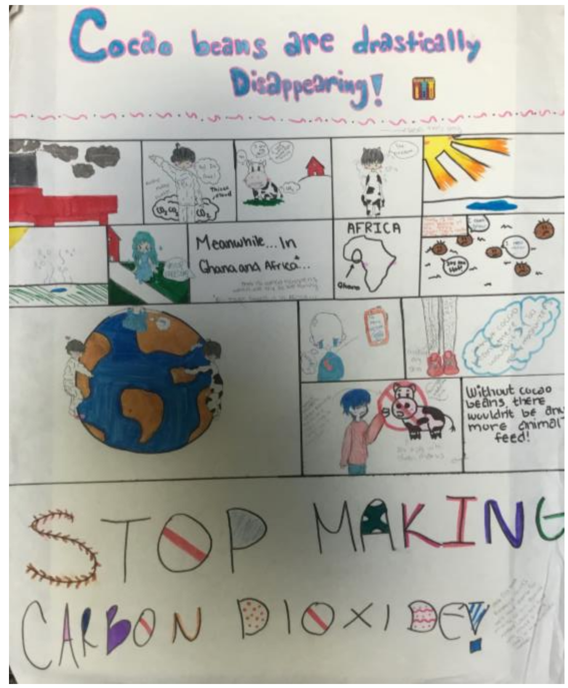

Public Service Announcement Cartoon: The effect of climate change on cacao beans
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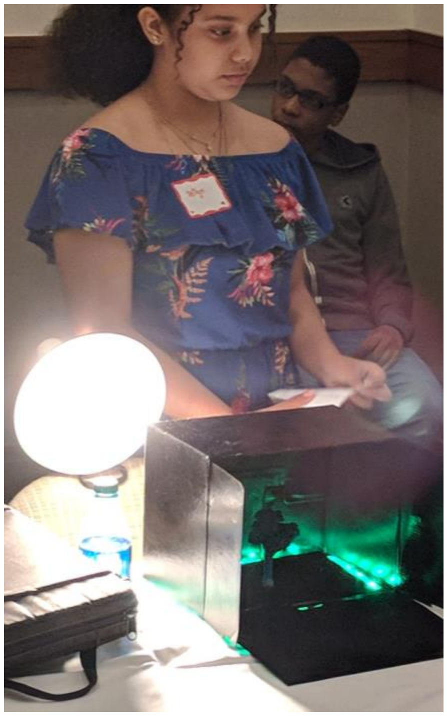
Cycle 1 (Summer 2018)	 An animated short film: Climate Change Wars
Cycle 2 (2018-2019 School Year)	 Youth and one of their STEAM instructors work on their board game on water equity* (*Jayda and Lara's project)  Youth share their board game with peers, parents, mentors, and instructors at the end-of-the-year symposium*

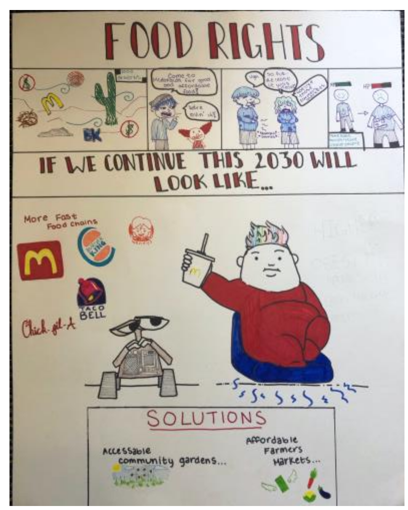
Cycle 3 (Summer 2019)



A youth shares her model of the greenhouse effect (she programed the LED lights to change color when the temperature sensor reached a certain level)

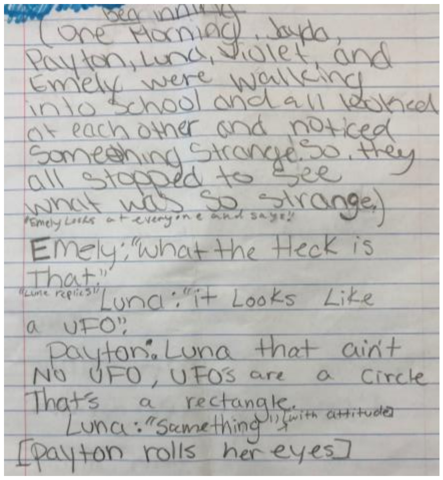
Youth share their vision for the design of apps (e.g., translation app, time machine app)

For their documentary, youth interview one of their STEAM instructors on the local effects of gentrification

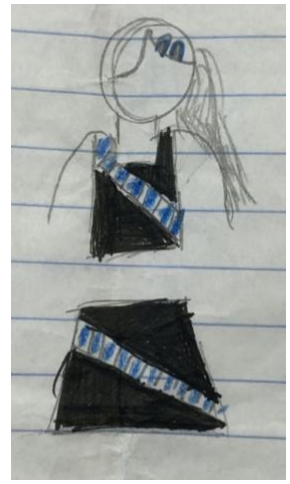


Public Service Announcement Cartoon: Food Rights

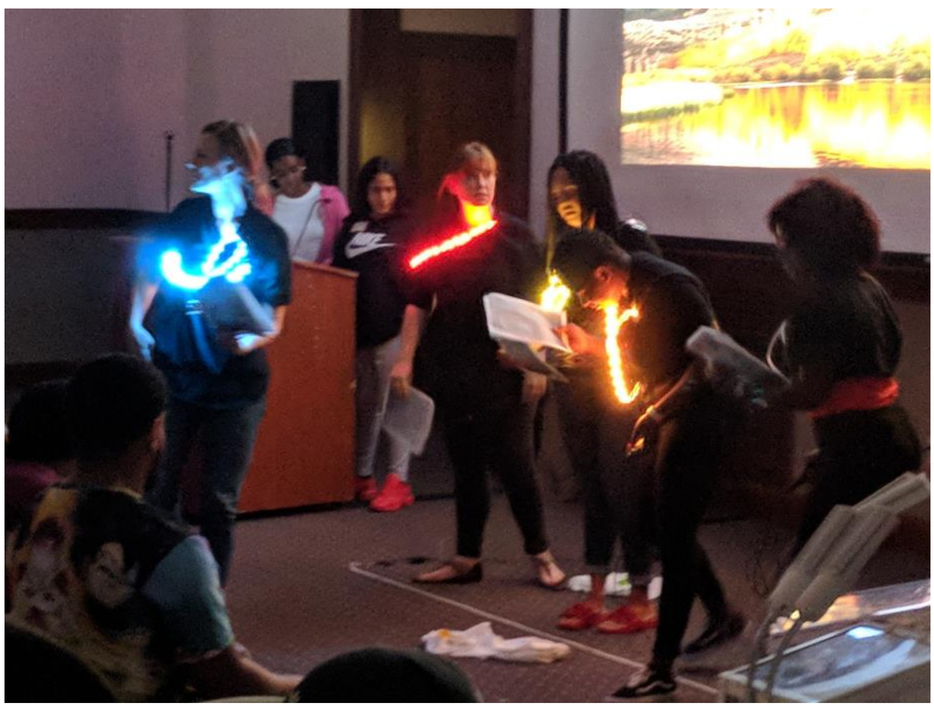
Cycle 3 (Summer 2019)



Beginning
(One Morning, Jayda, Payton, Luna, Violet, and Emely were walking into School and all looked at each other and noticed something Strange. So, they all stopped to see what was So strange)
"Emely Looks at everyone and says!"
Emely: "what the Heck is That"
"Luna replies!" Luna: "it Looks Like a UFO".
Payton: Luna that ain't No UFO, UFO's are a Circle That's a rectangle.
Luna: "Something" {with attitude}
[Payton rolls her eyes]



A play about the local effects of climate change:
Youths' drafts of their script and two of the characters' costumes*
(*Jayda and Lara's project)



A play about the local effects of climate change: Two youth narrate the script as their instructors and mentors act out the scenes at the end-of-the-summer symposium*

Appendix D

Codebook for Paper 1

Targeted Design Element	**Code**	**Examples from Curriculum Implementation**
Community building activities	Introductions	what brought me here, collage about me
	Establishing community values	hopes and fears protocol, generating shared agreements
	Maintaining a community	opening and closing circles (e.g., how are you feeling on a scale from 1-10?); theater games (e.g., Zip, Zap, Zop)
Student choice embedded in projects	Building off of students' interest in various art forms	Movement-based arts-interest inventory
	Choice in project topic	Students form project groups based on topic preference (e.g., food rights, housing rights, greenspace rights)
	Choice in project format	Students select project format from a range of options (e.g., short film, speech, song)
	Choice in project artifacts	Students complete an interest survey on which processes they are most interested in doing; students pick two processes to incorporate in their final projects (e.g., coding lighting or sound, wearable technology/costume design)
Investigate local social and environmental justice issues	Connections between social and environmental justice issues and students' lives	Grafitti activity to reflect on why water is important to them, emergent student debate on whether or not water is wet
	Connections to students' communities	Collecting and testing water samples from local river, driving question related to youths' community (What would you like your community to be like in 10 years?)
	Conducting investigations	Testing the effectiveness of water filters

	Analyzing data	Analyzing water quality test data
	Argumentation	Students discuss multiple sources of information to discuss whether or not water should be privatized
	Designing solutions	Designing and constructing water filters
Design and create artifacts for their art-science project	Workshop: Coding for costume design	Wearable technology fashion design challenge
	Workshop: Coding for scenic design (coding lights and sound)	Coding LED lights to change color based on a temperature reading or based on a sound frequency
	Tour demonstration: 3D printing and laser cutting	Brainstorm ways to use 3D printing and laser cutting for projects
	Developing their projects	Students work together to iteratively develop artifacts for their projects (e.g., costume design sketches, coding LED lights, printing a 3D model)
Creating messages for their projects	Brainstorming messages	Students create initial storyboards to highlight a social or environmental justice issue for their project
	Envisioning messages	Teachers act out youths' storyboard; student volunteers create silent, still frames with their bodies (tableaus) based on youths' storyboards
Critiquing and refining art-science projects	Peer critique of project drafts followed by revisions	Students work in pairs to give feedback on each other's drafts
	Peer critique of presentations followed by revisions	Students practice presenting in front of the whole class and receive guided feedback
Reflecting on science, engineering, and performing arts	Relationships among science, engineering, and theater	Students analyze images of people engaged in activities (e.g., dance, basketball) and discuss if they are related to STEM, performing arts, or both.

Appendix E

Codebook for Paper 2

Category	Description
General views of doing science and doing performing arts	Perceived relationships between science and performing arts disciplines. Sub-codes include: • Compartmentalized view of science and art • Broad view of doing science (e.g., a way to help life problems, science as everywhere, science as part of who you are)
	Views of "doing science." Sub-codes include: • Topic-centered (e.g., chemicals, climate change) • Process-centered (e.g., predicting, explaining, asking questions, making observations) • Traditional science engagement (e.g., following directions, listening, asking for help)
	Views of "doing performing arts." Sub-codes include: • Narrow view of performing arts (i.e., staged theater) • Process-centered (imagining, creating, making jokes, listening, sharing, maintaining trust)
Views of art-science thinking practices in science and performing arts	Views of each focal art-science practices on each relational map (i.e., relative importance of the practice in her personal life, in science, and in performing arts) and any shifts that occur in these views over time. Sub-codes include: • Making observations • Exercising curiosity (asking questions) • Imagining and creating • Empathizing • Identifying problems and imagining multiple solutions • Learning through taking risks and making mistakes • Getting feedback and revising (critiquing) • Collaborating (working as a team) • Communicating through storytelling • Advocating for local change
Emotional connections with science and performing arts	Feelings about STEM subjects (context dependent). Sub-codes include: • Interest in science or coding (e.g., intrinsic, extrinsic) • Shift in interest in science or coding • Self-efficacy in science or coding • Self-perception in science or coding

	• Previous experience with science (e.g., first memory of doing science)
	Feelings about performing arts (e.g., theater, dance, music). Sub-codes include: • Interest in performing arts • Shift in interest in performing arts • Previous experience with performing arts • Self-efficacy in performing arts • Self-perception in performing arts
	Feelings about social justice issues. Sub-codes include: • Interest in social justice issues • Self-perception of agency in addressing social justice issues
Previous experience with science in school	Experience with school science. Sub-codes include: • Lack of epistemic authority (i.e., I learn from teachers) • Classroom management • Student engagement • Memorization of facts • Taking notes • Watching videos • Experiments • "Getting it right" • "Getting it done" • Individualism (e.g., completing work individually and efficiently, taking the state-wide test individually) • Advocating for herself and her learning
Hopes for future self	Future interests and hobbies. Sub-codes include: • Future interest in humanities (e.g., speaking multiple languages) • Future interest in STEM subjects (e.g., coding) • Future interest in performing arts (e.g., dance, hip hop, gymnastics)
	Future vision for herself. Sub-codes include: • Interest in going to college • Interest in STEM careers (e.g., medical doctor, nurse, computer science, counselor) • Role of science or coding in her future • Role of values (e.g., helping people) • The influence of participating in Dramatic Science on her future
Self-reported experiences in	Description of Dramatic Science. Sub-codes include: • Describing Dramatic Science

Dramatic Science	• Describing who would enjoy (or not enjoy) participating in Dramatic Science • Rationale for her participation in Dramatic Science
	Experience with science in Dramatic Science. Sub-codes include: • Self-efficacy • Preference for close-ended tasks • Preference for working individually • Preference for science over theater • Connections with school science
	Experience with performing arts in Dramatic Science. Sub-codes include: • Lack of experience with theater • Lack of interest in theater • Inspiring performing arts instructors (e.g., relevancy of theater, exercising humor)
	Experience in Dramatic Science in general. Sub-codes include: • Feelings were activity- and subject-dependent (e.g., theater is boring/frustrating, coding is fun) • Interest in trying new things (e.g., 3D printing) • Sense of agency
	Successes experienced by focal youth in Dramatic Science. Sub-codes include: • Success with "easy" activities • Success on projects was group-dependent (e.g., my group was focused, distribution of expertise) • Success on projects was activity-dependent (e.g., coding was fun) • Sense of enjoyment and pride with group projects • External recognition (i.e., receiving an award at the symposium, sharing my project with an audience) • Lack of a sense of success
	Challenges experienced by focal youth in Dramatic Science. Sub-codes include: • Frustration with open-ended tasks • Frustration with performing arts • Experienced stress when presenting the group project
	Most memorable experiences in Dramatic Science. Sub-codes include: • Project (e.g., finishing and sharing our project, being creative in our project, e-textile design challenge) • Coding

	• Not memorable
	Group projects (cycles 1, 2, and 3). Sub-codes include: • Description of her project and her group's rationale for their project choices (i.e., topic, story platform, her role in the project) • The most exciting or interesting part of the group project • The role of the component disciplines in the group project (e.g., performing arts, science, coding) • Experience engaging in art-science thinking practices during projects • Connection of the group project to school • Experience working with peers
Engagement with art-science thinking practices during program sessions and group projects	Engagement with the focal art-science thinking practices during program sessions and group projects. Sub-codes include: • Making observations • Exercising curiosity (asking questions) • Imagining and creating • Empathizing • Identifying problems and imagining multiple solutions • Learning through taking risks and making mistakes • Getting feedback and revising (critiquing) • Collaborating (working as a team) • Communicating through storytelling • Advocating for local change
Interactions and roles within learning activities and group project during program sessions	Interactions with peers and instructors. Sub-codes include: • Making a bid for recognition or demonstrating a sense of pride (e.g., "We're being so creative!", voluntarily showing her work to older CB youth) • Experiencing tensions with certain peers • Displaying interest and investment in group projects • External recognition from peers (e.g., peer-nominated for Youth Advisory Board, volunteered for activities by peers) • External recognition from instructors (e.g., receiving an award at the symposium) • Advocating for her peers (i.e., sticking up for her friend)
	Group work interactions. Sub-codes include: • Roles in her group (e.g., leader, key contributor, team player, "carrying the team") • Engagement and interest in learning activities during group projects (e.g., brainstorming a story, coding, costume design and construction)