Empowering Historically Underrepresented Youth in STEM: Integrating Environmental Justice and Data Science in Relevant and Agentic Lessons

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Submitted to the Graduate Faculty of the

School of Education in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2024

UNIVERSITY OF PITTSBURGH

SCHOOL OF EDUCATION

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April 1, 2024

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The evolving landscape of global environmental crises juxtaposed with the persistence of gender and racial gaps in STEM highlights the imperative for a critical, intersectional environmental justice movement that can equip youth with the computational thinking skills and social justice dispositions needed to address our world's most pressing problems. This need served as a catalyst for the development of a long-term, research-practice partnership (RPP) among a university, a computer science education organization, and urban, rural, and suburban school districts to iteratively address problems of practice related to the creation of a computer science educational pathway.

In response to findings from the RPP's previous studies, the team designed and implemented a project integrating environmental justice and data science in relevant and agentic lessons. Across three articles, this dissertation seeks to understand the influence of the curricula on youth participants (n=731), the implementation of the curricula in twelve third through eighth-grade classrooms, and the needs of classroom teachers to successfully facilitate learning that creates conditions that can empower young people, especially those historically underrepresented in STEM.

Delving into mixed methods research, the first study examines the impact of teacher-designed curricula that seamlessly integrate environmental justice, computer science, and data science. This explanatory sequential design study's findings demonstrate how these innovative

STEM curricula can catalyze the development of youth occupational identity while creating conditions that can empower historically marginalized students to boldly reshape and reinvent occupational landscapes. The second article, a comparative case study within a more extensive mixed methods explanatory sequential design, exposed the relationship between student and teacher conceptualizations of environmental justice. The third conceptual article responds to an absence in the field and a growing need, illuminated in the first two studies, to develop the Critical Environmental Justice for Teaching and Learning (CEJ4T&L) framework. Ultimately, CEJ4T&L seeks to cultivate environmental literacy and create conditions that empower youth to resist and dismantle the environmental racism threatening our planet's future through liberating pedagogies that cultivate transdisciplinary, critical problem-solving skills and a commitment to social justice.

Table of Contents

List of Tables

List of Figures

Acknowledgements

This dissertation is dedicated to my family. My parents (Steve and Margaret), words cannot express my gratitude for the support you have given me over the years in pursuit of my dream to be a science teacher educator. You were a source of constant motivation and have always been there to lift me up even when I could not see a path forward. This dissertation is as much yours as it is mine.

To my sister (Amy) and brother-in-law (Jimmy, aka Jimothy), thank you for showing up for me every step of the way. To my niece and nephew (Cecilia and James), thank you for bringing me joy throughout this process. Cece, you even got to press the button to send my dissertation to my committee! One of the highlights of my graduate experience was returning to Pennsylvania and spending more quality time with you. I am so grateful for the Costellos and Planks as well. I especially miss my grandparents and hope my journey would make them proud.

To my advisor, Cassie Quigley, thank you for your support and mentorship throughout these years. Thank you for trusting me and opening the doors to unimaginable opportunities. To my committee, Bea, Danielle, and Veena, thank you for helping me remember my why and for helping me grow as a scholar. To Tinukwa, Emily, Eleanor, Steve, Aileen, Gary, and Heather thank you for going above and beyond to support me at Pitt. To “Cathy” for being the most epic writing backdrop.

To Ogechi, thank you for your friendship, all the volleyball and milkshake breaks, and for planting writing trees with me. To Hillary, my academic sister, thank you for always being my partner, sounding board, and conference buddy. To Anna, I can always count on you to show up. There is no one I would rather share a defense day with and thank you for sharing Grendel with Merry and me. To Debralyn, my day one LSAP buddy, I am so proud of us! We made it, and we did some good along the way. To Sarah, Meghan, Olivia, Hannah, Terrence, Leyla, Erin, and bri, thank you for helping me navigate graduate school and for the years of friendship. To my current and former Pitt students, thank you for your words of encouragement, inspiring me, and keeping me grounded in my why.

To Camp Kirchenwald, thank you for sparking my love of teaching and outdoor education. To my Tulsa family, thank you for believing in me and inspiring me even though we were so far away from each other. To my Hale Junior High family and my former students, I thought of you every step of the way. Thank you for teaching me to be resilient, critical, and hopeful.

Thank you to my sweet pup, Merry Christmas. You bring so much joy to my life, and you have been there every step of the way, reminding me to get outside and appreciate the little things. I cannot wait for our next adventure.

Last but not least, I want to thank all the students and members of the research-practice partnership for sharing your experiences and learning alongside me. Your contributions made this work possible. For everyone's generous contributions and support, I am beyond grateful. Thank you.

1.0 Introduction

Environmental justice has been a passion of mine since I was a child, and this passion grew into a career that influenced this dissertation and how I conceptualize environmental justice. I was exposed to the idea of environmental justice and the fact that manipulating Mother Nature comes with a price from a very young age. My father was a forest ranger, and he nurtured in me a deep connection with nature alongside a nuanced understanding of human impact on the environment. I was also privileged to spend my childhood summers exploring the woods and lake at my family's farm at the pinnacle of Cambria County, not far from Johnstown, Pennsylvania. The unassuming Little Conemaugh River and the busy railroad tracks made infamous by an unnatural disaster, the Johnstown Flood, ran directly next to my mother's childhood home in Summerhill, PA, shown in Figure 1 (Google Earth, 2024).

Toward the end of the 19th century, Johnstown was a booming iron, coal, and steel industry hub in Western Pennsylvania. The air was thick with smog from factories, the dense forests of the Allegheny mountains surrounding the city were harvested for industry, and the Conemaugh River's channel narrowed from the discarded industrial byproducts like slag. These human impacts on the environment made the people of Johnstown more vulnerable to annual flooding in the Spring. To escape the hustle and bustle of industry, those who were made unimaginably wealthy by the labor of the people of Johnstown created an escape high above it in the South Fork Fishing and Hunting Club and beautiful, manmade Lake Conemaugh. The members of the club ignored repeated warnings that the earthen South Fork Dam would eventually fail, and on May 31, 1889, it did just that, killing over 2,000 people in towns and villages in the path of the unstoppable wall of water and debris (Roker, 2018).

The proximity of my grandparents' home and our family's farm to the site of the United States' deadliest flood coinciding with the fact that my grandfather had been the President of the Johnstown Flood Museum and a board member of the Cambria County Historical Society, meant that I was keenly aware that the 1889 Johnstown Flood had been one of the earliest examples of how people with power and privilege can recklessly manipulate nature and the environment for their benefit with historically marginalized people paying the ultimate price. The Johnstown Flood is the earliest mainstream example of a key point of the Environmental Justice Movement in the United States that is often overlooked by those who focus solely on saving the planet or on humanity's impact on the environment. The Johnstown Flood and its aftermath illuminated "the simple idea that those who create risk, and have the ability to reduce risk, must bear responsibility for costs of that risk—even when all they may have intended was restoration of their souls by healthful recreation…" (Roker, 2018, p.260). It is a story of intent versus impact, natural processes versus human intervention, and illustrates the relationship between power, privilege, and environmental justice.

My personal connection to nature and passion for the environment was nurtured by the unique privilege of enjoying peaceful recreation on a lake built by my grandfather high in the Allegheny Mountains. While our family's small lake was carefully constructed in a way that did not pose dangers like Lake Conemaugh and the South Fork dam, the irony of my complicated relationship with the "villains" of the Johnstown Flood story is not lost on me. As I wrote this dissertation, I took breaks in nature by riding my bicycle through a university named after Andrew Carnegie and parks named after other prominent members of the South Fork Fishing and Hunting Club, like Henry Clay Frick and Andrew Mellon, who were complicit in actions that led to the unnatural disaster at Johnstown. My connections to the Johnstown Flood not only opened my eyes to a deeper understanding of the way power and privilege mediate humans' impact on the environment and the ways that impact inequitably harms people with less power; it also helped me understand the discomfort educators and learners can feel about their own complicated relationships with environmental justice.

From experience, I know that discomfort can lead to avoidance, defensiveness, and actions coming from a place of guilt. Through the process of articulating salient aspects of my identity and experiences, I purposefully lean into the discomfort and analyze ways that it may influence my research. For me, environmental justice through a critical lens emphasizes how systems of power and privilege cause humans to harm other humans through harming the environment. Using a critical lens, we can move beyond awareness of the issue and analysis of why it happens, to action, allyship, and co-conspiratorship towards an environmentally just world.

In Windschitl et al.'s (2018) *Ambitious Science Teaching*, the authors describe a framework for science teaching through an investigative cycle where learners construct initial models of scientific concepts and phenomena based on their own backgrounds, experiences, and prior knowledge. As their teachers facilitate the investigative cycle, students collectively make sense of evidence presented in various learning experiences to refine and build upon their initial model. In this dissertation, I refer to a widely accepted definition of environmental justice from the United States Environmental Protection Agency.

> Environmental justice is the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work (United States Environmental Protection Agency, 2022).

This definition is part of my prior schooling knowledge. My conceptualization and initial model of environmental justice came from a combination of this definition, my socialization, and my experience as a science teacher. Over the past five years, I have added additional experiences and evidence as my mental model of environmental justice has shifted from something that resembled the United States Environmental Protection Agency's definition to what I present in my third dissertation article, a framework for teaching and learning about critical environmental justice.

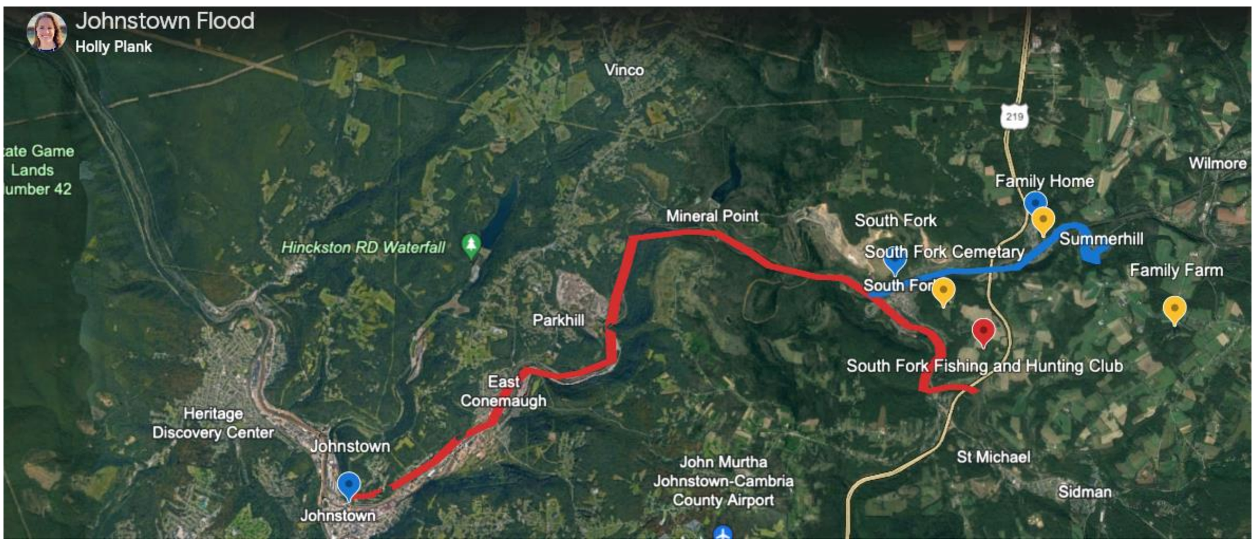


Figure 1. Johnstown Flood Path

1.1 Researcher Positionality

In the previous section, I shared my positionality regarding environmental justice. As an educational researcher, it is also crucial for me to acknowledge my unique constellation of identities, experiences, and perspectives that influenced how I designed the studies in this dissertation and how I collected, analyzed, and interpreted the qualitative and quantitative data

(Milner, 2007), and how I made sense of the contributions of the articles. Several aspects of my identity were especially salient as a researcher member of the research-practice partnership and a former practitioner. First and foremost, I am a white person at a predominantly white institution. I am also a former middle school and physical science teacher, outdoor educator, and current pre-service teacher educator. I identify as a cis woman in the female-dominated field of education, but at the same time, my gender identity is underrepresented in Earth and Space Science.

My former students at Hale Junior High School in Tulsa, Oklahoma, also influenced my choice to engage in this work. The vast majority of my students were considered historically underrepresented in STEM. I loved watching their occupational identities evolve from their responses on our “getting to know you” survey during the first week of my eighth-grade science class to their high school graduation and beyond. When I asked them what they remembered from our class or what inspired their occupational pathway, they never recollected a teacher-centered lecture or cookie-cutter laboratory investigation. Instead, they described outdoor field experiences, engaging with local scientists about their science fair projects, citizen science initiatives, and projects that focused on real-world problems in our community. The lessons and projects they remembered years later were community-based and relevant to their interests. They gave my students a sense of agency where our learning environment positioned them as problem solvers and competent sensemakers.

My former students’ memories, the assets they brought to our classroom, and the lessons that got them fired up informed the lessons I wrote for the Environmental Justice Institute professional development, which I will describe later in this chapter. They also influenced the questions I ask in interview protocols and how I interpret data and literature throughout my dissertation. At the same time, my background and experience did not mirror that of most of my students. I grew up with access to the outdoors and the power and unearned privilege that comes with walking through the world as a white person. For those reasons, I also considered how I am uniquely positioned to elevate environmental justice issues among teachers and school communities who have the privilege of seeing it as a global issue that impacts others, not necessarily them. Creating conditions that empower historically underrepresented youth in STEM is, in my opinion, a collective responsibility of STEM educational researchers and teacher educators. STEM educators must start with and center equity and justice in our decision-making to foster environments that can empower youth, especially those historically underrepresented in STEM, to address our world's most pressing problems.

My "why" behind becoming a science educator is to create conditions to empower all students, especially those historically excluded from nature and underrepresented in STEM, to create pathways and futures that allow them to address the problems they really care about. As I transitioned from a full-time classroom teacher to grappling with my power and responsibility as a white person engaging in research at a predominantly white institution, I needed to confront my relationship with settler colonialism.

To confront settler colonialism in my research, I must move from simply acknowledging my positionality to acting on my principles in designing and carrying out my studies (Patel, 2021). Throughout the process of creating this dissertation, I was careful to align my actions with my values. In this case, one of my values is research driven by the immediate needs and interests of students and their teachers. The studies in my dissertation originate from questions, concerns, and barriers that surfaced when students, teachers, school leaders, and research team members described their experiences. When educational researchers deeply embed themselves in a reciprocal research-practice partnership, they need to listen and respond to the needs of the practitioners.

Transformational educational research cannot happen in isolation. While I led the tool design, data collection, analysis, and writing of the articles in this dissertation, my research-practice partners supported many aspects of this work. Our research team includes two graduate students and a faculty member from a predominantly white institution. All three of us are former classroom teachers from different grade levels, subjects, and regions of the country.

1.2 Background

Over the past decade, there has been a proliferation of educational research about ways to support the empowerment of historically underrepresented, marginalized, and excluded youth in science, technology, engineering, and mathematics (STEM), and especially computer science, within Pre-K-12 contexts (Cheryan et al., 2015; Madkins et al., 2019; McAlear et al., 2018; Quigley et al., 2023; Ryoo et al., 2020; Tan & Calabrese Barton, 2016; Tissenbaum et al., 2019). The reasons for this emphasis on historically underrepresented youth in STEM span from an extension of civil rights and social justice movements in science education (Dimick, 2012) to the ongoing need to meet the increasing demand for a diverse pool of workers in rapidly evolving STEM (Marshall & Grooms, 2022; National Science Board, 2019), and national security (National Commission on Excellence in Education, 1983) careers, to concerns over disproportionate dropout rates in related higher education programs (Falco, 2017; NASEM, 2021), to the need for diverse perspectives to innovate and address “wicked problems” in STEM (Wright & Monsour, 2020). Rittel and Webber (1973) refer to a problem as “wicked” if it has complex causes and complex solutions. Representation in STEM is itself a wicked problem (Davenport et al., 2021). At the same time, diversity of thought and perspectives is needed to address global wicked problems like climate change and environmental justice (Wade et al., 2020). Despite the efforts of countless practitioners, scholars, organizations, and government initiatives, inequities in STEM persist.

While the literature often emphasizes inequity among racial and gender identities, other intersecting lines of difference can illuminate inequities in STEM, including but not limited to socioeconomic status, neurodiversity, physical ability, sexual orientation, immigration status, native language, and urbanicity. Urbanicity is used throughout this dissertation to describe whether the school district is situated in an urban, suburban, or rural setting. Language like urban, rural, and suburban is sometimes used in educational research and practice circles as coded language to describe the racial and socioeconomic diversity and access to funding associated with different school districts. While this stereotype often reflects reality in our partner schools, I also make the distinction to emphasize the proximity and relationship to urban infrastructure, industry, green spaces, nature, and environmental hazards.

Ultimately, inequitable representation in STEM across lines of difference results from overlapping systemic inequities, including barriers to accessibility for pathways to opportunity from an early age (Zarrett & Malanchuk, 2005), retention in high-quality informal and formal STEM programs (Witherspoon et al., 2016), experiences of success (Callahan et al., 2019), exclusionary learning environments (Arif et al., 2021), stereotypes (Luo et al., 2020; 2021; Master et al., 2016), and value alignment (Beyer, 2014).

Many programs and initiatives designed to engage historically underrepresented youth in computer science are offered in out-of-school and informal educational environments (Peppler & Bender, 2013). Consequently, students already interested in computer science are attracted to and opt into these programs. Programs and initiatives accessible to all students in formal Pre-K-12 learning environments are often based on scripted curricula that are not culturally relevant, responsive, or sustaining (Madkins et al., 2019). Underfunded schools are frequently pressured to focus on tested subjects and do not have the capacity to hire or train faculty to teach traditional computer science, let alone design and facilitate culturally relevant computer science curricula (Code.org, 2020; Goode et al., 2020). A teacher who uses culturally relevant computer science pedagogical practices would leverage students' lived and cultural backgrounds and experiences as asset-based resources to design and facilitate computer science curricula that center on issues of equity and justice (Madkins et al., 2019).

On the other hand, traditional computer science curricula can perpetuate stereotypes and create conditions that empower only those who are already interested in computer science or see themselves represented in the curricula (Cheryan et al., 2015). As a result, school-based computer science continues to marginalize girls and students of color, leading to underrepresentation in related occupations and lower higher education graduation rates (Carter, 2006).

The evolving landscape of global environmental crises juxtaposed with the persistence of gender and racial gaps in STEM highlights the imperative for a critical, intersectional environmental justice movement that equips youth with the computational thinking skills and social justice dispositions needed to address our world's most pressing problems. This need served as a catalyst for the development of a long-term, research-practice partnership (RPP) among a university, a computer science education organization, and urban, rural, and suburban school districts to iteratively address problems of practice related to the creation of a justice-centered STEAM (science, technology, engineering, the arts and humanities, mathematics) and computer science educational pathway.

Since the mid-twentieth century, critical research and critical theory have drawn scholars seeking to critique or disrupt the systems of power and domination in both the processes of traditional research and the content of that research (Kincheloe & McLaren, 2011). Critical educational practitioners and researchers build on Dr. Paulo Freire's (1970) philosophy of critical pedagogy (Cachelin & Nicolosi, 2022; Freire, 1970). In his book *Pedagogy of the Oppressed*, Freire argues that teaching and learning must be liberatory in nature by centering on social justice issues (Freire, 1970). More recent abolitionist teaching scholars including, Dr. Bettina Love, argue for teaching and learning that emphasizes joy. "Abolitionist teaching is not just about tearing down and building up but also about the joy necessary to be in solidarity with others, knowing that your struggle for freedom is constant but that there is beauty in the camaraderie of creating a just world" (Love, 2019, p. 120). Freire and Love's scholarship seeks to disrupt and reimagine educational systems that continue to marginalize historically minoritized youth through a critical lens. The work of these scholars has influenced my understanding of abolitionist teaching, liberatory education, and critical pedagogy. My dissertation work is in conversation with this discourse as it applies to STEM teacher education and environmental justice education.

My dissertation contains three articles, the first two of which are empirical explorations of the work of the Computer Science/ STEAM Pathways RPP. In response to the observations and findings of the first two empirical articles, the third article proposes a conceptual framework for critical environmental justice specifically for teaching and learning contexts. The framework leverages critical pedagogical practices and builds on Pellow's (2018) critique of the environmental justice movement. "A critical justice view of equity works to disrupt the systems that historically have shaped inequalities and how they mediate day-to-day experiences while also cultivating empowering teaching and learning interactions, outcomes, and structures" (Tan &

Calabrese Barton, 2018, p. 50). Pellow also argues that the environmental justice movement needs to be intersectional across lines of difference including race, socioeconomic status, gender, ability, and more (2018). A fundamental purpose of working toward a critical environmental justice framework is to move environmental justice education to action that centers on intersectional social justice.

1.3 The Computer Science/STEAM Pathways RPP

This dissertation leverages data, findings, and learning from the Computer Science/ STEAM Pathways Research-Practice Partnership's Environmental Justice Pathways project. Before diving into the project, it is important to understand how an RPP is different than traditional research. Developing RPPs is an increasingly popular strategy for addressing the research-practice gap in education in ways that allow partners to center equity and work across lines of difference (Farrell et al., 2022; see also Akkerman & Bruining, 2016; Coburn et al., 2013). Farrell et al. (2022) define RPPs as "a long-term collaboration aimed at educational improvement or equitable transformation through engagement with research. Participants organize these partnerships intentionally to connect diverse expertise and shift power relations in the research endeavor to ensure that all partners have a say in the joint work" (p.4).

RPPs are also a mechanism for disrupting traditional power dynamics in institutional research, addressing problems of practice like representation in STEM, and implementing new science standards through long-term, mutually beneficial collaborations among researchers and practitioners (Farrell et al., 2022). RPPs must be reciprocal for each partner, sustainable, and a mechanism for boundary-crossing or working across lines of difference (Akkerman & Bruining, 2016; Plank et al., 2023).

The vision for the Computer Science/ STEAM RPP stems from the ongoing work of one school district identified with the pseudonym “Falcon View” in my dissertation’s first and second studies. Falcon View is a growing suburban public school district in Western Pennsylvania. This district had previously developed a robust STEAM program vertically and horizontally aligned across grade levels and content areas. Falcon View has offered summer learning opportunities, organized by their director of technology and innovation, for interested school leaders and STEAM-related teachers across the region’s urban, rural, and other suburban school districts.

Falcon View School District wanted to build on its strength in STEAM or transdisciplinary problem-based instruction (Quigley & Herro, 2016) to address a problem of practice. This dissertation broadly refers to the STEM field and STEAM as an approach to learning about STEM through transdisciplinary problem-solving in educational settings. The problem of practice in the Computer Science/STEAM Pathways RPP revolved around the fact that students in the district who were opting into elective computer science courses and, ultimately, computer science-related post-secondary majors and careers mirrored troubling national trends, meaning they were disproportionately white and male. By creating a third through eighth-grade pathway for computer science using their strength in STEAM instruction as a resource, Falcon View hoped it could disrupt that pattern to eventually make elective high school computer science courses more representative of the district’s demographics. The district’s director of technology and innovation partnered with two leading STEAM educational researchers and graduate students with practitioner experience and research interest in STEAM (including myself) to launch the RPP in 2019 collaboratively.

The teacher participants, their grade-level, content, school, and number of students who opted into participating in the research study are shown in Table 1. Interested STEAM-related teachers and school leaders who had previously participated in Falcon View's summer learning opportunities were invited to collaborate in a new state grant-funded project to improve computer science and computational thinking skills. Specifically, the founding members of the RPP wanted to develop a third through eighth-grade computer science and STEAM pathway in the region beyond just Falcon View during the 2019-2020 academic year (see Year 1/ Project 1 in Figure 2).

Our team designed a study in the first of five projects to understand how teachers designed and implemented lessons that integrated computational thinking and collaborative problem-solving in a STEAM context (Herro et al., 2021). We found that approximately 85% of the participating practitioners successfully implemented computational thinking skills and practices, but data analytics was largely absent in their teaching practice and instructional unit design (Quigley et al., 2023). Our research team also found that historically underrepresented students in computer science were more likely to engage in computational thinking lessons that were culturally relevant (Herro et al., 2021). Student interviews indicated that students participating in the study, especially girls and students of color, were interested in addressing problems related to social justice and the environment, such as climate change, food deserts and insecurity, and pollution.

During the height of the COVID-19 pandemic, research team members worked on a second project with one of the partner schools to address the problem of practice of what it takes to launch a new RPP between formal and informal education partners (see Project 2. In Figure 2). The research team leaders applied for funding to engage in a third project, building on the successes and addressing the challenges that surfaced during the first project. The purpose of this third project, The Environmental Justice Pathways Project, was three-fold. First, the research team would use what they learned in the second project to strengthen the RPP and ensure alignment between members and the collective vision. Second, research and practice partners would work together to address the design and facilitation gap of data analytics from the previous project. Third, the data analytics component of computational thinking would be integrated into lessons that were relevant to students, centered justice, and fostered student agency (see Project 3 in Figure 2).

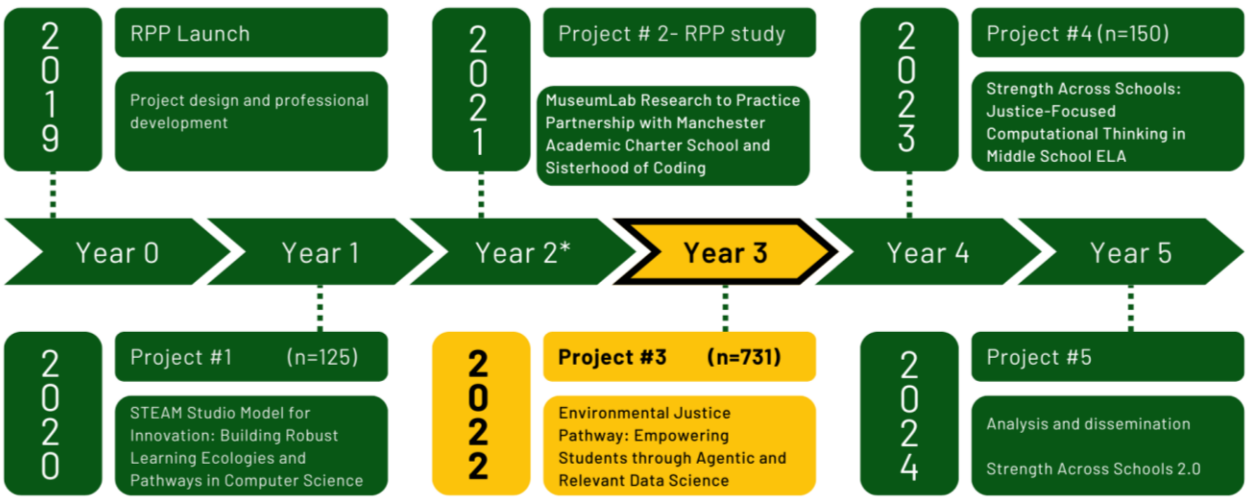


Figure 2. Computer Science/ STEAM Pathways RPP Timeline and Project Descriptions

Table 1. Environmental Justice Pathways Research Participants

	School*	Teacher* & Grade	Subject	*n*
Rural	Greenridge Elementary & Middle (Public)	Polar, 5	STEAM	18
		Ridge, 6 & 7	Computer Science	62
	Forest Hills Elementary (Public)	Fern, 3	STEAM	66
		Primrose, 4	4th Grade	33
		River, 5	5th Grade	14
	Skyline Middle (Public)	Plum, 6	Science	54
		Maple, 6	STEAM	
Suburban	Falcon View Elementary & Middle (Public)	Winter, 4 & 5	Technology	226
		Luna, 4	STEAM	259
		Lotus, 8	Computer	80
		Meadow, 7 & 8	Technology	78
Urban	Sporting Green Elementary (Public)	Summer, 5	Science	34
	Mountain Vista Middle (Charter)	Dahlia, 6	Math	33
		Rose 7	Science	23
		Wren, 8	Engineering	15

Note. n=Number of students who completed the post-survey. *All school and teacher names have been changed to protect the identity of the individuals.

1.4 The Environmental Justice Pathway Project

Our research team collaborated with interested practitioner teacher leaders to develop a co-generative professional learning model that started with a co-created workshop for participating teachers to learn strategies for integrating environmental justice and data science in the Fall of 2021. Our team chose environmental justice due to its relevance for students, lack of representation in Pennsylvania state-mandated standards at the time, and potential for integrated, agentic data science lessons that would engage historically underrepresented youth in meaningful problem-solving.

On the first day of the workshop, the researchers provided participants with a framework for understanding the connections between environmental justice and data science and the project objectives in whole group sessions. The practitioners could also engage in the example lesson plans from a student's point of view. The model lessons allowed them to explore tools for integrating environmental justice and data science, such as the Citizen Science Interactive app. The app's creators at Data for Good at Columbia University designed the app to allow students to engage in data science practices by exploring natural disasters. Our participants could also interact with low-tech options for integrating data science and environmental justice in relevant and agentic lessons. These low-tech experiences included hand-drawn data collection and data visualizations. At different points throughout the day, the facilitators gave practitioners opportunities to reflect on how they could apply these tools and strategies in their context, share their experiences and ideas with other members of the research-practice partnership, and start to collaboratively plan instructional units they would implement later in the school year. On the second day, practitioners could choose sessions based on their grade band, content, and interest. Researchers and practitioners facilitated these sessions within the research-practice partnership. After engaging in the sessions, the practitioners had time to collaboratively design integrated instructional units using the tools from the institute. During this time, the session facilitators were available for feedback and collaboration.

Practitioners received three comprehensive example instructional units and an instructional unit plan template, all of which I designed, shown in Appendix A. Each example lesson utilized different tools that the teachers experienced in the Environmental Justice Institute, including the Smell My City app (Smell My City, n.d.), Coding Nature, and the Citizen Science Interactive app. The template, which I designed, allowed teachers to articulate the standard alignment, objectives, lesson sequence, real-life applications, career connections, and student agency. There was space for teachers to write notes for each lesson's preparation, assessment, and extensions within the instructional unit plan. Additionally, the template supported teachers in planning for integration by providing them with relevant computational thinking competencies and practices and guiding questions for the environmental justice component. These guiding questions included prompts such as: 1) How can we ensure everyone can access a healthy environment to live, learn, and work? 2) How can we use data to understand where (or how) environmental issues impact communities of color and high poverty more than other communities? Brief descriptions of the teacher-designed lesson plans are included in Appendix A.

The research team supported teacher participants in developing instructional units with lessons that integrated environmental justice and data science. The teachers who opted in to the research study taught the instructional units to 995 students in twelve third through eighth-grade classrooms. The quantitative data is from 731 students with parent/guardian consent and who assented to take both the pre- and post-surveys. This data was used in the first and second empirical studies in this dissertation. The findings from these studies influenced the design of the conceptual framework in the third article: a concept paper addressing challenges that members of the RPP faced while teaching and learning about environmental justice.

1.4.1.1 The Project's Connection to Statewide Policy Implementation

In 2015, the Commonwealth of Pennsylvania published the Pennsylvania Environmental Literacy Plan, which builds on the goals of the Pennsylvania Environmental Education Act of 1993 (PDE, 2015). The plan includes four overarching goals aligned with the Mid-Atlantic Elementary and Secondary Environmental Literacy Plan, the North American Association for Environmental Education Guidelines for Excellence, and the Chesapeake Bay Program Environmental Literacy Indicator Tool (CBF, 2014; NAAEE, 2021; PDE, 2015; Sickler, 2018).

The Pennsylvania Department of Education is making statewide policy changes to implement its environmental literacy plan (ELP) by including environmental literacy and justice in its state education standards. These amendments should be foregrounded by first building an understanding of the impact of environmental injustices such as poor air quality, water contamination, exposure to dangerous chemicals, insufficient access to green space, inequitable protection from increasingly extreme weather, and more in local communities and schools. The Environmental Justice Pathways Project explored data that illustrates environmental injustices such as these through culturally and locally relevant curriculum design.

The Environmental Justice Pathway project is a design-based project that occurred within an ongoing RPP between university researchers and third through eighth-grade classrooms in rural, suburban, and urban districts in Western Pennsylvania. As Pennsylvania started implementing the new science and technology standards, the focus on environmental justice became even more relevant because policymakers explicitly included it in the environmental literacy and sustainability section of the latest standards adopted in 2022 (PDE, 2022).

This dissertation, as well as the Environmental Justice Pathways project within the Computer Science/STEAM Pathways RPP, seek to directly support the first goal of the Pennsylvania Environmental Literacy Plan, "every student in the region graduates with the knowledge and skills to make informed environmental decisions" (NAAEE, 2021; PDE, 2015). What sets this work apart is the commitment to centering justice in student-centered lessons that are relevant to them and providing them with the agency to use data to make environmental decisions can create conditions that empower youth, especially those historically underrepresented in STEM, to continue to make informed and just decisions beyond the formal education context.

The implications of this project and dissertation also align with the second goal of the Pennsylvania Environmental Literacy Plan, "all educators in the region responsible for instruction about or in the environment have access to sustained professional development opportunities, tools, and resources that support their efforts to provide students with high-quality environmental education" (NAAEE, 2021; PDE, 2015). Our research team published the relevant and agentic lessons created by the practitioners in the project on a public webpage. The work has also informed curriculum frameworks for the new Pennsylvania Environmental Literacy and Sustainability Standards, and a pre-service STEM teaching and learning methods course that I redesigned and piloted at my university.

1.4.1.2 Situating the Environmental Justice Pathways Project

Before collecting data in the Environmental Justice Pathways Project, I also engaged in a geospatial analysis of the region where I located the RPP schools to understand their proximity to "Environmental Justice Regions" and how that may impact the knowledge and experience each school's students and teachers bring to the curricula. This process was part of an effort to map out ways a conceptual framework for critical environmental justice in teaching and learning could support educators and youth in the geographic region of the Computer Science/ STEAM Pathways RPP.

To uniformly define these areas in different contexts, the Pennsylvania Department of Environmental Protection (PA DEP) highlights census tracts where 20% or more of the population lives in poverty or 30% or more is considered a minority (PA DEP, 2024). PA DEP uses the language "non-white" to describe people whose racial and ethnic identities are historically minoritized and oppressed in the context of the United States (2024). It is also possible for both predetermined factors to be true. Environmental Justice regions are essentially areas vulnerable to anthropogenic and natural environmental hazards. Historically, Environmental Justice regions are also areas where populations with power and privilege tend to use the NIMBY (Not in My Backyard) concept to shield themselves from the hazardous effects of consumption of the Earth's natural resources (Gibson, 2005). These regions do not provide insight into possible sources of environmental hazards and the proximity of point sources to vulnerable populations that can be found through mapping and geospatial analysis. Air pollution, water pollution, and residual waste sources were derived from larger themes of Pennsylvania Environmental Protection Agency monitoring locations. These points are known pollutant release zones (see Figure 19 in Appendix A).

Mapping and spatial analysis through Geographical Information Systems (GIS) allows educational researchers to visualize spatial and geographic relationships and draw conclusions from relatively transparent tools (Hogrebe et al., 2008; Rodriguez et al., 2016). Geospatial representations can provide a unique perspective on how some environmental justice indicators are distributed across the RPP's region and school districts in the Environmental Justice Pathway study.

Kelly (2019) highlights the promise of mapping and geospatial techniques for educational research but implores researchers to carefully consider historical context in GIS studies. Pacheco and Valez (2009) developed Critical Race Spatial Analysis (CRSA), a method of mapping and spatial analysis that allows researchers to explore inquiries related to educational equity with historical context in mind through "geographic and social spaces" (p. 293). Vélez and Solórzano later operationalize CRSA as "an explanatory framework and methodological approach that accounts for the role of race, racism, and white supremacy in examining geographical and social spaces and that works towards identifying and challenging racism and white supremacy within spaces as part of a larger goal of identifying and challenging all forms of subordination" (Vélez & Solórzano in Morrison et al., 2017, p.20).

This process of mapping environmental justice regions and hazards in relationship with partner schools in the Computer Science/ STEAM Pathways RPP influenced the design and facilitation of the Environmental Justice Institute professional development, informed conversations with members of the RPP, and inspired practitioners to use mapping as a data science process to engage students in seeing the complexity of gaining access to information that reveals environmental injustices in their communities and around the world.

1.5 Overview of the Literature Reviewed

Pre-K-12 STEM educators are uniquely positioned to provide support and access to educational opportunities that can liberate and empower historically underrepresented youth to leverage computational thinking skills to address our world’s most pressing problems, like those related to environmental justice. Educators need quality training at the pre-service and in-service levels to effectively design and implement curriculum and learning environments that positively influence students' occupational identity development and conceptual understanding of environmental justice.

Computational action is a framework that connects the broader field of computing with opportunities for youth to engage in community-based problem-solving (Tissenbaum et al., 2019). When educators view computing through a social justice lens, their students can relate directly to computer science content that may otherwise feel disconnected from their lives. Therefore, authentically integrating a justice-centered concept like environmental justice can bridge computing (and, therefore, data science) and computational action, as illustrated in Figure 3. The RPP focused on environmental justice in response to youth interest and its alignment with computational action. Forming a deeper understanding of environmental justice provides students with opportunities to learn about circumstances that can directly impact their lives and communities. They can also experience digital empowerment by using a critical lens to collect, analyze, visualize, and communicate with data connected to environmental justice.

Figure 3. Digital Empowerment Through the Integration of Data Science and Environmental Justice

One of the goals of my dissertation is to determine ways that educators can build learning environments that can empower youth, especially those historically underrepresented in STEM, by designing and facilitating curricula that integrate computational thinking and environmental justice in relevant and agentic lessons. These conceptual threads, the methods of engaged research within RPPs, and mixed methods connect the three articles beyond the story of how they originated.

Across this collection of articles, I reviewed a broad range of research, including over 200 papers altogether. The literature reviews are divided between the three articles in Chapters two, three, and four. This introductory chapter presents a concise overview of the significant literature, as each article is embedded within its distinct literary context. The objective of this section is to situate the studies within the broader landscape of educational research literature. Subsequent sections outline core themes and summarize the main topics that are throughlines between the three articles. Key points from the literature bases unique to each article are also synthesized.

1.5.1 Underrepresented Youth in STEM

The 2022 Science and Engineering Indicators report by the National Science Board reveals disparities in the demographic makeup of the STEM workforce in the United States compared to the proportions in the overall employed population. Despite some progress in increasing representation from historically underrepresented, marginalized, and excluded groups of people in the STEM fields, women still comprise only 26% of computer and mathematical scientists and 16% of engineers, significantly lower than their 48% representation in the general workforce. Similarly Black or African American individuals comprise 5.7% of computer and mathematical scientists and 4.0% of engineers, which is lower than their 7.2% representation in the broader workforce. Latinx individuals constitute 6.3% of computer and mathematical scientists and 8.3% of engineers, compared to 9.2% of the workforce. Conversely, men comprise 74.2% of computer and mathematical scientists and 83.9% of engineers despite representing only 52.1% of the workforce. Asian individuals represent 25.3% of computer and mathematical scientists and 17.2% of engineers, exceeding their 13.5% representation in the general workforce (Bureau of Labor Statistics, 2020; National Science Board, 2022). Scholars debate whether Asian boys should be considered overrepresented or underrepresented in discussions about computer science and STEM education (United Nations Department of Economic and Social Affairs, 2020; Varma, 2018). Either decision oversimplifies a very complex reality. Based on the initial choices of the research team, the first article in this dissertation uses the term overrepresented to denote white boys and underrepresented to denote students that self-identify as girls, transgender, non-binary, or a third gender, Black, Latinx, Native American, Pacific Islander, or multiple races. Multiple qualitative data sources are emphasized in the study to understand data trends on a more individual student level. In the second study, I chose to group self-identified Asian boys into the underrepresented youth category for the quantitative data analysis to better represent the historical relationship between social identity and power and privilege in the United States.

Cheryan et al. (2017) explained the more significant gender gaps in computer science and engineering with 1) masculine cultures in these occupations, 2) insufficient early educational experience, and 3) gaps between genders in self-efficacy. Washington (2020) calls for more cultural competence in computing at the undergraduate level to decrease attrition between major selection, degree completion and getting and maintaining a job in the computing industry. While the 2021 State of Computer Science Education report from code.org, Computer Science Teachers Association (CSTA), and the Expanding Computing Education Pathways (ECEP) Alliance celebrated an increase in K-12 computer science offerings from 2018, there is still much room for improvement. For example, the report showed that 49% of students enrolled in computer science at the elementary level identify as female. Still, that number drops to 44% in middle and 31% in high school. Disparities also persist in access to quality computer science programs in schools with higher percentages of historically underrepresented and economically disadvantaged students (Code.org, 2021; CSTA, 2021). This literature aligns with the observations of the researchers and practitioners in the Computer Science/STEAM RPP.

1.5.2 Occupational Identity Development

How do youth develop discipline-specific and occupational identity in computer science? Youth occupational identity development encompasses their self-concept, self-efficacy, and sense of belonging related to their desired future career (Callahan et al., 2019). Occupational identity, a youth's vision of their future selves in the workforce, is often missing from elementary and middle school educational experiences (Callahan et al., 2019). However, educators can leverage the knowledge of the tenets of occupational identity development to positively influence adolescent's educational experience and strengthen pipelines in STEM occupations for students with historically underrepresented race and gender identities (Callahan et al., 2019; see also Cheryan et al., 2015; Dou et al., 2021; Kalender et al., 2019; Kang et al., 2019). Self-efficacy in discipline-specific tasks can influence the development of discipline-specific identity (Kalender et al., 2019) and occupational identity (Bandura et al., 2001). Pajares and Miller found that self-efficacy was a more robust indicator than self-concept of success with discipline-specific problem-solving strategies in mathematics (1994). Their study showed that self-efficacy also mediated the effect of gender on self-concept and supported Bandura's theory (Pajares & Miller, 1994).

Belonging is an identity concept that comes with ongoing participation and builds on the foundations of self-concept through exposure and self-efficacy through engagement (Callahan et al., 2019; see also Hagerty et al., 1995; Mahar et al., 2013; Whiting et al., 2018). While students can experience a sense of belonging in traditional school settings related to their occupational identity development, our framework suggests a connection between belonging and student engagement in a professional community of practice (Callahan et al., 2019). In a traditional school setting, a professional community of practice for computer science might look like a coding club. Opportunities for students to engage in authentic communities of practice tend to occur in out-of-school time settings, which is beyond the scope of this study.

Homophily, or when youth tend to bond with those with whom they have a cultural affinity, can hinder belonging and occupational identity development for historically underrepresented youth (Callahan et al., 2019). Affinity-based mentorship and participation in authentic communities of practice can address this barrier. Callahan et al.'s framework (2019) comes from the Connected Learning Alliance. This non-profit organization centers equity, learner-centered approaches, and digital media technologies in out-of-school time learning contexts. We, therefore, did not think it was practical to expect the influence of authentic participation to improve youth's sense of belonging in computer science, data science, and environmental justice in a formal school setting. Instead, we focused on the first two influences of occupational identity development, including exposure and engagement, for the Environmental Justice Pathways project studies.

1.5.3 Content Integration

The practitioners and researchers in the Computer Science/ STEAM Pathway RPP have expertise in content integration and, specifically, transdisciplinary pedagogies centered in STEAM instruction. The goal of the RPP was to build a computer science pathway by leveraging strengths among the researchers and practitioners in STEAM learning. Despite the expertise of the researchers and some of the practitioners of the RPP in content integration, disciplinary divisions of content that silo teachers are still very prevalent even in upper elementary and middle school classrooms. There is no widely accepted definition of the overarching concept of content integration or the individual types of content integration, including interdisciplinary, multidisciplinary, and transdisciplinary content integration (Quigley et al., 2020; Roehrig et al., 2021).

STEAM is a transdisciplinary learning process that integrates contents within science, technology, engineering, the arts and humanities, and mathematics as needed to address real-world problems (Quigley et al., 2017). Transdisciplinary learning exists on a continuum of content integration that educators can use to move beyond traditional, disciplinary, or multidisciplinary learning that starts with the subject matter (Quigley et al., 2017; Radakovic et al., 2022; Vasquez et al., 2013; Wang & Knoblach, 2018). While transdisciplinary learning that centers the problem first can be more rigorous and realistic, there is a time and place for disciplinary, multidisciplinary, and interdisciplinary learning (Helmane & Briska, 2017; Rennie et al., 2012).

The STEM education field is built on a foundation of content integration or connections between the disciplines of science, technology, engineering, and mathematics (Roehrig et al., 2021; Wang et al., 2011). Content integration can occur at a multidisciplinary level across multiple classrooms, the interdisciplinary level, where more than one discipline is used to address problems, or the transdisciplinary level, where disciplines are brought in as needed to address a real-world problem (Bybee, 2013; Quigley et al., 2019; Roehrig et al., 2021). The purpose of the Computer Science/STEAM RPP's Environmental Justice Pathway project called for content integration, and the practitioners designed curricula that lent themselves to mostly interdisciplinary and transdisciplinary learning.

1.5.4 Computational Thinking

Figure 4 shows the theoretical connections between computer science, computational thinking, and data science (K-12 Computer Science Framework Steering Committee, 2016; Mills et al., 2021; Weintrop et al., 2016). There are seven Computer Science Core Practices: "1) fostering an inclusive computing culture, 2) collaborating and computing, 3) recognizing and defining computational problems, 4) developing and using abstraction, 5) creating computational artifacts, 6) testing and refining computational artifacts, and 7) communicating about computing" (K-12 Computer Science Framework Steering Committee, 2016).

Core practices three, four, five, and six in Figure 4 inform the Computational Thinking Skills and Computational Thinking Practices. The computational thinking skills include abstraction, algorithmic thinking, debugging, decomposition, pattern recognition, and selecting tools (Barr & Stephenson, 2011; Mills et al., 2021). There are also three computational thinking practices, including automation, computational modeling, and data practices (Mills et al., 2021). While data science can include aspects of all the skills and practices for computer science and computational thinking, Mills et al. categorize them into three overarching skills: collecting, analyzing, and visualizing and communicating with data (2021). The findings from the previous computational thinking study in the RPP indicated that practitioners in this RPP needed more support in designing and implementing the data science and analysis component of computational thinking (Herro et al., 2021).

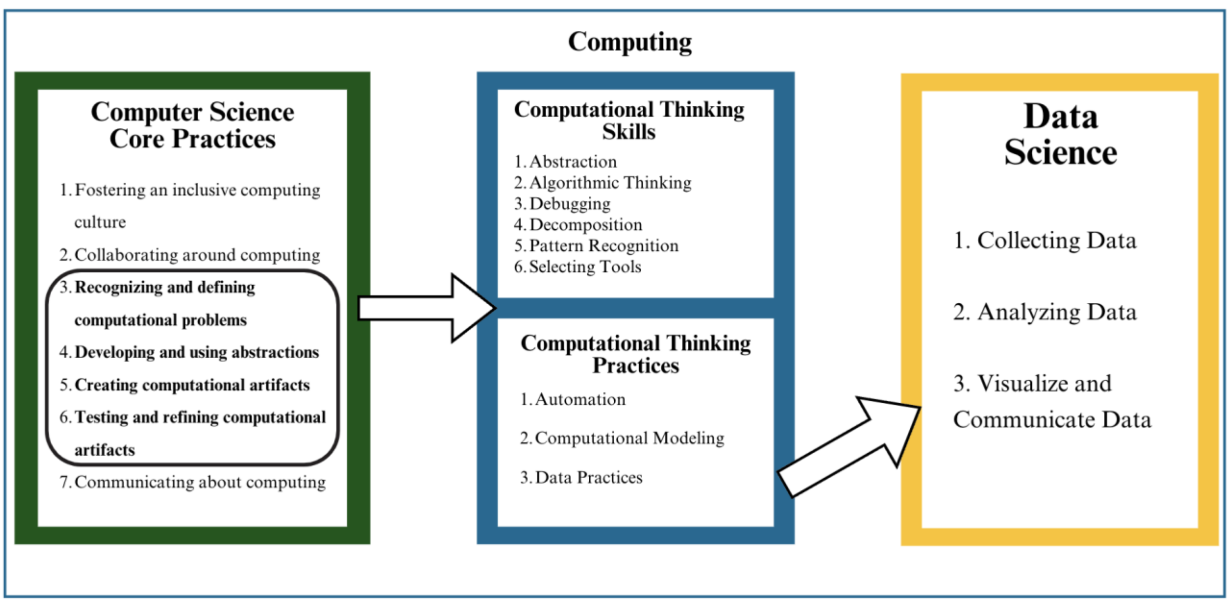


Figure 4. Connections Between Computer Science, Computational Thinking, and Data Science

1.5.5 Critical Environmental Justice

The scope of the Environmental Justice Movement has broadened over time to encompass various other justice movements, such as climate justice, water justice, food justice, and health justice (Adamson, 2011; LaDuke et al., 2009). At its core, the Environmental Justice Movement builds on the environmentalism movement focused on sustainability, preservation, and human impact on the environment to reveal ways that environmental benefits and impacts from environmental harms, both natural and unnatural, are inequitably distributed among populations of people along lines of race and socioeconomic status in particular (Bullard, 1994; Kushmerick et al., 2007; USEPA, 2022). The emphasis of Critical Environmental Justice moves beyond sustainability and inequitable impact to interrogate the structures of power and privilege that cause environmental racism (Pellow, 2018). The conceptual framework for Critical Environmental Justice for Teaching and Learning aligns with Pellow's critiques of the Environmental Justice Movement and the foundational concepts of his framework for critical environmental studies, and it translates this work for educational researchers, classroom teachers, curriculum writers, and policymakers for teaching and learning contexts (Pellow, 2018).

1.6 Overview of the Methodological Approach and Trustworthiness

I collected all the quantitative and qualitative data and have been part of data collection for other studies in the RPP since 2019, as illustrated in Figure 2. My first two empirical studies and third conceptual article used the data and experiences from project three in year three of the RPP, highlighted in yellow in Figure 2. The conclusion chapter of my dissertation discusses how these studies and the third project influenced subsequent projects and studies.

Before collecting data, I held meetings to explain the consent and assent procedures. I prioritized consistency in data collection and the study design to form a level of recognition and comfort between the researchers, practitioners, school administrators, and students. I interviewed students and teachers in places where they were comfortable. The research team interviewed students in small groups, often on the classroom floor, where they had been working on activities related to the instructional unit. Teachers had the option to Zoom in from their homes for their interviews.

My colleagues and I collected several primary and secondary data sources to better understand the nuances of the classroom learning environments and elevate student experiences. In addition to the surveys and interviews, we collected instructional unit plans and student work and photographed student work. We recorded students explaining their projects to establish a more holistic picture of the student and teacher experiences in the project. Interacting with students during the instructional unit plans allowed them to make their thinking visible in a low-stakes environment. The lesson observations also gave us a shared starting point in small group interviews. We took collaborative field notes during observations and recorded memos afterward to capture our questions and reflections.

This data was used in the first and second studies in my dissertation. While collecting and initially analyzing the data for the first study, I developed the idea for the second study. Practitioner members of the RPP mentioned that students were very invested in the environmentalist aspects of the work, Still, they were not necessarily getting the human, justice aspect of it in some of the partner schools. I designed the second study to understand some of the tensions they had mentioned and what I saw in the data. The third conceptual article came from a need I saw throughout the study and in my service work outside of the RPP to support classroom teachers with ideas and strategies for teaching environmental justice.

The two empirical studies in this dissertation leverage the strengths of quantitative and qualitative methods through mixed methods study designs. Both studies use an overarching explanatory sequential mixed methods design where the quantitative and qualitative data are collected in parallel and analyzed separately (Creswell & Plano Clark, 2018). The quantitative portions of the studies analyze different constructs within the pre- and post-survey given to student participants before and after they engaged in the integrated curriculum. Creswell and Plano Clark argue that mixed methods research addresses "a need to explain initial results," "enhance an experimental study with a qualitative method," "to describe and compare different types of cases," and a need "to obtain more complete and corroborated results" (2018, p.9-11). Given the magnitude of the Environmental Justice Pathways project, the diversity of the classroom contexts as cases, our rich data collection, and the nature of research questions, mixed methods study design was essential.

The Environmental Justice Pathway pre- and post-survey consists of demographic information, a series of Likert-type questions that were constructed based on a series of previously validated rubrics in the field (Bandura, 2006; Herro et al., 2017; Langheinrich et al., 2016; Marsh & O'Neill, 1984; Shavelson et al., 1976; Tsai et al., 2019) and a series of short answer questions. The survey asked students to self-report demographics like gender, race, grade level, teacher, school, birthday, city, and country of birth. Students answered brief questions about their current understanding of environmental justice, computer science, and data science. The Likert-type questions were modified based on grade level, so the elementary and middle school students took survey versions. The questions were grouped into categories that measured self-efficacy, self-concept, interest, and identity within the three disciplines. In the post-survey, students were also asked questions to help them reflect on their experiences with the curricula. See Appendix A for a complete list of questions on each survey.

Likert-type questions are prevalent in educational research surveys because they can help measure self-reported dispositions and attitudes among students, educators, administrators, or families (Chen & Liu, 2020; Likert, 1932). However, there is an ongoing, unresolved debate in educational research as to whether Likert-type scale survey data should be treated as nominal data that can only be categorized, or as ordinal data that can be categorized and ranked, or as interval data that can be categorized, ranked, and evenly spaced in quantitative data analyses (Chen & Liu, 2020). This dissertation treats the same pre- and post- survey data differently depending on how it is used in the two mixed methods explanatory sequential design studies.

In the first study, the Likert-type data is a dependent variable analyzed through descriptive statistics and transformed into an interval variable to analyze variance between underrepresented and overrepresented populations. In the second empirical study, the Likert-type data is also a dependent variable analyzed through descriptive statistics and transformed as a nominal and ordinal variable to analyze variance without rank. The quantitative data in both mixed methods studies was secondary to the more robust qualitative analyses. The quantitative analyses occurred first alongside data exploration to determine trends, tensions, and questions that could be explained and explored with the qualitative data sources. When a more robust collection of qualitative data sources is used to explain a less substantial quantitative pre- and post-survey analysis, Creswell and Plano Clark recommend abbreviating this study design as quan + QUAL= to demonstrate the weight of each method, their relationship to each other, and their relationship to the studies' outcomes (2018). Participants represented in the quantitative and qualitative data sets are described in Appendix A.

Numerous qualitative data sources are used differently in the two empirical articles to understand student experiences, teacher experiences, curricula design and implementation, and the learning environment where students were constructing knowledge and engaging in sense-making. Appendix A shows the lesson plan template each teacher-practitioner used to design their relevant and agentic instructional unit for the project. Chapter 3 includes vignettes from some of the lesson plans as part of the qualitative data analysis, and a brief description of each instructional unit design is also included in Appendix A. The semi-structured interview protocols for the teachers and student focus groups are also included in Appendix A alongside the elementary version of the post-survey. A semi-structured interview protocol allowed our research team to connect the interview protocol to predetermined conceptual and thematic frameworks while maintaining an informal conversational feel with participants that coincided with the flexibility to respond to the context of the observation and students' responses (Adams, 2015).

The conceptual paper, on the other hand, uses a combination of narrative and analytical review methodologies to provide an overview of the primary debates in environmental justice education, assess how the education field is moving forward with critical theories, and inform a conceptual framework for Critical Environmental Justice for Teaching and Learning (CEJ4T&L) that can be used as a tool for educational researchers and practitioners (Amorim-Maia et al., 2022; Greene et al., 2006). This combination allows the engaged research methods associated with a RPP and the findings in the first two empirical studies to be used alongside literature review methods to build a conceptual framework.

1.7 Organization of the Dissertation

Chapters two, three, and four are fully contained articles following a three-article dissertation structure, including introductions, literature reviews, methods, results, and discussions. Chapter five discusses common themes and next steps in science education research.

2.0 Study 1: Using A Mixed Methods Explanatory Sequential Design To Understand How Integrated Curricula Shapes Youths' Occupational Identity

This mixed methods explanatory sequential design study was part of a long-term research-practice partnership (RPP) between researchers at a university, a computer science education organization, and rural, suburban, and urban school districts in the Western Pennsylvania. In response to a previous study within the RPP, this study explored the impact of teacher-designed curricula integrating environmental justice and data science on youths' occupational identity development in twelve 3rd- 8th grade classrooms.

The purpose of this study was to explore how youth participating in curricula integrating data science and environmental justice influences their self-efficacy in related occupations. Key findings suggest that teachers can create conditions that nurture youth self-efficacy through curricular influences including exposure and engagement with representative role models and designing learning experiences that center student agency and relevant civic action. Youth resisted occupational identity development initiatives geared toward a specific occupation by reimagining career pathways to center justice and leverage computational thinking skills.

Keywords: occupational identity development, self-efficacy, self-concept, computational thinking, data science, Environmental Justice, research-practice partnership, integrated curriculum

Using a Mixed Methods Explanatory Sequential Design to Understand How Integrated Curricula Shapes Youth's Occupational Identity

Youth occupational identity development encompasses self-concept, self-efficacy, and belonging related to their desired future career (Callahan et al., 2019). Career pathways (Zhang & Barnett, 2015), vocational identity (Chen & Solberg, 2018), and occupational identity development (Callahan et al., 2019) are more common topics in high school and post-secondary contexts than elementary and middle school education experiences. However, educators can leverage the knowledge of the tenets of occupational identity development to positively influence adolescent's educational experience and strengthen pipelines in STEM occupations for students with historically underrepresented race and gender identities (Callahan et al., 2019; see also Cheryan et al., 2015; Dou et al., 2021; Kalender et al., 2019; Kang et al., 2019).

The purpose of this study is twofold: first, to explore how youth participating in curricula integrating data science and environmental justice influences their self-efficacy in related occupations; second, to provide implications for teacher educators and research-practice partners to support youth self-efficacy development. This dual focus on theory and practice allows us to critically examine equity, justice, and opportunity-gap implications.

This study is part of an ongoing research-practice partnership (RPP) between a university, a computer science education organization, and Western Pennsylvania rural, suburban, and urban school districts. The RPP exists to iteratively address problems of practice related to the creation of STEAM and computer science pathways in partner school districts. In response to a previous study within the RPP this study explores the impact of teacher-designed curricula integrating environmental justice and data science on youths' occupational identity development in twelve third through eighth-grade classrooms.

2.1 Introduction

Computer science learning in the broader educational landscape concentrates on out-of-school time learning opportunities or elective courses (Peppler & Bender, 2013). Even when traditional schools incorporate computer science during the day, the programs are frequently taught with pre-designed curricula or as one-off lessons disconnected from the mainstream curriculum (Carr & Cooper, 2019; Grover & Pea, 2018). Existing pre-designed curricula often need to be better connected to students' interests, daily lives, backgrounds, and prior experiences to successfully engage learners, particularly those historically underrepresented and marginalized in computer science and engineering (Cheryan et al., 2015; Ryoo et al., 2020). Although the conversation about relevance and access in computer science is familiar, only a few computer science learning opportunities still center on culturally relevant pedagogy or social justice (Madkins et al., 2019).

The RPP designed this study to respond to the gaps found in a previous research study in the Computer Science/ STEAM Pathways RPP. Figure 5 shows the connections between computer science, computational thinking, and data science (Mills et al., 2021; see also Computer Science Teachers Association, 2013; Grover & Pea, 2018; Wing, 2008). The Computer Science Core Practices used in early childhood to post-secondary education contexts include four practices directly aligned with crucial skills and practices in computational thinking (Mills et al., 2021). Computing is an umbrella term that includes the computer science field and the computational thinking framework (Mills et al., 2021; see also Computer Science Teachers Association, 2013; Grover & Pea, 2018; Tissenbaum et al., 2019; Wing, 2008). The researchers used these connections to support practitioners' understanding of the connections between data science and computer science. This project built off the foundational work the RPP by building data science into the pathway by providing students with opportunities to understand the data science processes of asking questions, observing, gathering, and organizing data, analyzing, synthesizing, and communicating findings (Lee et al., 2021).

An essential component of justice-centered education is environmental justice, a movement that emerged in the 1980s to combat environmental racism and respond to the limitations of mainstream environmentalism (Bullard, 1993; Morales-Doyle, 2017). Infusing environmental justice was an opportunity to make computer science and data science more relevant and accessible to students. By focusing on data science, teachers allow students to consider data related to their lives and communities and create representations, solutions, and a deeper understanding of environmental justice. Digital empowerment is a concept discussed in the field of computer science education by Tissenbaum et al. (2019). By integrating environmental justice and data science content in lessons that center student agency and relevant problem solving, the practitioners in the Environmental Justice Pathways project facilitated opportunities for their students to be empowered through computational thinking, specifically data science. When students explore justice-oriented topics and address problems they care about using their computational identity, they exemplify digital empowerment (Tissenbaum et al., 2019; see also Freire, 1970; Thomas & Velthouse, 1990).

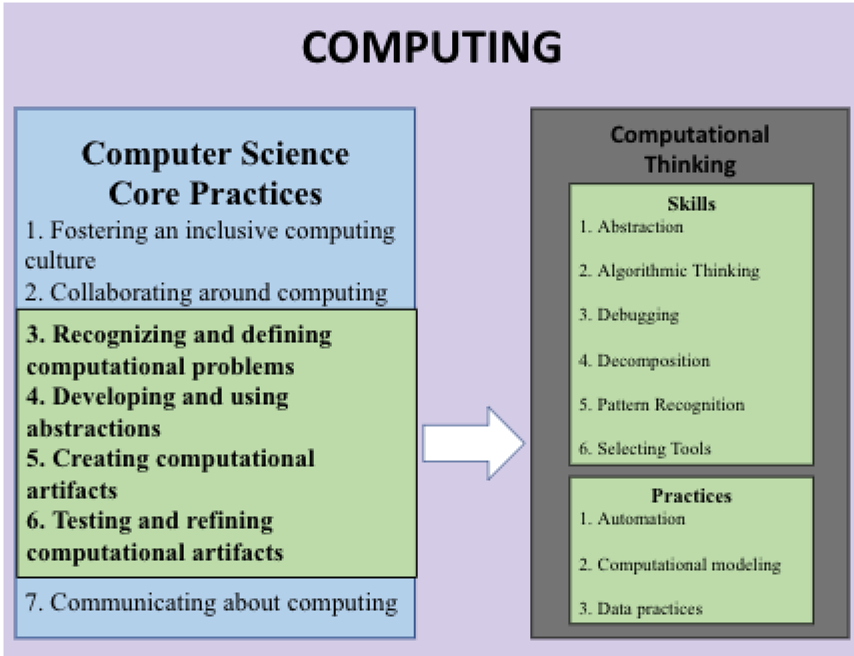


Figure 5. Data Science Connection to Computer Science

2.2 Background

2.2.1 Historical Representation

According to the National Science Board's 2022 Science and Engineering Indicators report, although some STEM fields have reached parity levels across gender and race, there is persistent and significant racial/ethnic and gender inequality in engineering and the computer/information sciences. The racial and gender demographics of the STEM labor force in the United States do not reflect the proportions of these groups in the general employed population. While there have been improvements in the proportion of workers from historically underrepresented races and ethnicities in the STEM labor force, women comprise 26% of mathematical and computer scientists and 16% of engineers (compared to 48% in the United States workforce). Black people or African Americans represent 5.7% of computer and mathematical scientists and 4.0% of engineers (compared to 7.2% of the United States workforce). Latinx people represent 6.3% of computer and mathematical scientists and 8.3% of engineers (compared to 9.2% of the United States workforce) (United States Bureau of Labor Statistics, 2020; National Science Board, 2020; 2022). On the other hand, men account for 74.2% of computer and mathematical scientists and 83.9% of engineers while only representing 52.1% of the U.S. workforce. Asian people represent 25.3% of computer and mathematical scientists and 17.2% of engineers compared to 13.5% of the United States workforce (National Science Foundation, 2011; National Science Board, 2020).

Although the United States has increased its support of STEM education since 2009, gender and racial inequities remain (Jarrett, 2015). Based on this data, this paper will use the term overrepresented to denote white and Asian boys and underrepresented to denote students that self-identify as girls, transgender, non-binary, or third gender, Black, Latinx, Native American, Pacific Islander, or multiple races.

2.2.2 Youth Occupational Identity Development

Not only is environmental racism/injustice more likely to affect girls, non-binary youth, and youth of color, but these demographics are also significantly underrepresented in computer science. Computer science, engineering, and environmental justice careers must be more representative. Understanding factors influencing youth's occupational identity development for specific career pathways is essential. Issues of relevance and access are not new. Various identity development frameworks can help researchers understand factors that influence interest, engagement, sense of recognition, self-efficacy, self-concept, performance-competence, participation, sense of belonging, identity, and motivations to pursue and sustain a career in a specific discipline (Callahan et al., 2019; Dou & Cian, 2021).

A recent report from the Connected Learning Alliance detailed social and behavioral science influences and barriers to how youth develop occupational identity or formulate a vision for themselves in the workforce (Callahan et al., 2019). This study explores occupational identity development in youth in formal schooling for grades three through eight. Figure 6 shows a funnel of influences and occupational identity outcomes in adolescence (Callahan et al., 2019). Figure 7 shows a similar model of barriers to occupational identity development and their related outcomes. These figures illustrate that a person's identity outcomes of self-concept, self-efficacy, and belonging are connected to their influences of exposure, engagement, and participation (Callahan et al., 2019). Given the short implementation period for the curricula intervention in this study, we focus on the foundational role of youth's sense of belonging played by self-concept and self-efficacy.

Racial and gender differences persist in computer-related self-efficacy (Cheryan et al., 2015; Dou et al., 2021; Tsai et al., 2019) and self-concept (Hoffman et al., 2019; Hur et al., 2017; Janneck et al., 2013; Langheinrich et al., 2016; Madkins et al., 2020; Sainz & Eccles, 2012) as well as related STEM fields (Bandura et al., 2001; Bui & Miller, 2016; Callahan et al., 2019; Dou & Cian, 2021; Kalender et al., 2019; Kang et al., 2019; Pajares & Miller, 1994).

When educators expose students to a curriculum related to an occupation, they develop mental models that influence their self-concept or self-evaluation of their current abilities and capacities (Callahan et al., 2019; Hur et al., 2017). Research on self-concept is well-established, and there has been a rise in computer-related self-concept research in the last two decades (Janneck et al., 2013; Langheinrich et al., 2016; Madkins et al., 2019; Sainz & Eccles, 2012; Shavelson et al., 1976). Students' self-concept influences their occupational identity and more immediate choices to pursue related activities or leadership roles within them (Pajares & Miller, 1994; Callahan et al., 2019). Self-concept and its related influences and direct outcomes are at the top of the funnel in Figure 6.

As we move down to the middle section of the funnel in Figure 6, students engage in activities in the curriculum with knowledge and skill objectives that parallel professional practices. This process influences students' self-efficacy or their subjective sense of their ability or capacity to be successful in the future (Bandura, 1977; Callahan et al., 2019; Hoffman et al., 2019). It has been widely accepted that self-efficacy in computer science is intertwined with general academic learning achievements and computational thinking skill-learning performance (Tsai et al., 2019; see also Callahan et al., 2019; Cheryan et al., 2015; Hur et al., 2017; Kalendar et al., 2019).

Researchers can use Bandura's integrative theoretical framework to better understand students' experiences in an integrated curriculum. Bandura argues that a person's self-efficacy will determine whether they approach a task, persist through challenges, and perform successfully (1977). An integrated curriculum designed to support computer science and environmental justice can set students up for exposure to the necessary building blocks for self-efficacy described by Bandura, including performance accomplishments earlier in their Pre-K-12 career, vicarious learning, social persuasion, and emotional arousal (1977).

Self-efficacy and self-concept provide a foundation for belonging in STEM careers (Callahan et al., 2019). We cannot build a practical pathway to belonging, the last section of the funnel in Figure 6, without understanding how the integrated curriculum in upper elementary and early middle grades can influence youth's self-efficacy and self-concept. We sought to understand better the relationship between participation in a curriculum integrating data science and environmental justice on youth's occupational identity development or vision of their future selves in the workforce. To this end, we intend to address the following research questions:

1. How and to what extent does participation in a curriculum integrating data science and environmental justice influence youth's self-concept and self-efficacy in related occupations?
2. How does participating in a curriculum integrating data science and environmental justice influence youth's occupational identity?

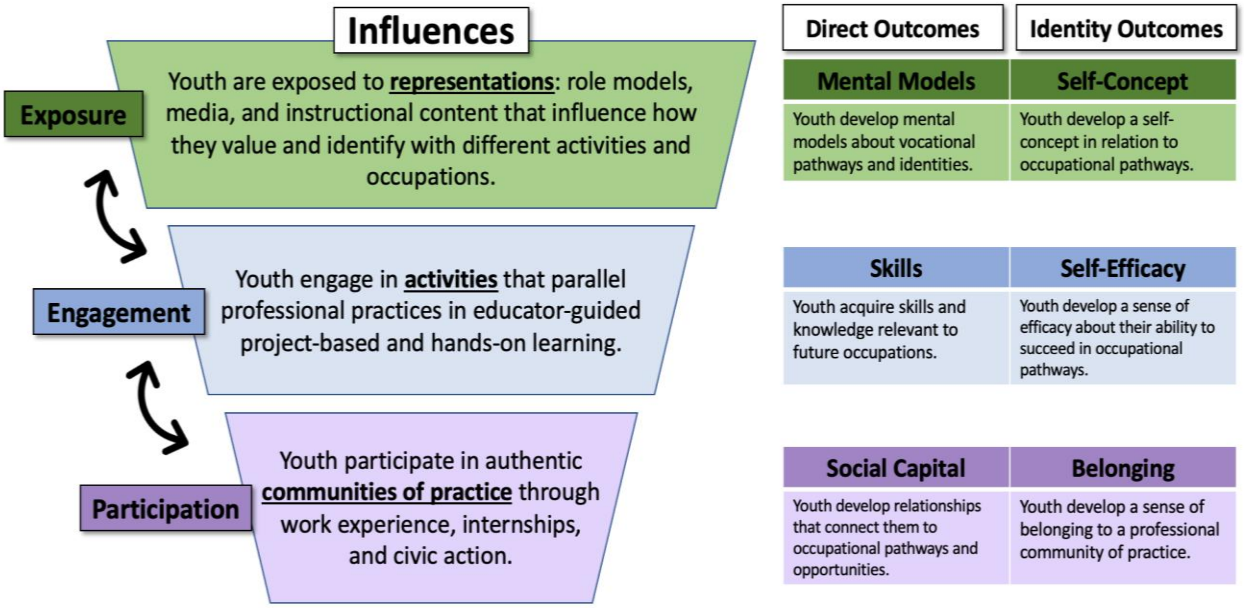


Figure 6. Funnel of Influences and Occupational Identity Outcomes

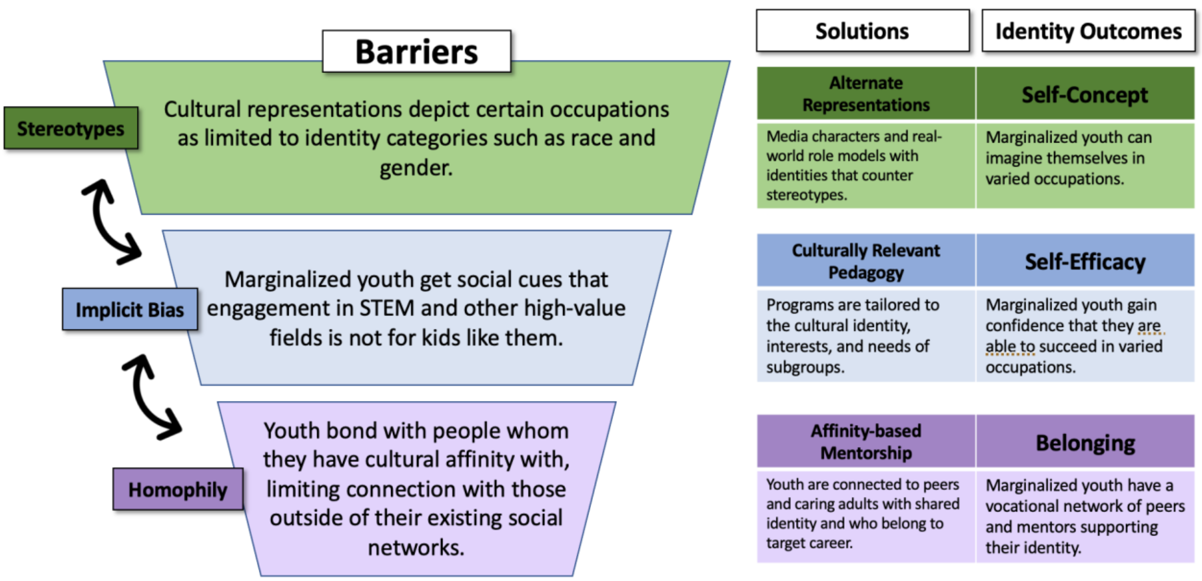


Figure 7. Funnel of Barriers and Occupational Identity Outcomes

2.3 Methodology

2.3.1 Positionality

As educational researchers, we acknowledge that our identities, backgrounds, and experiences influence how we design our studies and collect, analyze, and interpret data (Milner, 2007). To confront settler colonialism in educational research, we move from acknowledgment to action in how we designed and carried out our study (Patel, 2021). Our research team includes four white women. Two members are graduate students at predominantly white institutions. One member runs an educational consulting business and is the former director of innovation at one of the school sites. The other member is a faculty member at a predominantly white institution. Each research team member is a former classroom teacher from a different grade level, subject, and region of the country.

2.3.2 Data Sources and Collection

The 12 classroom teacher participants include practitioner members of the existing research-practice partnership and additional teachers who attended a co-generated environmental justice and data science integration workshop and volunteered to participate in the research component. Table 19 in Appendix B includes each teacher's grade level, subject, school, and urbanicity (whether the school is considered urban, suburban, or rural) and the number of student participants in their classrooms.

Before collecting data, the research team held meetings to explain the consent and assent procedures. I prioritized consistency in data collection and the study design to form a level of recognition and comfort between the researchers, practitioners, school administrators, and students. The students and teachers were interviewed by the research team in places where they were comfortable. The research team interviewed students in small groups, often on the classroom floor, where they had been working on activities related to the instructional unit. Teachers had the option to Zoom in from their homes for their interviews.

The research team collected several primary and secondary data sources to understand better the nuances of the classroom learning environments and student experiences. In addition to the surveys and interviews, the team collected instructional unit plans and student work, photographed student work, and recorded students explaining their projects. Interacting with students during the instructional unit plans allowed them to make their thinking visible in a low-stakes environment. The lesson observations also gave us a shared starting point in small group interviews. The research team took collaborative field notes during observations and recorded memos afterward to capture our questions and reflections.

Before implementing the instructional units, the practitioners shared their lesson plans with the researchers for feedback. The researchers administered a pre-survey to students and set up a time to observe a lesson from the instructional unit, interview students, interview the teacher, and administer the post-survey. The time between pre- and post-survey administration varied depending on when the teachers decided to implement the curricula and the length of the instructional unit. Most students had approximately two months between taking the pre- and post-survey. Appendix B also includes information about the integrated instructional unit plans designed and implemented by the practitioners. The participating practitioners teach a variety of content areas, including STEAM, science, math, computer science, technology literacy, technology education, engineering, and self-contained elementary grades.

Pre/Post Student Surveys. An online pre-survey was administered during the fall semester before teachers engaged in lessons or units about environmental justice or data science. The timing of the pre-survey varied due to COVID-19 interruptions. The research team administered a corresponding post-survey after students completed all parts of the integrated instructional unit. The survey included demographic information, including self-described gender and race. The survey also included three sections with eight questions, each on a 4-point scale (1=strongly disagree, 4=strongly agree) related to self-concept, self-efficacy, interest, and identity by disciplines. Self-efficacy questions started with, "I can become good at…." Bandura offers guidance for constructing self-efficacy scales but cautions that there is "no all-purpose measure of perceived self-efficacy" (2006, p.307). Instead, he argues that tools designed to measure perceived self-efficacy must be customized for the discipline (Bandura, 2006). Tsai et al. (2019) developed the Computer Programming Self-Efficacy Scale for Computer Literacy Education (CPSES). CPSES uses "I can" sentence stems to measure self-efficacy related to computer programming domains. "Can is a judgment of capability; will is a statement of intention." (Bandura, 2006, p. 308). Therefore, we use "I can" to understand youth's perception of their self-efficacy related to each discipline. This sentence stem was also applied to environmental justice-related survey questions and data science, an essential aspect of computing.

Self-concept questions used the sentence stem, "I am good at…". Langheinrich et al. (2016) designed a survey instrument that measured multiple dimensions of computer-related self-concept (CSC) based on The Shavelson Model (Shavelson et al., 1976) and the Self-Description Questionnaire III (Marsh & O'Neill, 1984). We focus on the component of perception of individual abilities using the sentence stem "I am good at." Identity questions asked students about their identity with, "I am a(n)..." Finally, interest was gauged using the sentence stem "I like…" The disciplines include environmentalism, data science, and computer science. The research team asked students short answer questions to understand their learning, interests, conceptualization of the constructs, and perspectives on the instructional unit. These statements are shown in Table 3.

Table 2. Occupational Identity Related Constructs on Student Pre/Post Intervention Survey

Occupational Identity Construct	Pre/Post Survey Statement
Self-Concept	
EJ	I am good at caring for the environment.
DS	I am good at making sense of data.
CS	I am good at computer science and coding.
Self-Efficacy	
EJ	I can become good at helping the environment.
DS	I can become good at making sense of data.
CS	I can become good at computer science and coding.
Identity	
EJ	I am an environmentalist.
DS	I am a data scientist.
CS	I am a coder or computer-type person.
Interest	
EJ	I like learning about how to care for the environment.
DS	I like using data.
CS	I like computer science and coding.

Notes: Environmental Justice (EJ), Data Science (DS), Computer Science (CS). Surveys were distributed to students before and after engaging in the curricular intervention.

Collaborative field notes. Each participating teacher invited members of the research team to observe at least one day of their integrated instructional unit. During the observation, research team members recorded observational field notes in a shared document. This format allowed researchers to interact, ask questions, and focus on various aspects of the learning environment.

Semi-structured interviews. Immediately following the observation day, the research team interviewed three to ten students in each of the 12 classrooms. These interviews included questions that allowed students to share their conceptualizations of environmental justice, their connection to it, and their perspective on the instructional unit. One research team member also interviewed each of the 12 teachers after completing the instructional unit and administered the student post-surveys. These semi-structured interviews allowed teachers to give voice to their design, reflect on the implementation, and articulate their conceptual understanding of environmental justice.

Artifacts. All 12 teachers submitted instructional unit plans before the observation. The research team collected student work samples from each teacher. Photos were taken during the observation to capture students' engagement with the content. Following the post-implementation interviews and before submitting finalized instructional unit plans, teachers were encouraged to make revisions based on adjustments to the original instructional unit plans they made during implementation.

Table 3. Descriptions and Contexts for the Environmental Justice and Data Science Integrated Lesson Plans

Lesson Title	Grade/Content	N School Context
Understanding and Educating Others on the Environmental Advantages of Reusable Water Bottles	3rd-5th STEAM	34 Urban Elementary
What's All the Buzz About Bees?	3rd-5th STEAM	66 Rural Elementary
Understanding Human Impact on the Environment Using Data Visualization Techniques Through Earth Time	3rd-5th STEAM	259 Suburban Intermediate School
Coding Nature	3rd-5th Technology Literacy	226 Suburban Intermediate School
The Love Canal Tragedy: A Case Study in Environmental Justice	5th Grade Science	14 Rural Elementary
Community Water Environmental Impact Using Data Visualization Techniques	6th Grade Science	27 Rural Middle School
Environmental Justice: How to Better the Community We Live In	6th Grade STEAM	27 Rural Middle School
Environmental Justice and Data Science	6th Grade Math	33 Urban Middle School
Environment Data Driven Letter	8th Grade Math	15 Urban Middle School
Understanding Environmental Justice Through the Use of MIT App Inventor	6th-8th Technology Education	78 Suburban Middle School
Sustainability Challenge: Sustainable Agriculture Cultivated by Today's Young Minds	7th Grade Science	23 Urban Middle School
Using Visualizations to Inspire Curiosity: How Does Our Environment Affect Us?	8th Grade Computer Science	80 Suburban Middle School

Note: Full lesson summaries available upon request

2.4 Analysis

We used an explanatory sequential mixed methods design (quan+QUAL=) that collects quantitative data first and then explains the quantitative results with in-depth qualitative data (Creswell & Plano Clark, 2018). In the first quantitative phase of the study, we collected pre- and post-survey data from third through eighth-grade students at urban, suburban, and rural schools in Western Pennsylvania to assess if participating in instructional units that integrate data science and environmental justice influenced their self-concept, interest, identity, and self-efficacy in occupations related to these disciplines.

Given the nature of our study, we look at identity and interest. Identity is a student's conscious awareness of themselves as, in this case, environmentalists, computer scientists, and data scientists. However, academic interest is a topic or field a student wants to explore further. Identity and belonging are the last aspects of occupational identity to develop, so we consider academic interest a precursor to identity.

In the second phase, we conducted the qualitative portion of our study as a follow-up to the quantitative results to help explain how participation can shape occupational identity. This exploratory follow-up phase explored aspects of occupational identity, primarily through students' short answer responses and semi-structured small-group interviews. Secondary data sources that supported this analysis included observational field notes, student work samples, and instructional unit plans or individual lesson artifacts.

2.4.1 Quantitative

To answer the first research question, we were particularly interested in ascertaining if there is a statistically significant difference between pre- and post-survey results for self-efficacy. We used paired samples t-tests to determine whether there were statistically significant mean changes in self-concept, self-efficacy, interest, and identity. The research team tested the four constructs for three topics: environmental justice, data science, and computer science. These statistical tests allowed the researchers to explore the dataset and different subsets by grade level, gender, racial identity, and urbanicity.

A paired samples t-test determined whether there was a statistically significant mean change between the pre-and post-survey student-reported self-efficacy in environmental justice. The researchers detected sixteen values that were more than 1.5 box lengths from the edge of the box in a box plot. Inspection of their values did not reveal them as extreme enough to be outliers, and they remained in the analysis. The normality assumption was not violated, as assessed by visual inspection of the Q-Q plot. Students reported higher self-efficacy in environmental justice in the post-survey ($M=3.62$, $SD=.608$), as opposed to the pre-survey ($M=3.54$, $SD=.684$), a statistically significant increase of 0.77, 95% CI (Confidence Interval) [.025, .129], $t\ (730) = 2.895$, $p<.005$, $d=.107$. The mean change was statistically significant from zero. Therefore, we can reject the null hypothesis and accept the alternative hypothesis that the pre-and post-survey results are significantly different. This procedure also tests environmental justice self-concept, identity, and interest (Table 5). The self-efficacy constructs for all three topics were practically greater than the self-concept, interest, and identity constructs even though they were not statistically significant. Students responded more favorably to self-concept, self-efficacy, identity, and interest questions related to environmental justice than data science or computer science.

Table 4. Student Pre/Post Survey Results for Self-Concept, Self-Efficacy, Identity, and Interest Grouped by Environmental Justice, Data Science, and Computer Science Disciplines

Construct	Pre Mean Score (SD)	Post Mean Score (SD)	Mean Change (SD)	r p-value	95% CI LL	UL	t-value	p-value
EJ Self-Concept	.37 (.694)	.34 (.700)	-.029 (.796)	.348 <.001*	-.087	.029	-.976	.329
EJ Self-Efficacy	3.54 (.684)	3.62 (.608)	+.077 (.715)	.392 <.001*	.025	.129	2.895	.004*
EJ Identity	2.84 (1.003)	2.57 (.981)	-.268 (.993)	.500 <.001*	-.340	-.196	-7.302	<.001*
EJ Interest	3.38 (.696)	3.46 (.682)	+.083 (.755)	.401 <.001*	.029	.138	2.989	.003*
DS Self-Concept	2.87 (.853)	2.94 (.919)	+.070 (1.033)	.322 <.001*	-.005	.145	1.830	.068
DS Self-Efficacy	3.14 (.839)	3.19 (.860)	+.050 (1.003)	.303 <.001*	-.024	.123	1.331	.184
DS Identity	2.31 (.972)	2.01 (1.013)	-.296 (1.134)	.348 <.001*	-.378	-.213	-7.032	<.001*
DS Interest	3.03 (.830)	2.96 (.915)	-.072 (1.049)	.281 <.001*	-.148	.005	-1.839	.066
CS Self-Concept	2.86 (.920)	2.87 (.980)	+.014 (.997)	.451 <.001*	-.059	.086	.372	.710
CS Self-Efficacy	3.24 (.859)	3.26 (.911)	+.023 (1.013)	.346 <.001*	-.050	.097	.623	.534
CS Identity	2.62 (1.071)	2.60 (1.120)	-.018 (1.093)	.503 <.001*	-.097	.062	-.441	.659
CS Interest	3.06 (.963)	2.98 (1.050)	-.074 (1.003)	.506 <.001*	-.147	-.001	-1.997	.046*

Note: N=731. This table contains the pre- and post-survey mean scores, mean score difference, 95% confidence intervals, t-value, and p-value for constructs about Environmental Justice (EJ), Data Science (DS), and Computer Science (CS). CI=confidence interval; LL=lower limit; UL=upper limit. *Statistical significance. Pre-surveys were distributed in October/November and post-surveys were distributed after teachers finished teaching the instructional units between December and February.

2.4.2 Qualitative

The qualitative analysis aims to explain the quantitative findings for occupational identity influences and answer the second research question about how participating in the integrated curriculum influences youth's occupational identity. We looked across the 24 small-group student interviews and 731 student short-answer responses. We used an a priori coding scheme based on influences of *exposure* and *engagement* as well as the barriers of *stereotypes* and *implicit bias* to understand students' *self-concept*, *self-efficacy*, *interest*, and *identity* that was also measured in the quantitative data (Saldaña, 2015; Callahan et al., 2019). The a priori coding scheme allowed us to locate specific examples of the eight constructs.

2.5 Results

2.5.1 Quantitative

Table 5 includes quantitative self-concept, self-efficacy, identity, and interest findings. Overall, students reported higher self-efficacy in EJ after engaging in the integrated curriculum in the post-survey (M=3.62, SD=.608), as opposed to before engaging in the curriculum in the pre-survey (M=3.54, SD=.684), a statistically significant increase of 0.77, 95% CI [.025, .129], t (730) =2.895, $p<.005$, d=.107. The self-efficacy constructs for all three topics were practically greater than the others. All four constructs related to environmental justice were greater than data science and computer science.

Given our first research question about self-efficacy, we are particularly interested in the statistically significant increase in self-efficacy in environmental justice and the lack of statistically significant change in self-efficacy for computer science and data science between the pre- and post-surveys. Additionally, we saw a statistically significant increase in environmental justice interest and a decrease in identity for environmental justice and data science.

To explain these quantitative findings and answer the second research question about how participating in the integrated curriculum influences youth's occupational identity development, we turned to qualitative data analysis. We used an a priori coding scheme to explore occupational identity concepts, influences, and barriers related to environmental justice, data science, and computer science.

2.5.2 Qualitative

The qualitative data analysis helped us understand how and to what extent participating in a curriculum integrating data science and environmental justice influences youth's self-efficacy and occupational identity in related occupations. We started with a coding round using an a priori coding scheme to understand occupational identity concepts from Callahan et al.'s conceptual framework, including influences and barriers to occupational identity development (2019). In this way, we aligned our quantitative and qualitative data analysis to Callahan et al.'s conceptual framework on occupational identity (2019).

The three themes, 1) Constructing Mental Models 2) Agency and Relevance 3) Disrupting and Reimaging Career Pathways, come from Callahan et al.'s funnels of influence and occupational identity outcomes (2019). The first and second themes are related to the direct outcomes of exposure, which are mental models and self-concepts concerning occupational pathways. The second theme also connects with one of the outcomes of engagement, which is self-efficacy, because the youth are connecting to future occupational pathways based on their current understanding of the discipline. Engagement also gives students agency through acquired skills and self-efficacy. Finally, youth will need to be able to participate in authentic communities of practice to develop social capital and a sense of belonging. Relevance is a crucial steppingstone to ongoing participation. The final theme moves beyond Callahan et al.'s (2019) occupational identity development framework to represent how youth in the study are pushing back on the very concept of occupational identity development.

2.5.2.1 Constructing Mental Models

The first theme, connections to mental models and pathways, comes from the top level of Callahan et al.'s (2019) Occupational Identity Funnel of Influences in Figure 6. This theme includes three codes representing how teachers' instructional unit design and implementation allowed for connections to mental models or internal frameworks students use to make sense of the world around them and how students described mental models in the interviews. The theme of constructing mental models suggests that exposure to environmental justice and data science through building upon prior formal *school experiences*, making *personal and community connections* to the curricula, and being exposed to meaningful and *representative role models* can influence youth's self-concept and occupational identity development.

School Experiences

In our study, youth discussed exposure to role models, digital media, and instructional content related to data science, computer science, and environmental justice through their experiences in formal schooling. For example, when asked whether the instructional units on environmental justice and data science were necessary, one sixth-grade girl said, “It’s important to teach kids, especially younger ones, so they know they shouldn’t do these things to the environment.” She was referring to litter she photographed while engaging in the Coding Nature-nature walks around her school’s campus. She remembered when she first learned about littering and shared that schools should teach it to kids sooner. This school experience provides a mental model using instructional content to an aspect of environmentalism that supports that is a foundation for environmental justice.

Personal and Community Connections

Youth are constantly building and revising mental models related to their school and personal lives. In our study, youth shared connections between the integrated instructional units and their personal lives outside formal schooling. A fifth-grade boy from the suburban school district shared, “There are a lot more severe storms now and more flooding, which I’ve seen even recently in [hometown] and stuff. So, I feel like that will get worse.” This student connects the instructional content on environmental justice and his experience with increasingly severe weather and natural hazards in his hometown. Another student in the same small group said they had also seen that on the news. This way, personal connections can connect integrated curricula to local community issues.

Representative Role Models

One barrier to exposure, occupational identity development, and self-concept is stereotypes. In our study, students shared comments aligned with typical racist, sexist, ableist, or otherwise oppressive stereotypes, often coinciding with lower self-concept and less personal identification with environmental justice and data science. Other comments were deficit-based or associated with limited "either/or" thinking. For example, one 7th-grade girl shared, "I am not a terribly creative person, so I'm not normally good at MIT App Inventor." This comment does not fit a common stereotype that computer science is not for creative people. However, the student focuses on a perceived deficit in comparison with her peers that negatively influences her self-concept concerning computing.

On the other hand, students were excited to share when their teacher included meaningful role models that disrupted stereotypes in their instructional units. One middle school math teacher shared stories and video clips about her friend, an environmental lawyer, and her brother-in-law, who made a video about environmental justice in his community. She also shared a video about Dr. Robert Bullard, a scholar widely accepted as the father of environmental justice. The teacher, Dr. Bullard, her friend, and her brother-in-law all had racial identities representing the students in the classroom. Another student was impressed that Dr. Bullard is a Black man saying, "That dude is the FATHER of Environmental Justice." This example was the first anecdote the student group surfaced in the interview. Elevating Dr. Bullard in a classroom with primarily Black students disrupts a stereotype about STEM and environmental work perpetuated by systems of oppression that led to historical underrepresentation in the field. These instructional strategies also exemplify the utility of digital media in elevating role models and therefore, supporting youth's development of mental models and self-concept in these occupations.

2.5.2.2 Agency and Relevance

Instructional strategies that allow for student agency and highlight the relevance to instructional content are vital in supporting youth's self-efficacy and self-concept in computing and environmental justice and building a foundation for belonging, ownership, and accountability in the field. This theme includes three related codes: productive struggle, relevance, and locally relevant pedagogy. There were many examples in the data where students highlighted their agency and ability to engage in productive struggle in the lessons. Students shared stories that highlighted how the relevance of the curricula and emphasis on civic action created conditions that empowered them to solve problems they cared about in a formal school environment.

Productive Struggle

To acquire skills and develop a sense of efficacy related to environmental justice and data science occupations, students must be allowed to engage in a productive struggle with skills and practices in computational thinking that parallel professional practices. Students cited computational thinking practices as the primary source of struggle in the integrated instructional unit plans. One 3rd-grade girl talked about how productive struggle influenced her identity development as a coder in response to another student saying they were not a coder because they were "bad" at it. She said she would consider herself a coder "…because anyone who codes are considered a coder. It doesn't say, good coder. It's just a coder. You can be bad, but you're still a coder. You used code." The student has expanded her understanding of what it means to be a coder as a third grader.

Productive struggle supports all three influences and related outcomes in occupational identity. Youth are exposed to instructional content that allows them to build mental models that influence their self-concept. In this case, coding is an activity that parallels computer science professional practice in a hands-on and project-based way. The project-based nature of the curricula gives numerous opportunities for student agencies and a relevant problem to address. These opportunities to practice the skills and experience success after reasonable struggle positively influence self-efficacy. Finally, when youth realize that they do not have to immediately master the knowledge and skills of an occupation to identify with it, they are more likely to express a feeling of belonging through participation in classroom-based communities of practice.

Relevance

For instructional content to be relevant for students, they described the need for it to be useful and interesting. If students could connect the integrated instructional unit and their perceived utility of the knowledge and skills, they would be more likely to speak favorably about it. One 7th-grade boy talked about class activities he found helpful: "[Our teacher] should keep having us do storyboards so we can have our designs ready…we draw our design on paper and then do MIT App Inventor." Storyboarding, an app, is an "unplugged" computational thinking strategy where students decompose the problem, recognize patterns, and iteratively design their computational model.

In our study, teachers often tailored the instructional unit to what they knew about their student's interests. For instance, several students remarked in the small group interview that they loved photography. One teacher mentioned that many students in her class were in the photography club, so she knew she wanted to do Coding Nature after the Environmental Justice Institute workshops.

Locally Relevant Pedagogy

Designing and facilitating a curriculum that is inspired by culturally relevant pedagogy and leverages locally relevant pedagogy is a complex, nuanced process. Our study considered the instructional units somewhat culturally relevant if they centered on justice or civic action and found ways to tailor instruction to students' cultural identities. More teachers were able to infuse locally relevant scenarios and pedagogies in their curricula design and implementation.

Students mentioned how their lessons within the instructional unit were justice-centered when asked to share their understanding of environmental justice. One student said, "Asthma is a big problem [in our community] because the pollution is so bad… They can't breathe!" Another student shared, "All people should be treated equally, no matter how much money they have. Because people who don't have enough money always have to live near very polluted areas." Her group member added, "People with more money have enough money to live away from the polluted areas." Another student shared that exposure to air pollution is something her family has experienced for generations. She shared a story her mom told her. "My mom didn't even know the sky was blue until she was 12… she lived literally right next to a steel mill, so the air was pumped with pollutants, so the sky was yellow…"

A group of students at one of the urban schools brought up safety and foul odors on their walk to school. Interviewer: Are there any of those sources of pollution around here- like an incinerator, a factory, or a landfill? Student 1: Yeah, there's a lot! Student 2: They're surrounding our whole school. Student 3: We searched it up, and they're surrounding us. Interviewer: Is that fair? Student 3: No! It's not fair because the people who are working there are actually a lot closer to it. And it can make them sick and make us sick because they're so many so close to us! Student 2: But if they're around it, they're putting it close to the poor people, so then the poor people don't have enough money to make them stop.

Several participating teachers invested their students in the integrated content with opportunities for civic action using data science and computational thinking skills to address local, relevant problems related to environmental justice. One middle school technology education teacher had his students use data they collected to inspire and create an app in MIT App Inventor that would address an issue of environmental justice in their community. Another teacher engaged her urban middle schoolers in the Chipotle-Earthforce Sustainability Challenge to design sustainable solutions using data science and computational thinking skills for environmental justice-related issues in their community. A math teacher at the same school created conditions for empowerment by supporting her students to write data-driven letters to the mayor about environmental justice issues based on surveys they designed, distributed, and analyzed in the community. Civic action also looked like using data science to tell a compelling story about issues related to environmental justice in the community in the Coding Nature lesson.

2.5.2.3 Disrupting and Reimagining Occupations and Career Pathways

Environmental Justice, Data Science, and Computer Science Career Connections

Students in the study could build on personal and schooling mental models to consider their career aspirations. Each student was asked, "What problem do you want to address in the world?" and "What do you want to be when you grow up?" Sometimes, there was a clear relationship between the problem and the career aspirations; other times, they were seemingly wholly unrelated. In the small group interviews, we were able to dig deeper to see if students could make a meaningful connection between their desired career and environmental justice, data science, or both. Most students could make the connection independently or with the support of other students in the group. For example, one student wanted to be a baker and said, "I'd want to look into information about the environment to see where to put my bakery and with the history of different ingredients to see which are the best for the environment." This student's career aspiration did not change from their short answer response on the pre-survey to the post-survey or this comment in a small group interview. However, they were able to make a meaningful connection between their vision of their future self in the workforce as a bakery owner and sustainable development. Another student wanted to be a businessperson and claimed they would need data science to advertise and create an app for their business. These are just a few examples of students in this study who shared how they are reimagining how they might use knowledge and skills from environmental justice, data science, and computer science in their future careers.

Reimagining Occupations and Pathways

Not all the youth's comments could be categorized in the existing constructs and influences related to Callahan et al.'s occupational identity development. The youth considered how they would use knowledge and skills from these disciplines in their desired careers, and they also described ways they would disrupt commonly accepted norms and practices in their desired careers to center equity and justice. For example, one 3rd grade student talked about what he believed physicians should do to strive for Environmental Justice, including convincing others that the problem exists and impacts some people more than others using data science. "A doctor would be convincing because they would check the [patient's] lungs and see that there's a lot of bad stuff in their lungs." The student talked about how doctors must convince the world that environmental injustice must be addressed to fight preventable diseases like Asthma. Another third-grade girl in his group jumped into the conversation, saying, "My question is how about if a poor person had Asthma and they couldn't pay their hospital bill?... Rich people don't know how much the poor people suffer." The students went on to discuss their responsibility to share the data. Another girl in the group concluded, "Because [people who are oppressed] deserve a better life and well, they should be helping the environment, but I don't think they should be doing all the work." The students in this group considered how their backgrounds and experiences would change how they see themselves in the future workforce and how they want to push back on societal expectations for the role of doctors and who needs to speak up for Environmental Justice.

2.6 Discussion and Implications

This study explored the interplay between youth participation in a curriculum integrating data science and environmental justice with their occupational identity development or vision of their future selves in the workforce. Our quantitative analysis suggests an integrated curriculum designed to reinforce data science, computer science, and environmental justice augments students' self-efficacy in all three domains. Additionally, the students' interest and self-efficacy about environmental justice showed marked improvement after engaging in the integrated curriculum. The survey results, however, revealed that the youth did not perceive as much progress in data or computer science nor a transformation in how they identified with any of the three fields. Nevertheless, the interviews with the students unearthed how the integrated curriculum's design and implementation supported the change in their self-efficacy, rationales for the underwhelming quantitative results concerning identity, interest, and self-concept, as well as an urgent need to disrupt and reimagine the students' role in shaping occupations and occupational identity. The students and teachers also found opportunities for authentic participation that can contribute to a sense of belonging in the occupation through civic action. Our findings contribute to understanding how underrepresented youths develop their occupational identities in environmental justice, data science, and building blocks of occupational identity, overcoming barriers to belonging in multiple disciplines, encouraging participation through civic action in schools, and disrupting and reimagining occupations. Table 6 lists discipline-agnostic integration strategies that support each of the three major influences in occupational identity development discussed in this article.

Table 5. Integrated Instructional Strategies Aligned to the Occupational Identity Development Influences and Outcomes

Outcomes	Influence	Instructional Strategies for Occupational Identity Development
Self-Concept	Exposure	Expose students to occupational role models that share their identity Tailor instructional content and digital media to student interests Explicitly connect classroom content and skills with occupational pathways Infuse opportunities for student agency. Give students multiple opportunities to develop skills in the disciplines
Self-Efficacy	Engagement	Scaffold instruction to give students opportunities for mastery Reframing mistakes and emphasize productive struggle. Present problems that are locally relevant.
Belonging	Participation	Use civic action to engage learners and support authentic participation Encourage collaborative problem-solving. Support students to make their mental models visible and revise them based on learning experiences.

2.6.1 Building Blocks of Occupational Identity

An integrated curriculum can support self-efficacy, a fundamental building block of occupational identity, in more than one discipline for all students. Historically underrepresented students create connections to mental models through school experiences, personal and community connections to the instructional content, and representative occupational role models. Our qualitative findings explain how the integrated curriculum sets students up for exposure to the necessary building blocks or sources for self-efficacy described by Bandura, including performance accomplishments earlier in their Pre-K-12 career, vicarious learning, social persuasion, and emotional arousal (1977).

For students to experience performance accomplishments, their teachers must scaffold the instruction to give them opportunities to develop skills in the disciplines and eventually master them (Bandura, 1977). Youth can learn vicariously and gain self-efficacy by engaging in collaborative problem-solving with their peers. Opportunities for productive collaboration can also be a source of self-efficacy through social persuasion or peer encouragement (Bandura, 1977). Finally, emotional arousal is a source of self-efficacy that comes from emotional reactions to tasks in the curriculum (Bandura, 1977). Although the quantitative data may not have been particularly impressive, there are still noteworthy findings. Students identified each source of self-efficacy and numerous examples of occupational identity influences, including exposure, engagement, and participation. Teachers can plan for engagement to influence self-efficacy and interest by identifying what students will find interesting, useful, and connected to their salient identities while designing relevant problems for them to address through productive struggle and skills aligned to professional practices. Youth also need explicit references to diverse career paths to connect their aspirations with helpful knowledge and skills in environmental justice, data science, and computer science.

2.6.2 Barriers to Belonging

One integrated instructional unit is insufficient time to shift occupational identity majorly. Youth can, however, reimagine their career aspirations with explicit connections to knowledge and skills from environmental justice, data science, and computer science. Instructors can also strategically disrupt common barriers to the sense of belonging that is key to the final stage of occupational identity development. Limited cultural representations and stereotypes negatively impact the likelihood that underrepresented youth will imagine themselves in computer science, data science, or environmental justice-related occupations. Educators can combat those stereotypes with alternate representations through role models, digital media, and instructional content (Callahan et al., 2019). Implicit bias can hinder shaping self-efficacy and interest through an occupational identity lens when youth encounter social cues that these high-value fields are not for people with backgrounds and experiences like theirs (Callahan et al., 2019).

More of the participating teachers were able to find alternative representations that were not aligned with the dominant culture and locally relevant pedagogies related to environmental justice than data science and computer science. For example, in the Environmental Justice Institute, the sessions introduced teachers to leaders in the Environmental Justice Movement like Dr. Robert Bullard who disrupts a stereotype about STEM and using data science in environmental work perpetuated by systems of oppression that can lead to inequitable representation in the field. However, the professional development did not connect teachers with representative role models who focused on computer science or data science.

This may be one of the reasons why quantitative data showed more occupational identity development in environmental justice than data science or computer science. Justice-centered content, curriculum, and project-based learning tailored to the students' interests and cultural identity sparked interest in the students for environmental justice. Even though they did not indicate increased interest in computer science or data science overall, they did indicate improved self-efficacy. Our goal was not necessarily to get all students to like computer science and data science. However, our results suggest that a justice-centered topic like environmental justice might engage more historically underrepresented youth in activities that parallel professional practices in computer science and data science, a source of self-efficacy.

2.6.3 Civic Action in Schooling

Our qualitative analysis found that students shared examples of participation and belonging in the formal school setting. Participation in authentic communities of practice is not reserved for informal, out-of-school time, or post-secondary settings. Callahan et al. highlight ways youth can participate in authentic communities of practice through work experience, internships, and civic action. Through civic action, youth can build social capital and foster a sense of belonging in a discipline or occupation. We were encouraged to see how the research-practice partnership practitioners designed lessons that gave their students authentic opportunities to engage in civic action related to environmental justice using data science and computer science knowledge and skills. Civic action is a critical component of environmental education (Berkowitz et al., 2005; Frungillo et al., 2022), and it is becoming more common in the literature about content integration (Hollstein & Smith, 2020; Kransny & Tidball, 2017; McDonald, 2011).

2.6.4 Disrupting and Reimagining Occupations

Occupational identity development must be more than an influence on self-construct, self-efficacy, and belonging. It also needs to inspire students to reimagine occupations and occupational pathways based on their values, needs, and identity. Students in this study will engage in occupations in the future that we cannot presently imagine. Existing occupations must be reimagined with equity, justice, and the future in mind. To realize their vision for the future, youth must disrupt and dismantle current systems, occupations, and occupational pathways. Our research-practice partnership sought to address a shared problem of practice by designing and implementing an integrated curriculum that supports student agency and leverages locally relevant pedagogy. However, the students in this study raised the bar for what we thought was possible by sharing their ideas for changing the fields and related occupations in computer science, data science, and environmental justice. Educators can create conditions that can empower youth to disrupt and reimagine these occupations in ways that align with their values and identity. Rather than focusing on youth occupational identity development, why not consider how youth influence occupations? Youth can advocate for alternative career pathway designs where an aspiring doctor designs an independent study in environmental justice and public health to pilot a suggested policy change. Students need educators to equip them with knowledge and skills that will allow them to redefine future occupations based on their identity, experience, and values. Figure 8 shows selected instructional strategies aligned with the occupational identity development outcomes and the findings from student experiences.

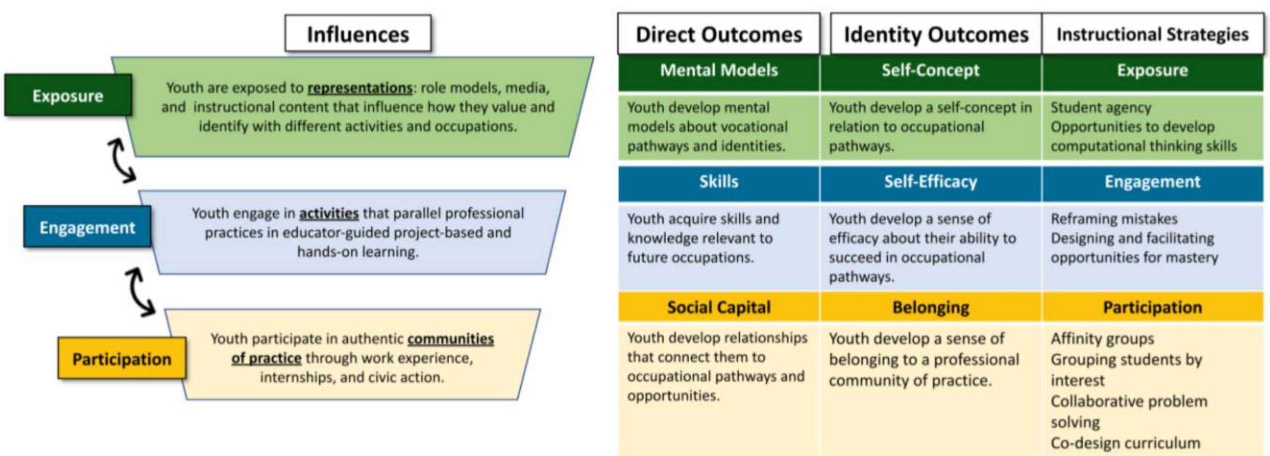


Figure 8. Modified Occupational Identity Development Conceptual Framework with Suggested Instructional Strategies Aligned with Influences and Outcomes

2.6.5 Limitations

Despite a sample size of 731 third through eighth-grade students in twelve classrooms, our sample must be more representative. Twelve students self-identified as a non-binary or third gender, and 18.9% of our population had more than one historically underrepresented or minoritized identity in computer science. This small sample limited the claims we could make and the analyses we could conduct. Despite these limitations, results from the present study mirror prior scholarship that suggests that historically underrepresented students need a foundation of positive self-perception to identify or feel a sense of belonging in STEM-related careers (Calabrese Barton et al., 2013; Cheryan et al., 2015; Cheryan et al., 2017; Kang et al., 2018; Master et al., 2016; Pajares & Miller, 1994).

2.7 Conclusion

Our study provides valuable insights into the interplay between an integrated curriculum in environmental justice and data science. We explored ways educators can design and implement integrated instructional units to shape the occupational identity development of historically underrepresented youth in third to eighth-grade classrooms. Our findings suggest that educators can support the development of mental models for connections to these occupations through relevant examples, role models, and activities that parallel professional practices. Through productive struggle, students can gain confidence in their ability to grow and succeed in given occupations. Our findings also highlight the importance of a curriculum that supports self-concept and self-efficacy in multiple disciplines and how authentic participation in civic action can spark interest and foster a sense of belonging.

While our quantitative results showed limited improvements in the student's interest, self-concept, and identity in the three disciplines, our student interviews revealed how the integrated curriculum positively impacted their self-efficacy and potential for reimagining their career aspirations, including data science, computer science, and environmental justice. Our study underscores the need to disrupt and reimagine the role of historically underrepresented youth in shaping occupations and occupational identity.

We urge educators to support youth to drive change in these fields by creating authentic participation and civic action opportunities in their schooling experiences. Instead of solely focusing on youth occupational identity development, we encourage education practitioners and researchers to consider how youth can influence and shape the occupations and industries they are passionate about. Our study offers valuable insights into the potential of integrated curricula to support students' self-efficacy across multiple domains and contribute to a more equitable and inclusive workforce. More research is needed on equity-oriented occupational identity influences for underrepresented youth and how youth can disrupt and reimagine occupations and pathways.

3.0 Study 2: Using A Mixed Methods Comparative Case Study Design To Understand Student And Teacher Conceptualizations Of Environmental Justice

The purpose of this mixed methods study is threefold: first, to understand how and to what extent the environmental disposition of students shifts after participating in curricula integrating environmental justice and data science; second, to explore students and teacher conceptualizations of environmental justice before and after participating in the curricula; third, to investigate factors that influence students' conceptualizations of environmental justice and their environmental dispositions. This study was part of a long-term research-practice partnership between researchers at a university, a computer science education organization, and rural, suburban, and urban school districts in the Western Pennsylvania. In response to previous studies by our research team within the research-practice partnership, this study leveraged comparative case study within a larger mixed methods explanatory sequential design to explore 731 student experiences with twelve teacher-designed instructional units that integrated environmental justice and data science in third through eighth-grade classrooms. Implications include recommendations for educating pre-service and in-service teachers about the teaching and learning of critical environmental justice in Pre-K-12 contexts. Teaching and learning that leverages CEJ4T&L multifaceted approaches to understand core concepts could create conditions that can empower youth, especially those historically underrepresented in computer science and STEM.

Keywords: environmental justice, mixed methods, science teacher education

Using a Mixed Methods Comparative Case Study Design to Understand Student and Teacher Conceptualizations of Environmental Justice

The Next Generation Science Standards (NGSS), grounded in the National Research Council's (2012) report, "A Framework for K-12 Science Education" incorporates disciplinary core ideas that relate human's relationship and impact on the environment (NGSS Lead States, 2013). The "Earth and Human Activity" disciplinary core idea includes standards that range from kindergarten to middle school to high school. In a kindergarten class, students are expected to be able to "communicate solutions that will reduce the impact of humans on…other living things in the local environment" like eliminating habitat destruction for natural resources like trees for paper (NGSS Lead States, 2013). By the end of middle school, students should be able to "apply scientific principles to design a method for monitoring and minimizing human impact on the environment" by limiting pollution and water usage (NGSS Lead States, 2013). In both examples, the standard encourages students to consider human impact on the environment. Other NGSS expectations require students to explore how humans are impacted by the environment. However, the full circle of human-environment-human interaction is not made explicit. For this reason, science teachers using NGSS could realistically miss supporting this connection, which serves as a foundation for the ongoing environmental justice movement if they stay at the level of environmentalism.

What factors influence student conceptualizations of environmental justice? To understand why students might conceptualize environmental justice in one way or another, it is important to understand how the environmental movement transformed into the environmental justice movement and the current movement towards critical environmental justice.

The first wave of the environmental justice movement gained widespread recognition in the 1980s building on the intersectional civil rights movements of the 1960s and the environmental movement of the 1970s (United States Environmental Protection Agency, 2022). The movements leaders included Dr. Benjamin Chavis Jr. who coined the term “environmental racism” and along with Charles Lee, wrote the groundbreaking report for the United Church of Christ Commission on Racial Justice entitled *Toxic Wastes and Race in the United States: A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites* (Chavis Jr & Lee, 1987; United States Environmental Protection Agency, 2022).

Dr. Robert Bullard, widely considered the father of environmental justice coined the term and wrote extensively alongside other scholars about environmental justice, catalyzed by blatant environmental racism in Warren County, North Carolina (Bullard, 1994; Bullard & Wright, 2012). These scholars, activists, and leaders were among the organizers of the historic “First National People of Color Environmental Leadership Summit” in 1991 that created the seventeen principles of environmental justice that have guided the movement to this day (Principles of Environmental Justice, 1991).

3.1 Conceptual Framework

Environmentalism is both a movement and a conceptual framework. There is a rich body of literature exploring the concept of environmentalism and factors that influence mindsets and behaviors associated with environmental concerns and action from early childhood to adulthood (Berkowitz et al., 2005; Bright & Eames, 2022; Chen-Hsuan Cheng & Monroe, 2012; Haluza-DeLay, 2013; Hollstein & Smith, 2020; Stapleton, 2020; Wells & Lekies, 2006). Dietz et al. (2002)

argue that the "social psychological values altruism, self-interest, traditionalism, and openness to change" are factors that influence environmentalism dispositions and actions, and they often differ along lines of gender (p. 353). Environmentalism is associated with protecting and preserving nature, habitats, and natural resources from unsustainable human impact (O'Riordan, 2013). This definition was used to inform the framework in Figure 9.

Environmental justice and critical environmental justice are also movements and conceptual frameworks. These movements exist at the confluence of environmentalism and ongoing social justice and civil rights movements. Social justice centers universal human rights and values diversity across lines of difference in identity (Dimick, 2012; Learning for Justice, 2018). Actions towards a vision of transformative social justice seek to disrupt systems of oppression to improve equitable access to opportunities as well as equitable participation in organizing and decision making (Edwards, 2006; Gutiérrez, 2016; Lowe, 2023; Madden et al., 2017; Morales-Doyle, 2017). Social justice education is inherently anti-bias, multicultural, and liberatory (Learning for Justice, 2018; Love 2019; Love, 2000). These conceptualizations of social justice were used to construct the framework in Figure 9.

The United States Environmental Protection Agency's definition is used to inform the conceptual framework illustrated in Figure 9.

> Environmental justice is the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work (United States Environmental Protection Agency, 2022).

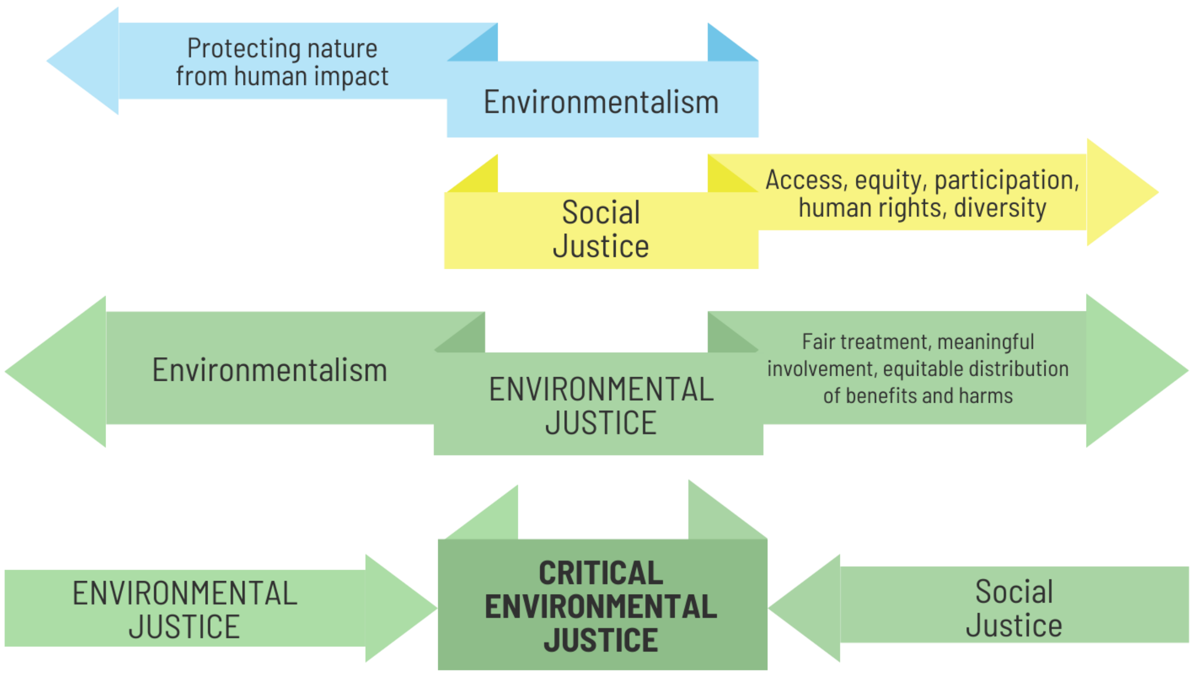


Figure 9. Environmental Justice Conceptualization Evolution Framework

Over time, the environmental justice movement has expanded to include the climate justice movement, water justice, food justice, health justice, and more. Alongside this expanded conceptualization of environmental justice, the second wave or generation of the environmental justice movement was sparked by scholars like Dr. David Pellow calling for a more critical understanding of environmental justice (Pellow, 2018). When a critical lens is used to understand the confluence of environmental justice and social justice, it becomes critical environmental justice as shown in Figure 9. In this case, social justice is more than just a lens to understand human relationships with the environment, instead it is a tool for interrogating and examining the relationship between human impact on the environmental and systems of oppression (Pellow, 2018; Vaandering, 2010).

Pellow's critical environmental justice studies connects the intersections of systemic oppression and environmental racism with the Black Lives Matter movement, the Israel-Palestine conflict, the United States prison system, and more (Pellow, 2018). His framework for critical environmental justice studies includes four pillars: 1) intersectionality, 2) transformative versus reform goals in the environmental justice movement, 3) multiscalar approaches on more than one scale, and 4) indispensability of all living beings within the environmental justice movement as illustrated in Figure 10. Critical environmental justice "views racism, heteropatriarchy, classism, nativism, ableism, speciesism (the belief that one species is superior to another), and other forms of inequality as intersecting axes of domination and control" (p.12). In this way, Pellow's definition of intersectionality moves beyond Crenshaw's (1989) definition to include non-human or more than human entities.

Figure 10. Four Pillars of Critical Environmental Justice Studies

3.2 Purpose of the Study

The purpose of this mixed methods study is threefold: first, to understand how and to what extent the environmental disposition of students shifts after participating in curricula integrating environmental justice and data science; second, to explore student and teacher conceptualizations of environmental justice before and after participating in the curricula; third, to investigate factors that influence students' conceptualizations of environmental justice and their environmental dispositions. This study was part of a long-term research-practice partnership between researchers at a university, a computer science education organization, and rural, suburban, and urban school districts in the Western Pennsylvania. In response to previous studies by our research team within the research-practice partnership, this study leveraged comparative case study within a larger mixed methods explanatory sequential design to explore 731 student experiences with twelve teacher-designed instructional units that integrated environmental justice and data science in third through eighth-grade classrooms. Implications include opportunities to center critical environmental justice studies in Pre-K-12 teaching and learning that could support the empowerment of youth, especially those historically underrepresented in computer science and STEM.

Research Question #1- How and to what extent does the environmental disposition of students shift after participating in an instructional unit that integrates environmental justice and data science?

Research Question #2- How do students conceptualize environmental justice after engaging in an instructional unit that integrates environmental justice and data science?

Research Question #3- What combination of factors influence students' conceptualizations of environmental justice and their environmentalist dispositions?

3.3 Methodology

An explanatory sequential mixed methods design was used that involved collecting quantitative data first, using that data to explore overarching trends and identify relevant classroom case studies that could be compared within the population, and then explaining the quantitative results with nested, in-depth qualitative data (Creswell & Plano Clark, 2018). This comparative case study nested within a larger mixed methods explanatory sequential design expands upon Guetterman and Fetters two general case study-mixed methods and mixed methods-case study design choices (2018, p.901), because the mixed methods are used to choose the case studies and as separate components within the cases themselves as seen in Figure 11.

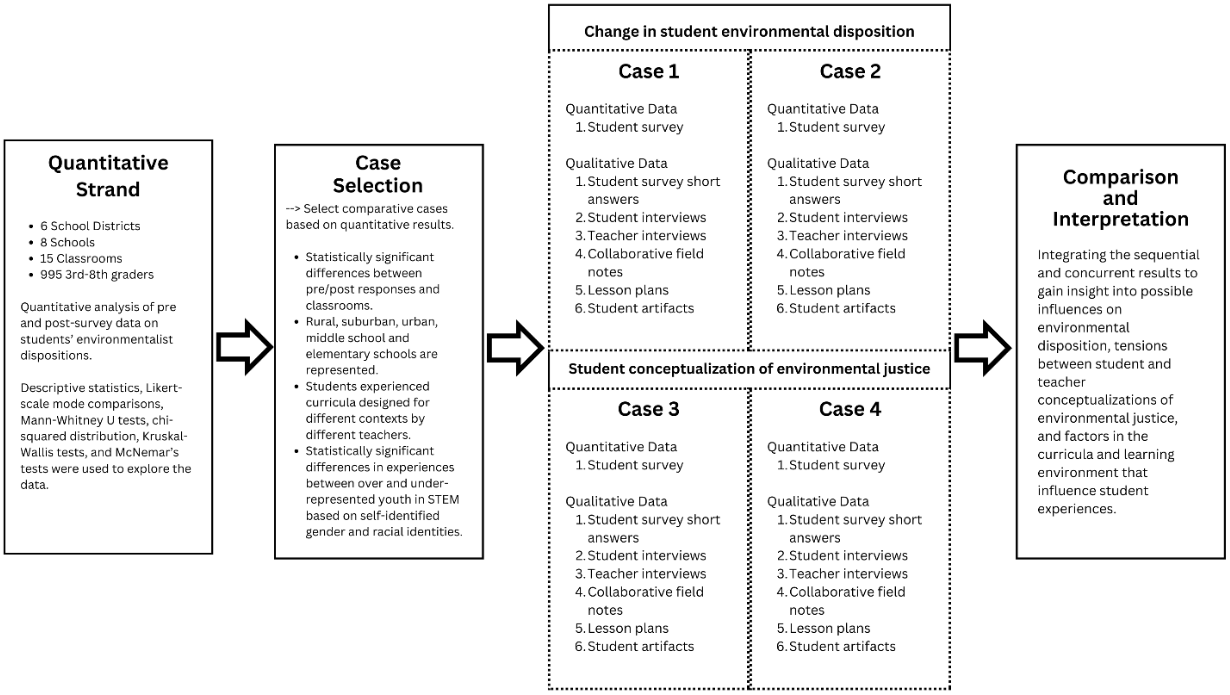


Figure 11. Explanatory Sequential Mixed Methods Study Design with Comparative Case Study Analysis

The study design included four phases. The goal of the first, quantitative phase was to answer the first research question: To what extent do students' environmentalist dispositions change after engaging in an instructional unit that integrates environmental justice and data science? Pre- and post-survey data was collected from students in rural, suburban, and urban schools to measure environmentalist dispositions and assess whether engaging in environmental justice lessons influenced their dispositions. Given the overall explanatory mixed methods sequential design of the study, the quantitative data was collected and analyzed first for overarching trends, tensions, and questions that could be answered with the various in-depth qualitative data sources (Creswell & Plano Clark, 2018). These data were analyzed broadly, broken down by race and gender of the students, and finally broken down by the potential case studies at the classroom level. These data were also analyzed using various statistical tests appropriate for analyzing modified Likert-type scale responses to understand trends and tensions related to students' environmentalist dispositions.

In the second, mixed methods phase of the study the overall quantitative data was broken down and analyzed by the potential case studies at the classroom level. This data was combined with qualitative data frequency counts from one of the short-answer response questions of the pre- and post-surveys were analyzed across the twelve classrooms with matched data. This analysis focused on how students conceptualized environmental justice before and after engaging in the curricula to understand which classrooms had higher or lower percentages of students whose conceptualizations of environmental justice moved beyond environmentalism. The goal of the second qualitative phase was to answer the second research question: how do students' conceptualizations of environmental justice shift after engaging in curricula that integrates environmental justice and data science?

Using a nested data sampling strategy, the quantitative data from all participants was used to select case study classrooms of students and teachers. Cases were chosen based on whether there were statistically significant differences between classes at similar grade levels, urbanicities, and subjects for each question. The frequencies of the codes for the short response questions were also considered along with the contexts of the classrooms to understand which classrooms had higher percentages of students who conceptualized environmental justice beyond the level of environmentalism. Finally, statistically significant differences between students along lines of race and gender were also analyzed. Two elementary and two middle school cases or classrooms were chosen based on the quantitative data as shown in Figure 11. Two additional cases were added that represented practical and compelling difference in student conceptualizations of environmental justice from the initial qualitative analysis despite having sample sizes that were too low to achieve statistical significance in the quantitative analysis.

The third qualitative phase was conducted as a follow-up to the quantitative results to help explain tensions in the environmental dispositions by exploring the students' written conceptualizations of environmental justice in the pre- and post-surveys by classroom case. A comparative case study was used to further analyze the qualitative data from these classroom subsets. Lieberman argues that there is a "synergistic value to nested research design: for example, statistical analyses can guide case selection for in-depth research, provide more direction for more focused case studies and comparisons, and be used to provide additional tests of hypotheses generated from small-N research (2005, p. 435).

In the fourth and final phase, various data from the four classroom cases were analyzed to paint a picture of the combination of factors in each case that may have influenced students' conceptualizations of environmental justice as well as their environmentalist dispositions before and after engaging in the instructional units that integrated environmental justice and data science. The goal was to answer the third research question: what combination of factors influence students' conceptual understanding of environmental justice and their environmentalist dispositions. Vignettes were written for each case to illustrate the classroom learning environment during curriculum implementation alongside selected student and teacher experiences.

Additionally, the Content Integration Lesson Development Rubric (ICIDAR) from the Environmental Justice Pathway study shown in Appendix C was used to evaluate the indicators of academic standard alignment, objectives, Environmental Justice Tie-In, Computational Thinking Competencies and Practices, and Student Agency (Chelednik et al., Under Review). The rubric was designed using the lesson plan template shown in Appendix A to assess content integration lesson development. It is referred to as ICIDAR, and it is also meant to be a tool to understand the differences between the lesson plan designs and enactment. The rubric includes six indicators that are rated on a 7-point scale.

3.3.1 Professional Development and Curricular Intervention

The twelve teachers in this study were part of a larger research-practice partnership that seeks to build a computer science and STEAM pathway for third through eighth grade students in urban, rural, and suburban school districts in the Western Pennsylvania. In this project, the practitioners attended a two-day professional development workshop entitled the Environmental Justice Institute led by research and practitioner members of the partnership including the authors one and three. Due to the ongoing COVID-19 pandemic, the workshop was offered virtually. The workshop sessions were designed to support the teachers in understanding the benefits of integrating environmental justice and data science, the connections between the Environmental Justice Pathways project and previous study findings in the research-practice partnership, and to develop instructional units that integrated environmental justice and data science for various subjects in their elementary and middle schools. The practitioners experienced several exemplary lesson plans designed by the research team as learners. These model lessons were also distributed in written form on a lesson plan template designed specifically for the project as shown in Appendix A. Our goal was not necessarily to get all students to like computer science and data science, but to instead equip them with the knowledge and skills needed to see computer science as a possible occupational pathway. The teachers were given time to work collaboratively with other teachers and the research team to design instructional units using the tools from the workshop, the lesson plan templates, and their own experiences. They received peer feedback and feedback from the research team throughout the workshop and before implementing the lessons in their classrooms.

3.3.2 Context and Participants

995 students took the post-survey across 15 classrooms. 731 of those post-surveys were matched to pre-surveys across 12 classrooms. The matched pairs were used in the quantitative analysis. 178 students self-identified as white boys and are included in the analysis of historically overrepresented students in STEM. 75.6% of students self-identified as a girl, non-binary, and/or a racial identity other than white. These students were included in the analysis of historically underrepresented students in STEM. The teachers in these classrooms were practitioner members of the research-practice partnership that had attended the two days of the co-generated Environmental Justice Institute in the Fall of 2021. Student participants in the post-survey by school and classroom teacher are included in Table 7. This table also shows the classroom teachers' subject, grade levels taught, and the urbanicity of the school (urban, rural, or suburban context). The participating practitioners teach subjects ranging from STEAM to science, mathematics, computer science, technology literature, technology education, engineering, and self-contained elementary grades. The names of the schools and teachers are pseudonyms.

Table 6. Environmental Justice Pathways Student and Teacher Research Participants

	School*	Teacher* & Grade	Subject	*n*
Rural	Greenridge Elementary & Middle	Polar, 5	STEAM	18
		Ridge, 6 & 7	Computer Science	62
	Forest Hills Elementary	Fern, 3	STEAM	66
		Primrose, 4	4th Grade General	33
		River, 5	5th Grade General	14
	Skyline Middle	Plum, 6	Science	54
		Maple, 6	STEAM	
Suburban	Falcon View Elementary & Middle	Winter, 4 & 5	Technology Literacy	226
		Luna, 4	STEAM	259
		Lotus, 8	Computer Science	80
		Meadow, 7 & 8	Technology Education	78
Urban	Sporting Green Elementary	Summer, 5	Science	34
	Mountain Vista Middle	Dahlia, 6	Math	33
		Rose 7	Science	23
		Wren, 8	Engineering	5

Note. n = Number of students who completed the post-survey.
**All school and teacher names have been changed to protect the identity of the individuals*

3.3.3 Data Sources and Collection

Before the teachers implemented the instructional units they had designed in the workshop, the first author visited their classrooms to administer pre-surveys for all the students. The teachers set up times for the first and second authors to visit during the implementation to observe the lesson, collect student work artifacts, and interview small groups of students. After the teachers were finished with the implementation, they administered the student post-surveys, shared the finalized versions of their lesson plans, and engaged in an interview with the first author.

Pre-and Post-Surveys for Students. Students took an online pre-survey in the fall semester before engaging in the instructional units. Due to the ongoing COVID-19 pandemic, the timing of the survey administration and instructional unit implementations varied greatly. The survey included demographic information including self-reported race and gender identity. A series of Likert-type questions on a 4-point scale without a neutral option were created based on previously validated surveys (Herro et al., 2017 see also Bandura 2006; Langheinrich et al., 2016; Marsh & O'Neill, 1985; Shavelson et al., 1976; Tsai et al., 2019) about environmental justice, computer science, and data science were included on both the pre-and post-surveys. The series of questions about environmental justice are listed in Table 8.

Table 7. Pre and Post Survey Questions About Environmental Justice

Pre and Post Survey Questions	
Q1	I like learning about how to care for the environment or world around me.
Q2	I am good at caring for the environment or world around me.
Q3	I know more than my friends about how to care for the environment or world around me.
Q4	I can become good at helping the environment or world around me.
Q5	I like the challenge of learning about how to care for the environment or world around me.
Q6	I want to find out more about how to care for the environment or world around me.
Q7	I am an environmentalist or someone who cares about the world around me.
Q8	I often ask questions about the environment or world around me.

Semi-structured interviews. Small groups of students from each classroom were interviewed immediately after the observation day. There were twenty-four groups of students interviewed in the twelve classrooms. The small groups ranged from three to ten students. The semi-structured interview questions for students covered a wide range of topics. This study focuses on the questions about environmental justice, students' experiences with the instructional units, and students' descriptions of the lessons and their learning environments. The twelve teachers were also interviewed by the first author after completing the instructional units. This study focuses on their descriptions of the learning environment, their experience with environmental justice, how their conceptualization of environmental justice shifted because of the project, their impressions of students' environmentalist dispositions and understandings of environmental justice specifically.

Collaborative field notes. The research team developed a system for taking field notes in a combined Google document to capture observations of the implementation of the lesson from the perspective of the teachers' facilitation of the lesson and how the students were engaging and responding to the lesson. This format allowed the researchers to interact, ask questions, and focus on the student and teacher aspects of the learning environment. The ICIDAR observation rubric shown in Appendix C was used to score the implementation of the lessons through the observational collaborative field notes as well as the design of the lesson through collected instructional unit plans written in the template provided during the Environmental Justice Institute workshops. The rubric was adapted by the second and first authors from a previously validated rubric created by the third author (Quigley et al., 2020). The rubric includes six indicators that are aligned with the lesson plan template created by the first author including academic standard alignment, learning objectives, connection to environmental justice, computational thinking competencies and practices, student agency, and real-life applications and career connections. The lesson plans and observations were each scored on six indicators using a seven-point scale. Please see Appendix C for a copy of the rubric.

Student Work Artifacts. After the instructional units were completed and during the observation, student work artifacts were collected including drawings, capture sheets, screen shots of Scratch and MIT App Inventor designs, videos of students engaging in design activities, and more. During the observation, the first and second authors took photographs of the observation to capture student work and ways they were engaging in the content. Teachers were encouraged to revise their lessons and include additional student work artifacts that were created outside of the lessons that were observed by the research team, when they submitted them at the end of the project's implementation period.

3.4 Analysis

3.4.1 Quantitative Analysis and General Results

To answer the first research question, each pre- and post-survey question pertaining to environmentalism disposition was analyzed controlling for various factors including urbanicity, grade level, gender identity, and racial identity. Table 9 illustrates the 731 paired responses broken down by elementary (3^{rd} through 5^{th} grade) and middle school (6^{th} through 8^{th} grade) classrooms. To better understand how students responded to each question, the number and percentage of responses to strongly disagree, disagree, agree, and strongly disagree on the modified Likert-type scale alongside the pre- and post-survey mode or most frequent response were calculated. The modified Likert-type scale is therefore treated as ordinal scale rather than an interval scale which would assume the differences in each response was equal in distance. Students were not able to respond neutrally on the survey, so the responses were grouped into a nominal favorable (agree) and unfavorable (disagree) dichotomy which allows for measurement of central tendency. Rather than using a paired samples t-test designed for a continuous dependent variable, a McNemar's test can be used for a dichotomous dependent variable.

Before engaging in the curricula, 489 (89.7%) of the elementary students responded favorably to the first question, *I like learning about how to care for the environment or world around me*. After engaging in the integrated curricula, the number of favorable student responses on the post-survey increased to 528 students (96.9%) with a concomitant decrease in the proportion of unfavorable student responses from 56 (10.3%) to 17 (3.1%). This change was a consequence of 52 unfavorable student responses on the pre-survey turning into favorable student responses on the post-survey, however 13 participants who initially indicated a favorable response, changed to an unfavorable response on the post-survey after engaging in the curricula. A McNemar's test (McNemar, 1947) with continuity correction (Edwards, 1948) determined that the difference in the proportion of favorable pre- and post-intervention was statistically significant for elementary grades, $x^2(1) = 22.215$, $p<.001$. A chi-squared distribution to approximate the p-value was used because there were more than 25 discordant pairs. The same test was used for middle schoolers answering the first question, but the results were not statistically significant.

For middle school respondents, only the seventh question revealed a statistically significant difference in the proportions of favorable pre and post intervention responses. For the question: *I am an environmentalist or someone who cares about the world around me*, 117 (62.9%) responded favorably. Following the intervention, the number of favorable responses decreased to 71 (37.1%) with a concomitant increase in the number of unfavorable responses from 69 (37.1%) to 115 (62.9%). This change was a consequence of 65 favorable responses pre-intervention becoming unfavorable post-intervention, but 19 participants who were initially unfavorable responded favorably following the intervention. The McNemar's test determined that the difference in the proportion of favorable pre- and post-intervention was statistically significant for middle grades, $x^2(1) = 24.107$, $p<.001$.

As shown in Table 9, except for questions three and seven, the difference in the proportion of favorable pre- and post-intervention responses was statistically significant with positive changes between 4.1% and 8.3% for questions 1, 2, 4, 5, and 6. Question 8 also had a statistically significant difference in the proportion between favorable pre-and post-intervention responses, but the change was negative (-11.2%). The modes for questions 7 and 8 were also lower and showed a decrease for middle school in question 7 and elementary school in question 8.

Table 8. Overall Results of Student Pre- and Post-Survey Likert-Type Responses by Grade-Level

	Likert-Type Response									
Grade/ Question Number	**1**	**2**	**3**	**4**	**M O**	**McN Change**	**Obs *Hyp**	**Agree**	**Disagree**	**T-statistic P-Value Diff**
Survey Question 1: I like learning about how to care for the environment or world around me.										
EQ1										
Pre	10	46	196	283	4	A-A	476	489	56	22.215
%	1.8	8.4	36.0	53.8		D-D	4	89.7	10.3	
Post	3	14	185	343	4	A-D	13 *32.5	528	17	**<.001**
%	0.6	2.6	33.9	62.9		D-A	52 *32.5	96.9	3.1	
										+7.2
MQ1										
Pre	4	29	108	45	3	A-A	136	153	33	.108
%	2.2	15.6	58.1	24.2		D-D	13	82.3	17.7	
Post	11	19	115	41	3	A-D	17 *18.5	156	30	.742
%	5.9	10.2	61.8	22.0		D-A	20 *18.5	83.9	16.1	
										+1.6
Survey Question 2: I am good at caring for the environment or world around me.										
EQ2										
Pre	7	52	211	275	4	A-A	467	486	59	17.280
%	1.3	9.5	38.7	50.0		D-D	4	89.2	10.8	
Post	9	13	257	266	4	A-D	19 *37.5	523	22	**<.001**
%	1.7	2.4	47.2	48.8		D-A	56 *37.5	96.0	4.0	
										+6.8
MQ2										
Pre	7	24	104	51	3	A-A	137	155	31	.000
%	3.8	12.9	55.9	27.4		D-D	14	83.3	16.7	
Post	11	21	111	43	3	A-D	18 *17.5	154	32	1.00
%	5.9	11.3	59.7	23.1		D-A	17 *17.5	82.8	17.2	
										-0.5

Table 8. Overall Results of Student Pre-and Post-Survey Likert-Type Responses by Grade-Level (continued)

Survey Question 3: I know more than my friends about how to care for the environment or world around me.										
EQ3										
Pre	35	145	265	100	3	A-A	289	365	180	1.515
%	6.4	26.6	48.6	18.3		D-D	87	67.0	33.0	
Post	28	135	248	134	3	A-D	76 *84.5	382	163	.218
%	5.1	24.8	45.5	24.6		D-A	93 *84.5	70.1	29.9	
										+3.1
MQ3										
Pre	20	68	78	20	3	A-A	72	98	88	1.049
%	10.8	36.6	41.9	10.8		D-D	53	52.7	47.3	
Post	18	61	81	26	3	A-D	26 *30.5	107	79	.306
Table 8 Continued										
%	9.7	32.8	43.5	14.0		D-A	35 *30.5	57.5	42.5	
										+4.8
Survey Question 4: I can become good at helping the environment or world around me.										
EQ4										
Pre	11	21	156	357	4	A-A	510	513	32	15.750
%	2.0	3.9	28.6	65.5		D-D	7	94.1	5.9	
Post	2	8	119	416	4	A-D	3 *14	535	10	**<.001**
%	0.4	1.5	21.8	76.3		D-A	25 *14	98.2	1.8	
										+4.1
MQ4										
Pre	5	18	77	86	4	A-A	153	163	23	.640
%	2.7	9.7	41.4	46.2		D-D	8	87.6	12.4	
Post	7	11	90	78	3	A-D	10 *12.5	168	18	.424
%	3.8	5.9	48.4	41.9		D-A	15 *12.5	90.3	9.7	
										+2.7
Survey Question 5: I like the challenge of learning about how to care for the environment or world around me.										
EQ5										
Pre	26	86	190	243	4	A-A	399	433	112	9.091
%	4.8	15.8	34.9	44.6		D-D	47	79.4	20.6	
Post	11	70	212	252	4	A-D	34 *49.5	464	81	**.003**
%	2.0	12.8	38.9	46.2		D-A	65 *49.5	85.1	14.9	
										+5.7
MQ5										
Pre	16	37	91	42	3	A-A	102	133	53	1.558
%	8.6	19.9	48.9	22.6		D-D	32	71.5	28.5	
Post	19	44	72	51	3	A-D	31 *26	123	63	.212
%	10.2	23.7	38.7	27.4		D-A	21 *26	66.1	33.9	
										-5.4

Table 8. Overall Results of Student Pre-and Post-Survey Likert-Type Responses by Grade-Level (continued)

Survey Question 6: I want to find out more about how to care for the environment or world around me.										
EQ6										
Pre	19	111	171	244	4	A-A	379	415	130	16.547
%	3.5	20.4	31.4	44.8		D-D	49	76.1	23.9	
Post	11	74	220	240	4	A-D	36	460	85	**<.001**
							*58.5			
%	2.0	13.6	40.4	44.0		D-A	81	84.4	15.6	
							*58.5			
										+8.3
MQ6										
Pre	10	31	81	64	3	A-A	115	145	41	2.521
%	5.4	16.7	43.5	34.4		D-D	23	78.0	22.0	
Post	14	39	85	48	3	A-D	30	133	53	.112
							*24			
%	7.5	21.0	45.7	25.8		D-A	18	71.5	28.5	
							*24			
										-6.5
Survey Question 7: I am an environmentalist or someone who cares about the world around me.										
Table 8 Continued										
EQ7										
Pre	74	112	184	175	3	A-A	112	359	186	.894
%	13.6	20.6	33.8	32.1		D-D	272	65.9	34.1	
Post	67	132	229	117	3	A-D	87	346	199	.344
							*80.5			
%	12.3	24.2	42.0	21.5		D-A	74	63.5	36.5	
							*80.5			
										-2.4
MQ7										
Pre	23	46	84	33	3	A-A	52	117	69	24.107
%	12.4	24.7	45.2	17.7		D-D	50	62.9	37.1	
Post	53	62	56	15	2	A-D	65	71	115	**<.001**
							*42			
%	28.5	33.3	30.1	8.1		D-A	19	37.1	62.9	
							*42			
										-25.8

Table 8. Overall Results of Student Pre-and Post-Survey Likert-Type Responses by Grade-Level (continued)

Survey Question 8: I often ask questions about the environment or world around me.										
EQ8										
Pre	87	135	202	121	3	A-A	196	323	222	18.653
%	16.0	24.8	37.1	22.2		D-D	156	59.3	40.7	
Post	92	191	156	106	2	A-D	127 *96.5	262	283	**<.001**
%	16.9	35.0	28.6	19.4		D-A	66 *96.5	48.1	51.9	
										-11.2
MQ8										
Pre	27	68	68	23	2	A-A	53	91	95	.721
%	14.5	36.6	36.6	12.4		D-D	65	48.9	51.1	
Post	47	56	62	21	3	A-D	38 *34	83	103	.396
%	25.3	30.1	33.3	11.3		D-A	30 *34	51.1	48.9	
										+2.2

Note. 545 participants, degrees of freedom-1, A-A participants answered 3 or 4 on the 4-point Likert-type scale on both the pre- and post-survey. D-D participants answered either 1 or 2 on the pre- and post-survey. A-D the participants' responses shifted from 3 or 4 on the pre-survey to 1 or 2 on the post-survey. D-A the participants' responses shifted from 1 or 2 on the pre-survey to 3 or 4 on the post-survey. E indicates elementary classrooms where participants were in grades 3-5. M indicates middle school classrooms where participants were in grades 6-8.

An analysis of variance Mann-Whitney U test was also run to determine if there were differences in post-survey scores between historically overrepresented and underrepresented racial and gender identities in the population, illustrated in Table 10. Distributions of the post-survey scores for white students and students of color were similar, as assessed by visual inspection. The null hypothesis for the independent samples Mann-Whitney U Test was that the distribution of each question is favorable and unfavorable response is the same across categories of race and gender (Mann & Whitney, 1947; Laerd Statistics, 2015). The conclusion was to retain the null hypothesis for questions that were not statistically significant and reject it for those that were statistically significant. Post-survey scores were not statistically significantly different between racial identity groups for elementary participants. However, question 5 did show a statistically significant difference for middle school participants. Post-survey scores were statistically significantly different, however, between over and underrepresented gender identities for elementary students on questions 1, 2, 6, and 7. In each case, the underrepresented gender group had a higher proportion of favorable respondents on the post-survey than the overrepresented gender population. There was a statistically significant difference for middle school students across lines of self-identified gender identity on question 7.

Table 9 Samples Mann-Whitney U Test Results for Underrepresented versus Overrepresented Race and Gender by Student Survey Question and Grade-Level

#	Race	Gender
EQ1	.823	**.009**
MQ1	.281	.343
EQ2	.060	**.014**
MQ2	.517	.275
EQ3	.190	.500
MQ3	.407	.789
EQ4	.286	.129
MQ4	.945	.418
EQ5	.123	.762
MQ5	**.014**	.193
EQ6	.141	**.003**
MQ6	.535	.071
EQ7	.667	**.036**
MQ7	.387	**.042**
EQ8	.836	**.035**
MQ8	.239	**.021**

Note. Null hypothesis- The distribution of the post-survey responses is the same across the categories- race and gender of participants. The significance level is .050. Asymptotic significance is displayed. E indicates elementary classrooms where participants were in grades 3-5. M indicates middle school classrooms where participants were in grades 6-8.

A non-parametric analogue of one-way analysis of variance called a Kruskal-Wallis H test was conducted to determine if there were differences in the post-survey responses between classrooms with different grade levels, subjects, teachers, and urbanicities. Distributions of the scores were similar for all groups, as assessed by visual inspection of a boxplot. Median post survey scores were statistically significantly ($p<.05$) different between groups for all eight survey questions for elementary classrooms, and for questions 1 and 8 for the middle school classrooms. See Table 11 for the p-values in the independent samples of the Kruskal-Wallis test for elementary and middle school classrooms (Kruskal & Wallis, 1952; Laerd Statistics, 2015).

Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons (Laerd Statistics, 2015). Statistical significance was accepted at the $p<0.0167$ level for the elementary classrooms given the three comparisons, and $p<.0083$ for the six comparisons. This post hoc analysis revealed statistically significant differences in post survey scores between classrooms that varied between questions and comparison classrooms as shown in Table 11. For the elementary classrooms, there were more consistent statistically significant differences between class E-A and class E-B than any other combination. This information was used to determine the two elementary class cases and two middle school cases for the qualitative case comparison analysis.

Table 10. Independent-Samples Kruskal-Wallis Test by Grade-Level and Post-Survey Questions to Determine Statistically Significant Differences Between Survey Responses Between Classrooms

Question # Grade Level	Test Statistic	P-Value	Pairwise Comparisons of Classrooms Adjusted Significance
EQ1	8.802	**.012**	E-A-E-C p=.382
			E-A-E-B p=.010*
			E-C-E-B p=.088
MQ1	13.124	**.041**	**M-B-M-A p=.005**
			M-B-M-F p=.004
EQ2	15.168	**<.001**	E-A-E-C p=1.0
			E-A-E-B p=.001
			E-C-E-B p=.001
MQ2	5.360	.499	
EQ3	31.701	**<.001**	E-A-E-C p=1.0
			E-A-E-B p<.0001
			E-C-E-B p<.0001
MQ3	8.698	.191	
EQ4	9.620	**.008**	E-A-E-C p=.017
			E-A-E-B p=.015
			E-C-E-B p=1.0
MQ4	5.983	.425	
EQ5	27.345	**<.001**	**E-A-E-C p=.009**
			E-A-E-B p<.0001
			E-C-E-B p=.001
MQ5	4.203	.649	
EQ6	43.002	**<.001**	**E-A-E-C p=.001**
			E-A-E-B p<.0001
			E-C-E-B p<.0001
MQ6	5.371	.497	
EQ7	33.812	**<.001**	**E-A-E-C p=.001**
			E-A-E-B p<.0001
			E-C-E-B p<.0001
MQ7	9.669	.139	
EQ8	46.362	**<.001**	E-A-E-C p=.246
			E-A-E-B p<.0001
			E-C-E-B p<.0001
MQ8	14.018	**.029**	**M-A-M-D p=.005**
			M-D-M-E p=.010
			M-A-M-C p=.015

Note. Null hypothesis- The distribution of the post-survey responses is the same across the categories-classroom by teacher. Degrees of freedom=2 for elementary classrooms and 6 for middle school classrooms. The test statistics are adjusted for ties. The p-value is asymptotic significant (2-sided test). Significance values have been adjusted by the Bonferroni correction for multiple tests for the pairwise comparisons of classrooms.

3.4.2 Qualitative Analysis

The qualitative analysis is used alongside the quantitative analysis to choose case studies for a comparative case study analysis. Three qualitative analyses were conducted to support this selection. The first and second author used the teacher-submitted lesson plans and the collaborative field observation notes to score each of the twelve classroom cases in each category of the ICIDAR rubric for the design and implementation of the instructional units. For this study, only the overall average scores for each teachers' design and implementation, as well as their score for the section specifically about environmental justice were used in the analysis. The environmental justice tie-in indicator looks at the teachers' design and implementation of the five guiding questions that were introduced during the Environmental Justice Institute. These questions include 1) how can we ensure that everyone has access to a healthy environment to live, learn, and work in? 2) how can we use data to understand where or how environmental issues impact communities with high poverty more than other communities? 3) what environmental injustices exist in my community? 4) how can we ensure everyone has a voice in the conversation about sustainability and protecting the environment? 5) How do citizens use data to advocate for environmental needs in their community?

In the second analysis, the first author coded the 731 matched pre- and post-survey short answer responses about how students defined environmental justice. Finally, the holistic secondary qualitative data sources were open coded to inform the creation of vignettes for the chosen case study classrooms (Goss, 2013; Saldaña, 2015). A vignette in qualitative educational research can be used for several different purposes. In this case, the process of writing the vignettes supported my analysis, and it also serves to illustrate depth to support readers in understanding the classrooms as cases.

3.5 Results

3.5.1 Quantitative Results

Table 12 includes quantitative comparisons findings between underrepresented and overrepresented genders broken down by elementary and middle school grades on the pre- and post-survey questions. Only questions with statistically significant differences from the analysis shown in Table 9 are reported in Table 11. For example, the p-value for elementary students responding to question 1 was .009. This means that differences between the overall scores and the increases between pre- and post-survey responses were statistically significant and not due to chance. Both over and underrepresented genders saw an increase in favorability between pre- and post-surveys. Overrepresented gender (OG) had an increase of 8.9% while underrepresented gender (UG) had a higher overall favorability with a less drastic increase of 5.3%. That question was not statistically significant for gender at the middle school level or race for either age group.

Using the statistically significant differences from Table 10, the selected case studies of E-A and E-B classrooms were compared across statistically significant question responses. The same comparison was reported in Table 13 for M-A, M-B, M-C, and M-D. In question 1, for example, the students in E-A had higher overall favorability on the pre-survey. However, class E-B's favorability jumped from 79.8% on the pre-survey to 100% on the post survey. For the same question, M-B started with a lower pre-survey score and had a decrease in favorability by 27.3% on the post-survey compared to a higher starting score and a decrease of only 4.8% for class M-A on the post-survey.

Table 11. Underrepresented Gender and Race Crosstabs for the Percentage of Statistically Significant Change in Proportion of Favorable Responses for Pre- and Post-Survey Questions by Grade-Level

Elementary School				Middle School					
#	UG	OG	Total	UG	OG	Total	UR	OR	Total
Q1									
Pre	91.7	87.9	89.7	.	.	.	.	.	.
Post	97.0	96.8	96.9	.	.	.	.	.	.
Diff	+5.3	+8.9	+7.2	.	.	.	.	.	.
Q2									
Pre	90.6	87.9	89.2	.	.	.	.	.	.
Post	97.7	94.3	96.0	.	.	.	.	.	.
Diff	+7.1	+6.4	+6.8	.	.	.	.	.	.
Q5									
Pre	.	.	.	.	.	.	68.9	73.2	71.5
Post	.	.	.	.	.	.	75.7	59.8	66.1
Diff	.	.	.	.	.	.	+6.8	-13.4	-5.4
Q6									
Pre	80.0	72.5	76.1	.	.	.	.	.	.
Post	86.4	82.5	84.4	.	.	.	.	.	.
Diff	+6.4	+10.0	+8.3	.	.	.	.	.	.
Q7									
Pre	68.7	63.2	65.9	69.5	54.3	62.9	.	.	.
Post	67.2	60.0	63.5	41.9	33.3	38.2	.	.	.
Diff	-1.5	-3.2	-2.4	-27.6	-21.0	-24.7	.	.	.
Q8									
Pre	64.2	54.6	59.3	51.4	45.7	48.9	.	.	.
Post	52.5	43.9	48.1	52.4	34.6	44.6	.	.	.
Diff	-11.7	-10.7	-11.2	+1.0	-11.1	-4.3	.	.	.

Note. Underrepresented genders (UG) include students who are self-selected, girl, non-binary, third gender, or others. Overrepresented genders (OG) include students who self-selected boys. An underrepresented race (UR) is any student who identifies as any race other than white. An overrepresented race (OR) is any student who identified as white.

Table 12. Classroom Comparisons for Statistically Significant Change in Pre- and Post-Survey Percentage of Favorable Responses by Question

#	E-A*	E-B*	E-Total	M-A*	M-B	M-C*	M-D	M-Total
Q1								
Pre	88.5	79.8	89.7	90.2	81.8	N/A	N/A	82.3
Post	92.7	100	96.9	85.4	54.5	N/A	N/A	83.9
Diff	+4.2	+20.2	+7.2	-4.8	-27.3	N/A	N/A	+1.6
Q2								
Pre	88.5	84.3	89.2	.	.	.	.	.
Post	94.8	97.8	96.0	.	.	.	.	.
Diff	+6.3	+13.5	+6.8	.	.	.	.	.
Q3								
Pre	66.7	65.2	67.0	.	.	.	.	.
Post	62.5	82.0	70.1	.	.	.	.	.
Diff	-4.2	+16.8	+3.1	.	.	.	.	.
Q4								
Pre	93.8	88.8	94.1	.	.	.	.	.
Post	96.9	98.9	98.2	.	.	.	.	.
Diff	+3.1	+10.1	+4.1	.	.	.	.	.
Q5								
Pre	78.1	79.8	79.4	.	.	.	.	.
Post	72.9	91.0	85.1	.	.	.	.	.
Diff	-5.2	+11.2	+5.7	.	.	.	.	.
Q6								
Pre	66.7	74.2	76.1	.	.	.	.	.
Post	71.9	92.1	84.4	.	.	.	.	.
Diff	+5.2	+17.9	+8.3	.	.	.	.	.
Q7								
Pre	65.6	70.8	65.9	.	.	.	.	.
Post	54.2	78.7	63.5	.	.	.	.	.
Diff	-11.4	+7.9	-2.4	.	.	.	.	.
Q8								
Pre	54.2	64.0	59.3	73.2	N/A	36.8	50.0	48.9
Post	32.3	73.0	48.1	61.0	N/A	35.5	20.0	44.6
Diff	-21.9	+9.0	-11.2	-12.2	N/A	-1.3	-30.0	-4.3

Note- Classrooms with an * are included in the vignettes.

3.5.2 Qualitative Results

The three-part qualitative analysis first started with an analysis of short answer responses to the question about defining environmental justice on the student pre- and post-surveys. The results of this analysis for post-survey responses are included in Table 14 by classroom case study. Each response was coded with one of four codes based on an a priori coding scheme illustrated in Figure 9 (Saldaña, 2015). A “1” in Table 14 corresponds with the blue “Environmentalism” code in Figure 9 where student responses related to appreciating nature, justice for nature, and protecting nature from human impact. A “2” in the table corresponds with the yellow “Social Justice” code where students’ responses emphasized an aspect of social justice including access, equity, participation, human rights, or diversity. Examples of responses that reached the level of environmental justice and critical environmental justice will be shared in the discussion section. A “0” was an incorrect guess or off topic/ unrelated response, and an “N/A” was left blank, or the student indicated that they did not know.

The second phase of the qualitative analysis involved analyzing each teachers’ lesson plans and collaborative field observation notes using the ICIDAR rubric. Table 15 shows the results of the analysis of lesson plans and observations for all classrooms using the ICIDAR rubric for overall design and implementation scores and the environmental justice tie-in indicator. Finally, the third phase includes vignettes that illustrate the holistic story that the student survey responses, student small group interviews, teacher interviews, lesson plan artifacts, and collaborative field notes tell to better understand the selected classroom cases.

Table 13. Frequency of Accurate Conceptualizations of Environmental Justice by Classroom Case

	E-A	E-B	E-C	M-A	M-B	M-C	M-D	M-E	M-F	Total
1	68	64	251	22	3	58	6	4	34	510
	70.8%	72.7%	69.7%	53.7%	27.3%	75.3%	60.0%	50.0%	85.0%	69.8%
2	25	16	78	14	7	18	4	3	3	168
	26.0%	18.2%	21.7%	34.1%	63.6%	23.4%	40.0%	37.5%	7.5%	23.0%
0	2	5	6	2	0	0	0	1	1	17
	2.1%	5.7%	1.7%	4.9%	0%	0%	0%	12.5%	2.5%	2.3%
N/A	1	3	25	3	1	1	0	0	2	36
	1.0%	3.4%	6.9%	7.3%	9.1%	1.3%	0%	0%	5.0%	4.9%
Total	96	88	360	41	11	77	10	8	40	731
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Teacher Score	2	1 *2	2	2 *2	2	2 *1	2	2	1	

Note- 1- Environment focused, 2- Justice focused, 0- unrelated, N/A- unsure

Table 14. Integrated Content Implementation and Design Assessment Rubric (ICIDAR) Scores by Teacher

Teacher	Classroom Association	Lesson Plan EJ Tie-In Score	Lesson Plan Average Rubric Score	Observation EJ Tie-In Score	Observation Average Rubric Score	Combined Average
Luna	E-A	2	4.67	3	5.50	3.79
Fern	E-B	4	5.67	4	5.67	4.84
River	*E-B	5	3.17	4	2.67	3.71
Winter	E-C	5	6.17	2	5.83	4.75
Polar	N/A	4	2.50	3	2.00	2.88
Primrose**	N/A	1	1.00	1	1.00	1.00
Summer	N/A	5	5.50	5	5.67	5.29
Plum	M-A	6	5.67	3	4.67	4.84
Maple	*M-A	7	6.17	7	5.50	6.42
Wren	M-B	4	6.00	4	5.50	4.88
Lotus	M-C	7	5.17	6	5.17	5.84
Meadow	*M-C	4	6.00	4	6.33	5.08
Dahlia	M-D	7	6.00	7	6.00	6.50
Rose	M-E	6	5.33	4	3.67	4.75
Ridge	M-F	1	2.33	1	1.67	1.5
Overall Average		4.53	4.76	3.87	4.46	4.41

3.6 Discussion and Implications

This study first sought to answer the research question: how and to what extent the environmental disposition of students shifted after they participated in an instructional unit that integrated environmental justice and data science. The quantitative analysis suggests the integrated curriculum designed to support students' ability to conceptualize environmental justice augments students' environmental dispositions among elementary student participants. For elementary students, those who self-identified with historically underrepresented gender identities were more likely to respond favorably to survey questions designed to measure their attitudes towards the environment than those who self-identified with gender identities that are historically overrepresented in STEM and computer science. This information was also used to identify two elementary and two middle school case studies that would be used in a mixed methods comparative analysis.

To answer the second research question about how students conceptualize environmental justice after engaging in the Environmental Justice Pathway instructional units, a qualitative analysis of all 731 student pre- and post-survey responses were analyzed using an a priori coding scheme to determine the whether the students' responses emphasized environmentalism, social justice, environmental justice, or critical environmental justice. These codes were applied to responses to a question asking students to define environmental justice revealed trends that can explain the quantitative results. For each code, three examples from the classroom case studies are shown.

Environmentalism-focused

Johnny (8th grade, white, boy, Lotus and Meadow, Falcon View Middle School, suburban)

- Pre-survey response:
  - "It's probably protecting nature and it would be important because most of our resources come from it."
- Post-survey response:
  - "When people stop someone or something that is hurting the environment. When you learn about it, it can help you choose to protect the environment when other people won't or can't."

This quote shows that Johnny conceptualization of environmental justice is still at the level of environmentalism. While he is thinking about human impact and action, the subject is still the environment rather than social justice. Environmentalism is a steppingstone for environmental justice.

Margaret (3rd grade, white, girl, Fern, Forest Hills Elementary School, rural)

- Pre-survey response:
  - "I don't know."
- Post-survey response:
  - "Environmental justice is how humans hurt the Earth."

Margaret's responses, like Johnny's, show growth in the confidence in her answer between the pre- and post-survey short answer responses. However, her conceptualization is still at the level of environmentalism.

James (4th grade, white, boy, Winter, Falcon View Intermediate School, suburban)

- Pre-survey response:
  - "I don't know."
- Post-survey response:
  - "Getting to know nature and spending time in nature. Consider environmental issues."

While James' response is still coded at the level of environmentalism, he reveals a connection in his mental model between a connection with nature and environmental issues.

Among the four chosen classroom cases, M-C (Ms. Lotus) had the highest percentage of students who shared a response to the post-survey that was given an environmentalism-focused code (75.3%), while Ms. Plum and Ms. Maple had the lowest percentage at 53.7%. The environmentalism-focused code was assigned to responses that were focused solely on the well-being of plants and animals, humans harming the environment (like Margaret's response), saving the planet, spending time in nature (like James' response), getting outside, not littering, destruction of habitats, protecting the environment (like Johnny's response), and justice for the environment. Many of these responses are aligned with the NGSS disciplinary core idea, Earth and human activity. However, the responses often did not center social justice or relate back to equity and human rights.

Environmental justice-focused

Cecilia (6th grade, white, girl, Plum and Maple, Skyline Middle School, rural)

- Pre-survey response:
  - "I think environmental justice is more like outside science."
- Post-survey response:
  - "Environmental justice is giving everyone the same food, water, air, etc. no matter what race, gender, salary, etc."

Steven (8th grade, mixed race, boy, Lotus and Meadow, Falcon View Middle School, suburban)

- Pre-survey response:
  - "Environmental justice is important because it is a basic human right."
- Post-survey response:
  - "Environmental justice is important because it is a basic human right. It allows everyone to have some level of agency over the decisions that impact their lives. Without environmental justice, many people are made to be victims of the plans and ambitions of others."

Amy (6th grade, white, girl, Plum and Maple, Skyline Middle School, rural)

- Pre-survey response:
  - "Treating the environment with kindness and respect (not ruining habits, rescuing injured animals). Environmental justice is being fair with the environment.
- Post-survey response:

- "Environmental justice is everyone, no matter their race, gender, location, getting the same water, nutrients, and hygiene. It's important to learn about because we need to make it known to people that it is a real thing that must be solved."

The environmental justice-focused code was assigned to responses that were either aligned with the United States Environmental Protection Agency's environmental justice definition or centered social justice. Several responses also mentioned aspects of critical environmental justice. These responses included ideas like building awareness of what other people are going through, equitable distribution of resources (like Cecilia's response), fighting for equal treatment along lines of difference (like Amy's response), civic action, access to decision making, autonomy, social movement, human rights (like Steven's response), health, and balance. Steven's pre-survey response was aligned with environmental justice, but his post-survey response and starts to hit on critical environmental justice pillars. Amy and Cecilia's responses show a shift between the environmentalism-focused code for the pre-survey response to an environmental justice-focused code on the post-survey as Cecilia initially focused on being outdoors. Amy shifted her response from emphasizing ecosystem preservation to solving problems related to basic human rights. Two classes that were not chosen for the comparative case studies due to their very small sample sizes had the highest percentage (by far) of responses that were aligned with either environmental justice or even critical environmental justice. Additionally, it is important to understood how individuals and communities impacted by environmental injustices understand them. For this reason, brief vignettes of these classrooms are included in Appendix C.

3.6.1 Classroom Case Study Vignettes

*Names of teachers, students, and schools are pseudonyms

E-A Vignette (Ms. Luna)

Ms. Luna's fourth-grade STEAM classroom hummed with excitement as her twenty-four students eagerly awaited the day's lesson in the "Think Tank." The STEAM classrooms at Falcon View Intermediate School are divided into two rooms, a think tank where students gather at the beginning of class to receive instructions and background information on their problem-solving task for the day, and the classroom where students engage in hands-on collaborative problem solving. The walls of both rooms are painted vibrant hues and adorned with colorful posters depicting various mindsets and skills related to science, technology, engineering, the arts and humanities, and mathematics. All third through fifth grade students at Falcon View Intermediate School take an elective STEAM course every year, and many students highlight the hands-on problem solving as reasons why they look forward to this class.

"Good morning, class!" Ms. Luna greeted her students and their fourth-grade homeroom teacher with a warm smile. Students are sitting on the carpet with their normal table groups. "Who can remind us of what we did last class?" Several hands shot up in the air. Ms. Luna called on James. "We had to choose a topic about habitat change," James said. "Our group is learning about coral bleaching." Students were given six options: wildfires, deforestation, city growth, rising sea levels, melting glaciers, and coral bleaching.

"Now, before we dive back into our exploration, we are going to talk about data analysis," Ms. Luna said, drawing the students' attention back to the Smart Board. "Can anyone tell me what data is?"

"It is something that you can't physically touch" one student exclaimed excitedly.
"It's information" another chimed in.
"Everything has it" added a third, pointing around the room.
"It helps us give information for a project."

"Great!" Ms. Luna praised. She went on to ask students who they think collects data and whether they thought she (Ms. Luna) and their homeroom teacher collect data as teachers. The students eventually concluded that data is used to make decisions after Ms. Luna described how Netflix uses data to give users recommendations. She showed students several different examples of how data can be represented visually on the board.

Ms. Luna moved the conversation to students' future careers saying, "A lot of different careers and jobs collect data." She showed students a 60-second video about a data scientist who is an old, white man. He talked about R, Python, and other software packages usefulness in communicating with others.

"Now, we are going to talk about how all of this is related to our habitat change," Ms. Luna explained. "We are going to be looking at this information using a website called EarthTime from Carnegie Mellon University." She showed students a two-minute video about EarthTime. After

further instructions, the students were given an assignment on Canvas that takes them through different parts of the world through EarthTime storytelling. In the assignment, students are divided up into roles like tracker, materials manager, scribe, and spokesperson.

With a clearer understanding of data science, the students moved back to the classroom with their table groups and eagerly delved into their research using EarthTime, a powerful tool that allowed them to analyze data from different areas around the world.

As the STEAM classroom buzzed with activity, the students explored the stories and answered questions about the data in their assignments. Ms. Luna and their homeroom teacher moved around the room supporting students with the technology and facilitating discussion among the table groups. After engaging in this analysis, students were asked to choose an area of the world that they felt was most impacted by environmental injustices for a follow-up project.

This snapshot of Ms. Luna's instructional unit focused more on data science and ecosystems than environmental justice. In a later lesson, she explicitly introduced the term environmental justice to her students. Ms. Luna asked students to revisit their EarthTime stories and consider, "which of these places do you think would struggle or need the most support to fix their problem?"

In an interview with Ms. Luna after implementing the instructional unit, she explained that she asked that question, "so they kind of see it like some places have a lot more resources than others… it's funny the way they understand it, because they were like 'Antarctica because nobody lives there.'"

Ms. Luna was also asked in the interview about how her understanding of environmental justice has shifted during this process. She said, "Any of this, I really didn't understand it, I wasn't really sure you know what it meant or how my students were going to understand it. I think going through the workshop and working with Ms. Lotus… she shared different examples and explained how it affected her community where she grew up and all kinds of different things, so then I felt like I started to really get a sense of it. And now I feel like I have enough of an understanding that whenever students ask me, or we talk about it, I can explain it in a way that they understand. But had I not had those conversations [in the workshop] … I don't think I would have been able to explain it to them yeah."

The fourth graders in Ms. Luna's class also see Mr. Winter for Technology Literacy at Falcon View Intermediate School, a large suburban district. In Mr. Winter's instructional unit for the Environmental Justice Pathways Project, students collected audio and visual assets by connecting with Nature around their school campus. The students used those assets and their budding coding skills to create multimedia and multimodal websites to share their observations and experiences in nature with others. Students also made explicit connections between computational thinking activities like coding and their observations in nature through narrative storytelling.

Mr. Wachter led the students through a different project, and his concept of environmental justice shifted too. "After learning a little more about it through this project, I think environmental justice, first of all, is the awareness of the environment and your impact upon it. And then at the higher level, it is when people who make decisions about the environment take everybody into consideration, regardless of their race, their color, their region, their wealth. They're all taken *into consideration whenever they're making those policy changes, so that we don't have environmental issues in the future. So that we all have a healthy environment. Things like Flint, Michigan are happening all the time, just because they were a poor area, those kinds of things happen." When he was pushed to consider how he would have defined it before the project, he said, "I was thinking about I probably thought just sustainability and just that. You know, not really taking other people into consideration, but more just talking about the environment. So that's probably how I would define it before, is that you just care for your environment."*

E-B Vignette (Ms. Fern)

In Ms. Fern's third grade STEAM classroom, every day was an adventure. For the Environmental Justice Pathways project, she designed a themed unit for her third-grade students on the connections between bees and environmental justice. As the STEAM teacher, Ms. Fern sees all kindergarten through fifth grade students at Forest Hills Elementary School throughout the week, including the students from Mr. River's general fifth grade classroom and Ms. Primrose's general fourth grade class. Her third-grade students engaged in ten different activities including creating bee-themed data glyphs about bees (mathematics, data science, art), exploring maps (geography), creating other visual data representations about bees (data science, mathematics), designing and constructing model bee hives (art, geometry, engineering), engaging in bee dances and modeling them with Sphero bolts (computer science, dance), reading two non-fiction books about the relationship between bees as a keystone species and humans' food systems (science, literacy), and coding Indie robots to behave like bees (computer science, computational thinking).

In an interview after implementing the instructional unit, I asked Ms. Fern if her definition of environmental justice had changed since engaging with the research-practice partnership saying, "I'm not looking for you to recite the EPA definition. I want to know what [environmental justice] means to you." When Ms. Fern is not teaching, she is a mother and a farmer. She told me a story about how her daughter and son's professional experiences have shifted her viewpoint and drew her to this project. Ms. Fern's daughter recently switched her college major from animal science to wildlife and fisheries. She said that her daughter realized her purpose was to save animals, and as a veterinarian her job was often to put down animals. She said that her daughter's experience and this project "truly opened my eyes…I have a farm and take care of the animals on my own. It's just me and the animals. I have a horse, a donkey, goats." Ms. Fern also talked about her son's experience living and working in Michigan with water quality, and issues that are also relevant to her school community. When asked about environmental justice issues that are relevant to her students, she said, "I think we have a lot to be honest, because we have a mix of like land, we have like where I live, there's farmland. And we have a lot of people like we have the pipeline owners, coal miners… we have issues with houses that fall into the ground. We have our water, it's not the best. If you drive through [the town], it's not beautiful. We have a lot of empty buildings; we have buildings that have grass and trees growing through them now. The river is not wonderful. It needs help. I mean, I know the mills, we've really cleaned up the mills or they're gone. Like, it's not as bad as when I was kid, I remember swimming in the river and coming out and having black spots all over me from the mills… We would still need to do a lot to clean [the community] up." She went on to mention people dumping in the river, talking about how dangerous it is to eat fish from the river or swim in it. "We need people to stop polluting."

In her reflections about the lessons, Ms. Fern shared the multitude of ways that she integrated various subjects into the bee instructional units. There was one thing she wanted to change when she taught this unit again in the future, and this showed up in her students' responses about defining environmental justice. "I think, no matter what, whatever I teacher again, I'm going to definitely make sure they understand the words environmental justice, like, I never really put that in there."

In Mr. River's fifth grade class, students used primary and secondary literature and photographs from the Love Canal (Kleiman, 2021) to understand environmental injustice case studies through storytelling. Students used data to understand the impact of soil contamination on public health. At the end of the lesson, students reflected on what would happen if this occurred in their town or to a place that held meaning and value for them. They wrote persuasive letters pertinent to their context.

In the interview afterwards, Mr. River shared, "The whole environmental justice has just alerted a big learning experience for me. I know when I was reading about the Love Canal and researching for the kids' lesson, I ended up finding myself reading more and more than I put into it, because it was just so interesting." When asked how his conceptualization of environmental justice shifted as a result of the project, he said, "I would have defined environmental justice for this, I would have thought. More along the lines of conservation. Rather than what it turned out to be, you know, I never really thought about. Companies just destroying the environment, toxic waste dump sites still affecting people eighty years later, and things like that I would have thought more along the lines of somebody trying to protect forest land… No, that was a big eye opener. I guess you're kind *of just thinking sometimes that you might put a little too much trust in big companies. That they're disposing of things safely and then find out that you know in 1940 they're dumping barrels of waste into the ground. We're still seeing side effects for people and know how it ruined generations of lives…money takes precedence, so therefore, if you have a lot of money, you can hide it a lot more."*

M-A Vignette (Ms. Plum)

Ms. Plum and Ms. Maple share the same 6th grade students, and they both participated as practitioners in the Environmental Justice Pathways project. Ms. Plum teaches sixth grade science, and Ms. Maple teaches a 6th grade STEAM class that all students must take at Skyline Middle School. In Ms. Plum's instructional unit, students designed and presented infographics based on data they collected on personal water use over time.

In an interview after the instructional unit concluded, Ms. Plum reflected on how her own conceptualization of environmental justice changed throughout the project. She said, "Environmental justice to me is being a citizen of our Earth. It's our responsibility to make sure that people have access to a clean environment and to do my part to help provide that whether it's recycling or helping provide clean air and clean water. I feel like just allowing everyone to have access to that is super important… This really opened my eyes to what it truly is."

In Ms. Maple's STEAM classroom, students designed surveys to better understand community trends related to environmental justice. In response to the data, students partnered with the *agricultural education educator at the school (who was not part of the project) to design an ongoing service-learning project to address the gap in access to fresh fruits and vegetables that students identified as an important problem in their community.*

Ms. Maple also reflected on how her conceptualization of environmental justice shifted throughout the project. She said, "So, before I would have defined it as more like pollution, littering, more along the lines of the Earth and conservation. That's more how probably like the kids think because that's what they went for first, they were like, okay, pollution, litter, I'm in! Not having food, you know pesticides, they also went in those directions, which I was in the same boat. And I was like, the justice part, it's kind of throwing me. And that was the hardest part for me. The environmental part was easy. But yeah, once we got into the justice part, I was like- oh- that makes perfect sense. Like not having the same thing, regardless of race, ethnicity, and the kids really latched on to that, just like I did, so I gave them a purpose to do something better. And just worrying about pollution, that's so broad. It gave them something they could sink their teeth into and feel good about doing."

She talked about how the mindset shift among her students sounded like during the instructional unit from an environmentalism/ conservation mindset to one that centered justice. Ms. Maple said her students were "excited to make a difference. To have some positive change to affect their community to change something in their community to help people I was really surprised. Like the ideas just started flowing, and they just talked and talked and talked for 20 minutes, which that's the most they've talked all year. They just got super excited and invested. I mean, we live in a very poor area. So, they face housing issues, health insurance issues, food issues, clean water, some places have some electrical issues. You know, we have a lot of projects. There are about four *projects that surround the school, they're hidden very very well. So, a lot of our kids come from those backgrounds. And they're constantly fighting to have the same resources that we have here in the middle of town with the middle class. So, you can see how it transfers over to their schooling. You know, they're less worried about schooling, more worried about where they're going to eat next, and are their lights going to be on and things of that nature. I watched my kids who have everything develop empathy for those kids in my room that were struggling and they kind of came to like a, you know, a compassionate empathetic understanding about the way each other lives. There wasn't any jealously or I have this, and you don't have that. And they were trying to figure out a way to make those project areas better."*

M-C Vignette (Ms. Lotus)

At Falcon View Middle School, students take computer science and technology education classes. Ms. Lotus teaches eighth grade computer science, and Mr. Meadow teaches seventh and eighth grade technology education. Both teachers signed up to be part of the Environmental Pathways Project. In Ms. Lotus' class, students engage in an activity called Looking Ten Times Two, where they work independently and merge into group work. Students also engage in a data talk and use EarthTime to discover the constant burning fire in Braddock, PA, and the environmental justice implications.

In an interview after she was finished implementing the instructional unit, Ms. Lotus reflected on how her understanding of environmental justice shifted throughout the project. She said, "Erin Brockovich, I've always loved those movies. So, there's like an interest in that so that is how I *understood environmental justice through seeing those movies… What it means to me now is like standing up for people who cannot stand up for themselves in terms of the environment. I'm, like I said, thinking of dark waters. I'll think of something like that in terms of that I think that's a good explanation for students even if they didn't see the movie."*

Meanwhile in Mr. Meadow's class, the same eighth grade students collected data on their households' habits related to recycling, water consumption, consumption of resources, travel, etc. After analyzing the data, students will create storyboards to design an app to address the environmental problem they explored. Students will use the MIT app inventor to code interactive apps to address a problem related to environmental justice for a designated audience.
Mr. Meadow reflected on how his own definition of environmental justice and that of his students shifted throughout the project. "So, when I talked to my students about it, and we do look at the EPA website and I show them the technical term. But is any to them like environmental justice is something that anyone can do regardless of if you're rich or poor, regardless of your religion, regardless of your skin color, regardless of where you came from, or where you're going. It's one little thing or there's a couple little things that you can do as an individual. That can help the environment, and it may seem like something so minute that it's not going to do anything, but if you look at the billions of people that are in the world, and if everyone did that little thing, it is going to make a difference."

"A lot of my kids, when we started talking about this, started saying things like how many people turn off the water when you brush your teeth. A couple hands will go up about how many people, you know, bring paper bags instead of single use plastics to lunch. My personal views lately, yes,

I told whenever we were coming up with example Apps that they could create the example projects. I told them I'm probably the worst offender at single use plastics like when I bring my lunch, it's like I have a plastic bag for my fruit, I have a plastic bag for my sandwich. All the plastic is made of oil, and you know all of that plastic takes years upon years upon years to break down when they're making bags that can be recycled or I can buy. A Tupperware container that can be rewashed over and over and cleaned and reused, so I definitely am more cognizant of my own environmental impact. It really sparked my interest when we were doing our training, we were talking a lot about Lake Mead in Las Vegas, and the lowering of the lake. I've actually been a big fan of hiking, and I do a lot of outdoors, so I've always been really big on recycling and picking up trash while we're on the trail and things." He went on to talk about how he has been researching Las Vegas and Lake Mead.

3.6.2 General Discussion

To answer the third research question, the results of the quantitative analysis, qualitative pre- and post-survey analysis, and analysis of the vignettes are combined. Four themes emerge that explain factors that influence students' conceptualizations of environmental justice and their environmentalist dispositions: 1) teacher mindsets about environmental justice, 2) personal connections, 3) civic action, and 4) transdisciplinary pedagogies.

3.6.3 Teacher Mindsets about Environmental Justice

Teachers' conceptualizations and mindsets about environmental justice impacted the way they designed and implemented the curricula in the Environmental Justice Pathways project and ultimately how and to what extent their students developed favorable attitudes towards environmentalism and conceptualized environmental justice in ways that truly centered justice. For example, Ms. Luna had not received prior professional development around environmental justice, and she could not accurately define it before engaging in the Environmental Justice Institute workshops. Even after the project, she referenced more about hearing the stories of her colleague than her own experience, despite being able to articulate an understanding that was more than environmentalism. In many ways, this is aligned with how her students ultimately conceptualized environmental justice. 70.8% articulated definitions that did not move beyond environmentalism. In the observation of Ms. Luna's 4th grade STEAM classroom, she scored a 3 out of 7 on the environmental justice tie-in indicator on the ICIDAR rubric. This was one point higher than her lesson design score only because she added in more in class discussion about fairness than she had originally planned. See Ms. Luna's vignette for a more detailed illustration of her environmental justice mindsets and how it materialized in the instructional unit implementation.

On the other hand, 34.1% of Ms. Plum and Ms. Maple's 6th grade science and STEAM students were able to articulate a definition of environmental justice that tied environmentalism with social justice. Ms. Plum's environmental justice tie-in scores on ICIDAR were 6 for the lesson plan and 3 for the observation. Ms. Maple's were both the highest possible score of 7. Ms. Plum thinks of environmental justice as being a "citizen of our Earth" and access to clean air and water for everyone. Ms. Maple discussed connections the environmental justice that were very personal to her students and school community. Based on the students' survey results, they seemed to be drawing more on their experience with her instructional unit than Ms. Maples, though the students were all able to experience both.

3.6.4 Personal Connections

Like Ms. Maple's ability to support student understanding of environmental justice through local, relevant connections to students' personal lives, teachers who were able to support their learners to build and recognize personal and community connections to environmental justice had higher percentages of environmental justice-focused conceptualizations on the post-survey. Classrooms with lower scores tended to have more generic or global level connections like Ms. Luna's EarthTime exploration. Ms. Wren and Ms. Dahlia were not chosen as case studies, because their sample size did not lend itself well to statistically significant results in the quantitative analysis. However, one of the benefits of mixed methods is that researchers are not limited by small sample sizes. All classrooms were included in the qualitative analysis, and Ms. Wren and Ms. Dahlia's classes at Mountain Vista Middle School in the urban center had compelling results. 63.6% of Ms. Wren's class were able to conceptualize environmental justice in a way that balanced environmentalism and social justice, while Ms. Dahlia had 40.0%. Like Ms. Maple, Ms. Dahlia scored a 7 out of 7 on the environmental justice tie-in indicator on the ICIDAR rubric for both lesson design and implementation. Ms. Wren scored 4 out of 7 on both. Ms. Dahlia was able to share her own personal connections to environmental justice with her students, but her lesson plans did not center action. Their vignettes are included in Appendix C.

3.6.5 Civic Action

Civic action is another theme in the results, and the presence of authentic civic action in the instructional unit was a key difference between classroom cases that showed more favorable environmentalism dispositions and accurate environmental justice conceptualizations. Ms. Wren, for example, had her students collect data of their choosing in the community, analyze it through an environmental justice lens, and use visualization and creative communication tools to advocate in partnership with local community leaders and even the city mayor. Civic action tended to be the social justice value that was highlighted most often in the definitions that were aligned with environmental justice followed by equity across lines of difference.

3.6.6 Transdisciplinary Pedagogies

This research-practice partnership leverages its collective strength in interdisciplinary, multidisciplinary, and especially transdisciplinary pedagogies. The classroom cases that were chosen for comparison each had groups of students who were able to experience more than one instructional unit. For example, Mr. River's fourth graders also had Ms. Fern as their STEAM teacher. Ms. Luna's 4^{th} graders also take Technology Literacy with Mr. Winter. Ms. Maple and Ms. Maple and Ms. Plum each teach all the 6^{th} grade students in their science and STEAM classes at Skyline Middle School. Finally, Ms. Lotus' eighth graders take Technology Education with Mr. Meadow. All three of the schools represented in the cases also have robust STEAM programs. Other than the case with Ms. Wren and Ms. Dahlia, the remaining classroom cases whose students only got to experience one instructional unit had lower scores overall.

3.7 Conclusion

The results of this study help explain tensions in environmentalist identity development and conceptualizations of environmental justice with third through eighth-grade students and their teachers at urban, suburban, and rural school sites in Western Pennsylvania. Educators can use this information to effectively integrate environmental justice with their existing curriculum and refine their practices to reflect critical social justice values. Teacher educators can use the results to enhance teacher preparation programs. Researchers and policymakers can use the results to advocate for including environmental justice standards.

4.0 Study 3: Toward A Framework For Critical Environmental Justice For Teaching And Learning

This concept paper addresses the evolving landscape of global environmental crises juxtaposed with the politics of fear, denial, and disinformation in science education, highlighting the imperative for a critical, intersectional environmental justice movement by proposing the Critical Environmental Justice for Teaching and Learning (CEJ4T&L) conceptual framework. In response to the absence of a critical teaching and learning framework in the environmental justice field, this article also outlines the knowledge, skills, and mindsets essential for Pre-K-12 educators to design and facilitate curricula that integrate environmental justice through a critical lens effectively. CEJ4T&L aims to fill this gap, offering a structured guide to help researchers and practitioners navigate the challenges of science denial, disinformation, and the politics of fear. This model expands the conceptualization of environmental justice to include four core concepts that serve as entry points for the Next Generation Science Standards: climate justice, collaboration and balance, food sovereignty and sustainable agricultural practices, and water justice. To support educators in translating the core concepts into classroom instruction, the framework proposes a transformative approach for Pre-K-12 educators to foster critical thinking about environmental justice through four multifaceted approaches to teaching and learning critical environmental justice that emphasize the need to disrupt underlying systems of domination and racism including: transdisciplinary pedagogies, social justice values, environmental sustainability practices, and connection with nature. By equipping students with these core concepts and approaches, educators can create conditions that empower them to navigate and address the complexities of contemporary environmental challenges in ways that center on equity and justice. The framework seeks to

cultivate environmental literacy and empower youth to dismantle the environmental racism threatening our planet's future through liberating pedagogies that cultivate critical problem-solving skills and commitment to social justice. The article concludes with strengths and limitations of the CEJ4T&L conceptual framework, ideas for implementation in teacher education contexts, and directions for future research.

Keywords: critical environmental justice, ecojustice, transdisciplinary, science teacher education

Toward a Framework for Critical Environmental Justice for Teaching and Learning

The increasing urgency of global environmental crises like anthropogenic climate change and water security exists alongside more widespread recognition of the inexplicable links between systemic racism and the inequitable impact of environmental issues on people and communities historically marginalized in a capitalistic society rooted in white supremacy. This juxtaposition has influenced the rapid evolution of the Environmental Justice (EJ) movement to include more critical perspectives and empower future movement leaders through EJ education. Since the EJ Movement started to gain traction in the United States in the 1980s, scholars have sought to conceptualize environmental justice and ecojustice in different contexts (Banzhaf et al., 2019; Bullard, 1994; Martinez-Alier & Shmelev, 2014; Wolfmeyer, 2018). The United States Environmental Protection Agency (USEPA) offers specific outcomes that they claim will help the country realize the following vision of EJ:

> Environmental justice is the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work (USEPA, 2022)

This vision reflects the achievements of the EJ movement while focusing on equitable participation of historically excluded people, policy design and enactment, and health justice across lines of difference including race, socioeconomic status, gender, ability, and more. However, this vision of EJ does not illustrate the inextricable relationship between white supremacy and environmental injustice through systems and structures of domination, highlight the need to dismantle underlying systems of domination and racism that influence the impact of environmental degradation on marginalized communities, elevate the promise of educating future leaders and decision-makers about environmental justice or provide suggestions for learning and teaching in times of science denial, disinformation, and politics of fear.

To construct learning environments that can empower youth, especially those who are historically underrepresented in STEM, educators from early childhood to higher education need to support their students' critical thinking about environmental justice to work towards dismantling underlying systems of domination and developing collaborative approaches to achieving environmental justice. To support student learning, educators need to personally understand the multifaceted approaches and core concepts that drive environmental justice studies and commit to liberating pedagogies and practices that will empower students to be critical problem solvers.

While the environmental justice field has moved towards a more expansive definition of the core concepts of environmental justice as well as a more critical understanding of the mechanisms of environmental injustices and the varied impacts of proposed solutions, there is still a need for specification in how these characteristics and criticality should be implemented within Pre-K-12 curricula and classrooms. Without a clear framework for teaching and learning about environmental justice, our youth will continue to miss out on opportunities to develop their environmental literacy and the social justice commitments needed to transform systems rooted in environmental racism that threaten the future of our planet. What knowledge, skills, and mindsets do Pre-K-12 educators need to design and facilitate curricula around environmental justice effectively? Through a thematic analysis of scholarly approaches evident in the environmental justice education literature, a conceptual framework emerges that can inform teaching and learning in critical environmental justice. This paper aims to propose a new framework for Critical

Environmental Justice for Teaching and Learning (CEJ4T&L) that will support teachers to strengthen and develop the knowledge, skills, and mindsets needed to build learning environments that can empower our youth to be able to understand the complex and interrelated processes that have led to contemporary environmental justice challenges, disentangle, and disrupt efforts to deny science, and spread disinformation, and ultimately support a commitment to accountability and action that centers social justice.

4.1 Background

The National Academies of Sciences, Engineering, and Medicine's vision for "equitable access to quality science learning experiences across K-16 education," argues that the United States needs to prioritize science education at a national, state, and local level (NASEM, 2021). All people, not just science educators and professionals, can use scientific knowledge and thinking skills to address urgent problems in their communities and worldwide. Ever since the publication of the Next Generation Science Standards (NGSS) in 2013, based on the National Research Council's publication of the ground-breaking report, "A Framework for K-12 Science Education", 49 states have adopted the Next Generation Science standards, closely aligned standards, or modified state-level science standards using the NRC's student-centered, three dimensions of science education 1) science and engineering practices, 2) crosscutting concepts, and 3) disciplinary core ideas to some degree (NRC, 2012; NGSS Lead States 2013; NSTA, 2023). Table 16 articulates the practices, crosscutting concepts, and disciplinary core ideas developed by the NRC in 2012. The committee that developed the K-12 science education framework argued that the science and engineering practices, crosscutting concepts (CCC), and disciplinary core ideas

(DCIs) needed to be authentically integrated into "standards, curriculum, instruction, and assessment" (NRC, 2012, p.2).

Table 15. The Three Dimensions of the Framework for K-12 Science and Next Generation Science Standards

Dimension 1: Scientific and Engineering Practices
1. Asking questions (for science) and defining problems (for engineering) 2. Developing and using models 3. Planning and carrying out investigations. 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations (for science) and designing solutions (for engineering) 7. Engaging in arguments from evidence 8. Obtaining, evaluating, and communicating information
Dimension 2: Crosscutting concepts
1. Patterns 2. Cause and effect: Mechanism and explanations. 3. Scale, proportion, and quantity. 4. Systems and system models 5. Energy and matter: Flows, cycles, and conservation 6. Structure and function. 7. Stability and change

Table 15. The Three Dimensions of the Framework for K-12 Science and Next Generation Science Standards (continued)

Dimension 3: Disciplinary Core Ideas
Physical Sciences PS1: Matter and its interactions PS2: Motion and stability: Forces and interactions PS3: Energy PS4: Waves and their applications in technologies for information transfer *Life Sciences* LS1: From molecules to organisms: Structures and processes LS2: Ecosystems: Interactions, energy, and dynamics LS3: Heredity: Inheritance and variation of traits LS4: Biological evolution: Unity and Diversity *Earth and Space Sciences* ESS1: Earth's place in the universe ESS2: Earth's systems ESS3: Earth and human activity *Engineering, Technology, and Applications of Science* ETS1: Engineering design ETS2: Links among engineering, technology, science, and society

To better understand the existing landscape of environmental justice education in formal Pre-K-12 settings in the United States, I analyzed the most recently published science standards in all fifty states alongside progress reports from the National Science Teacher Association (2023) to determine the extent to which each state had adopted NGSS as of January 2024. The results of this analysis are included in Appendix D.

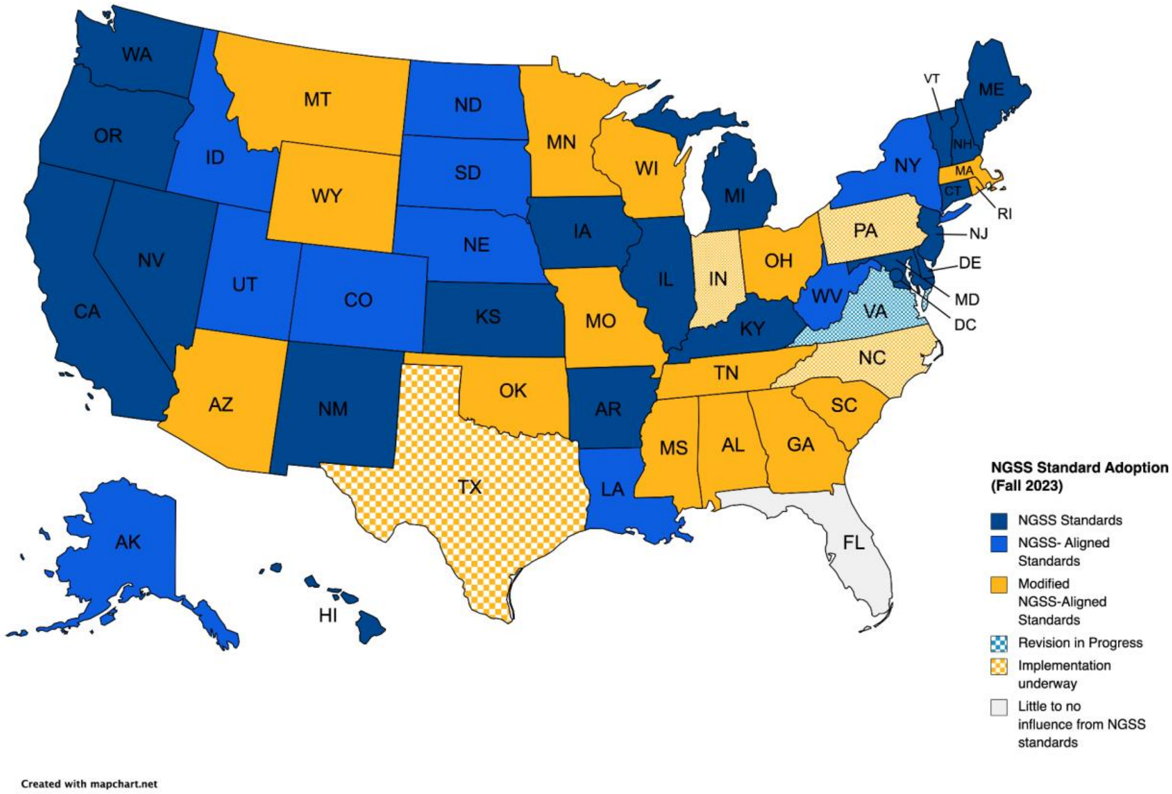


Figure 12. Map of Next Generation Science Standard Adoption and Implementation Status in the United States as of January 2024

The dark blue states in Figure 12 above, at some point between 2013 and January 2024, adopted the NGSS in their entirety. In 2011, twenty-six states were designated "Next Generation Science Lead States" (NGSS, 2013). Although these states were not required to adopt the NGSS, many lead states were among the first adopters. For example, in the Fall of 2013, the Delaware State Board of Education voted unanimously to adopt NGSS (DOE, 2020). As of January 2024, nineteen other states plus the District of Columbia, have chosen to do the same.

Lighter blue states adopted standards aligned with NGSS with minimal edits, deletions, or additions. For example, New York is part of this group of states that developed its iteration of the NGSS that is closely aligned with the NRC (2012) recommendations. New York is an NGSS Lead

State (NSTA, 2013). Since the Lead States were not obligated to adopt NGSS in its entirety or at all, New York chose to use NGSS as a guide. In many cases, the New York State P-12 Science Learning Standards, adopted in December 2016, are identical to NGSS (NSTA, 2023). These standards replaced the existing science education standards adopted in 1996. New York made very minor modifications to the NGSS, including adding early childhood standards and minor rearrangements in the sequencing. The standards will be fully implemented, including realigned Regent's assessments, by June 2026 (NYSED, 2021).

Dark yellow states adopted standards inspired by the NRC's three dimensions of science learning in Table 16, but there are significant modifications to the standards. Ohio, for example, is part of this group of states that developed science education standards after the release of the NRC framework and NGSS. In this category, there is some alignment to the three-dimensional learning aspect of NGSS, but there are also significant modifications, additions, or deletions compared to NGSS. Ohio's most recent science education standards were adopted by the State Board of Education in early 2018 and called the Learning Standards and Model Curriculum for Science (ODE, 2023). These standards emphasized detailed curriculum frameworks and place-based examples like the Lake Erie watershed. While the content and science/engineering practices mirror NGSS in many ways, the standards are not intentionally based on NGSS (ODE, 2023). Ohio was also one of the original twenty-six states considered Next Generation Science Lead States in 2011, but it chose not to adopt NGSS. On the Ohio Department of Education and Workforce website, it says, "the structure of Ohio's Learning Standards for Science is somewhat different from NGSS, but the research that provided A Framework for K-12 Science Education, from which each was developed, is the same…teachers are encouraged to use NGSS to support classroom instruction" (2023). The website also includes a "crosswalk" tool with NGSS.

Five states are in various stages of multi-year implementation plans with NGSS or related standards as of January 2024. These states are shown in blocked yellow if the implementation is underway or blue if the standards are still being revised. Despite significant differences, states in this category have enough foundational similarities that they either already have or could potentially crosswalk their standards with NGSS. Indiana is one example of a state that is in the process of implementing standards that are aligned with NGSS and the NRC framework. After NGSS was published in 2013, Indiana adopted its Academic Science Standards in 2016 (IDOE, 2022). At the time, they would have been shaded solid yellow on this map to represent significant modifications and departure from NGSS. These standards were much more disciplinary content-focused rather than three-dimensional, but they did include an environmental science section. In 2022, the Indiana State Board of Education approved the K-12 Indiana Academic Standards in science and computer science (IDOE, 2022). While these standards are aligned with the 2016 content scope and sequence, their three-dimensional structure is more aligned with NGSS and the NRC framework. The standards were implemented for the first time in the 2023-2024 school year.

Until recently, North Carolina, Ohio, Pennsylvania, Texas, and Virginia would have been in the same category as Florida, with standards that had little to no influence from NGSS or NRC (NSTA, 2023). One example is Virginia's adoption of new science education standards, the Science Standards of Learning in Fall 2018 (VDOE, 2023). These standards showed little to no influence from the NRC framework, but Virginia did choose to include environmental science standards based on the state's environmental literacy plan implementation strategy which will be discussed in the next section. Virginia initiated a review process that will result in new Science Standards of Learning in January 2025, with full implementation expected by 2026 (VDOE, 2023). This process will support better alignment with NGSS and the NRC framework (NSTA, 2023).

As of January 2024, Florida is the only state with science education standards that have little to no influence from NGSS or the NRC framework, and they have not begun revising or implementing revised standards (FLDOE, 2017; NSTA, 2023). The Florida Department of Education released a document called “Teaching Science in Florida: Understanding Next Generation Sunshine State Standards or NGSSS (FLDOE, 2017). These standards were approved in 2008 and have not been updated since. In this document, PJ Duncan, the Secondary Science Program Specialist at the time, argues that “no crosswalk between NGSS and our Florida Next Generation Sunshine State Standards (NGSSS) is possible” (FLDOE, 2017). For a full list of states and their stage of NGSS standard adoption, see Appendix D.

4.1.1 Environmental Literacy in the United States

NGSS includes core disciplinary ideas throughout the K-12 standards, like human impacts on Earth systems (NRC, 2012; NGSS, 2013). Core disciplinary ideas are categorized into life sciences, physical sciences, and earth and space sciences. Human impacts on Earth systems fall under the category of Earth and Space Science (ESS), but they are also aligned with content aligned with environmental sciences. While this is an improvement on previous science standards that disregarded the relationship between humans and their environment, the core ideas leave out environmental degradation's inequitable impact on humans. Instead, the focus is often on environmental concerns such as habitat destruction, water quality, availability of natural resources, and littering. Instances such as this have led the committee to recognize the need for integration of the “social, behavioral, and economic sciences,” which would include environmental justice studies, into the K-12 science education framework (NRC, 2012, p.14). In their report, the committee shared a call for a framework like CEJ4T&L, saying,

> The limited treatment of these fields in this report's framework should not, however, be interpreted to mean that the social, behavioral, and economic sciences should be omitted from the K-12 curriculum. On the contrary, the committee strongly believes that these important disciplines need their own framework for defining core concepts to be learned at the K-12 level and that learning in the physical, life, earth and space sciences, and engineering should be strongly linked with parallel learning in the social, behavioral, and economic science. (NRC, 2012, p. 14).

Several states, including Pennsylvania and New Jersey, have included standards or curriculum frameworks that directly address environmental justice in either social studies education or environmental education (PDE, 2022; Shendell et al., 2023). Many other states have informal education curricula that address environmental justice (NAAEE, 2019). While the traditional definition of environmental education is not explicitly critical or justice-centered, it can catalyze environmental justice education.

The North American Association for Environmental Education has released three reports, most recently in 2019, to understand the status of each state in developing and implementing comprehensive environmental literacy plans or ELPs (NAAEE, 2015; NAAEE, 2019). Environmental literacy plans are meant to increase environmental literacy (Hollweg et al., 2011) among citizens, especially youth. Environmental literacy, according to the National Environmental Education Foundation Benchmark Survey Report, can be measured by the extent to which citizens engage in "environmentally friendly behaviors" that reduce their environmental footprint, their disposition towards the environment, and the degree to which they are "environmentally informed" (NAAEE, 2015, p.14). Environmental literacy is also multifaceted knowledge about the environment, mindsets about the environment, and strategies that allow a citizen to apply knowledge and make decisions aligned with their environmental values (NAAEE, 2019).

Together with these reports, a report from Ruggiero in 2016, and an investigation of each state's Department of Education website were used to inform the table in Appendix D. Figure 13 illustrates the results of the most recent report with updates from state Department of Education websites between 2019 and January 2024 (see also Appendix D). Between 2008 and 2015, there was an increased interest in developing ELPs due to federal funding for environmental education connected to the proposed No Child Left Inside (NCLI) Act (NAAEE, 2019). With that bill never passing the Senate and subsequent legislation not tying funding to state-wide environmental literacy plans, interest has waned over time (NAAEE, 2019).

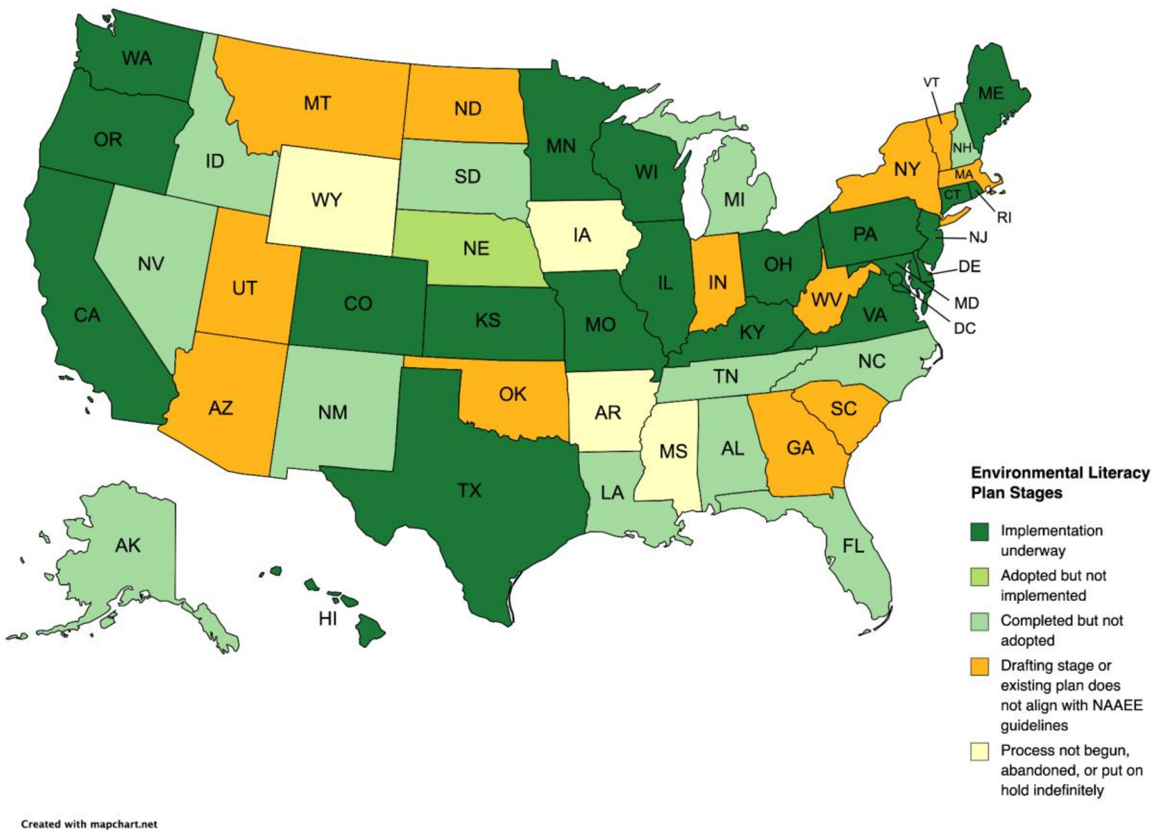


Figure 13. Map of Environmental Literacy Plan Stages in the United States as of January 2024

Twenty states plus the District of Columbia have moved forward with environmental literacy plan implementation without the promise of federal funding (shown in dark green in Figure 13). Ohio's Environmental Literacy Plan, for example, includes strategies for supporting Pre-K-12 preservice and in-service educators to engage in environmental education to support their students and ongoing assessments of environmental literacy (EECO, 2012). Several states in the ELP implementation phase, including Pennsylvania, New Jersey, and Virginia, are using ELPs to add additional environmental literacy and justice standards at a state level that address the gaps in NGSS standards. Given the No Child Left Inside (NCLI) Act's failure to get approved and funded, states like Florida have completed but not officially adopted or begun state-wide implementation of their ELPs (shown in light green). Nebraska even voted to adopt the ELP, but implementation is on hold pending federal funding (NAAEE, 2019). States shown in yellow are either still in the drafting stage, or their existing plan does not align with NAAEE guidelines for environmental education (NAAEE, 2019). Finally, there are four states including Arkansas, Iowa, Mississippi, and Wyoming that either never began the process, abandoned the process, or put it on hold indefinitely as of January 2024 shown in beige.

Although the political difficulties associated with transitioning to new science education standards and implementing state-wide environmental literacy plans over the last decade point to fundamental challenges to the goals of incorporating environmental justice in Pre-K-12 science standards across the country, there is a need to adequately support the educators in states that are implementing environmental justice education. Educational scholars argue that justice-centered curricula and educational experiences are more likely to engage historically underrepresented youth in STEM fields (Arif et al., 2021; Quigley et al., 2023) and reimagine the goal of science education beyond the STEM pipeline goal (Aikenhead, 2006) of providing youth with knowledge and skills that prestigious potential employers value (Morales-Doyle, 2017; 2018). Given the wide range of goals and purposes proposed within NGSS and NAAEE's guidelines for state ELPs, these frameworks require reconciliation. In this paper, we suggest a framework for conceptualizing the teaching and learning of CEJ in Pre-K-12 formal classroom settings.

4.1.2 Pennsylvania as a Case Study

The Commonwealth of Pennsylvania's journey in the adoption of NGSS-aligned state science education standards and the implementation of a state-level environmental literacy plan serves as a fascinating case study for how environmental justice studies can be aligned with formal educational standards and as an opportunity to use the CEJ4T&L framework to support implementation initiatives in teacher preparation and education programs.

In 2002, the Pennsylvania Science and Technology Standards/ Environment and Ecology Standards were adopted. The standards were revolutionary at the time as they were the first in the United States to explicitly mention evolution (PDE, 2022). However, after the release of the NRC framework in 2012 and the NGSS in 2013, forty-four states proceeded to update their science education standards between 2013 and 2021, leaving Pennsylvania with the oldest science standards in the country.

In September 2019, the Pennsylvania State Board of Education, directed the Pennsylvania Department of Education (PDE) to start updating the Commonwealth's science, technology, and environment/ecology standards (PDE, 2022). Between February and March 2020, there was a series of fourteen stakeholder engagement sessions that allowed various Pennsylvania organizations, businesses, advocates, educators, and families to comment on the priorities for the new standards (PDE, 2022).

In April 2020, a revision committee convened over nine days plus at least thirty additional meetings to review the stakeholder feedback and research relevant existing frameworks for science education (NRC, 2012; NGSS, 2013; Windschitl et al., 2020), technology education, agricultural education (National Council for Agricultural Education, 2015), environmental education (Frungillo et al., 2022; NAAEE, 2019), engineering education, and more (PDE, 2022). By September 2020, the committee's recommendations were adopted by the Board. The Pennsylvania Science Technology and Engineering, Environmental Literacy and Sustainability (STEELS) Standards were adopted by the state board of education on January 13, 2022.

Throughout the rest of 2022, various groups within PDE worked with stakeholders to create resources for the online STEELS Hub, like curriculum frameworks, an implementation guide, curriculum development resources, and more ahead of the final publication. On July 16, 2022, the STEELS standards were published as final in the Pennsylvania Bulletin, a weekly journal produced by the Commonwealth of Pennsylvania, as part of the amendment to 22PaCode Chapter 4 (PDE, 2022). Throughout the 2022-2023, 2023-2024, and 2024-2025 academic years, PDE is expected to work alongside the state Standards Aligned System, regional Intermediate Units (supports for groups of school districts based on geographical location), school district leadership, school administrators, teacher educators, and teachers throughout the Commonwealth to engage in each step of the STEELS Standards Implementation Guide around curriculum, assessment, professional development, leveraging cross-content connections, and communication (PDE, 2022). On June 30, 2025, the 2002 standards will sunset, and the STEELS standards will be implemented state-wide for the 2025-2026 academic year following the three-year window for implementation (PDE, 2022).

In addition to implementing NGSS-aligned standards, this process of designing the STEELS standards also supported the alignment of the standards with Pennsylvania's implementation of its Environmental Literacy Plan and the NAAEE environmental education principles (NAAEE, 2015). Pennsylvania built on its existing strength in Environment and Ecology standards to create a new domain of environmental literacy and sustainability (PDE, 2022). Table 17 illustrates the Environmental Literacy and Sustainability subsections alongside example, 6th-8th grade band standards. These standards will be used later in the article to show implications for the CEJ4T&L framework in various contexts. The Environmental Justice-focused standard asks teachers to support Pennsylvania secondary students in constructing "an explanation that describes regional environmental conditions and their implications on environmental justice and social equity" (PDE, 2022). While this standard is a step in the right direction, many preservice, novice, and veteran teachers will need support in developing their conceptual understanding of Environmental Justice to design and implement standards-aligned lessons for Pennsylvania students.

Table 16. Pennsylvania Integrated Standards for Science Environment and Ecology from 2022 Science, Technology, Engineering, Environmental Literacy and Sustainability Standards

Environmental Literacy and Sustainability
Agricultural and Environmental Systems and Resources
Agricultural Systems
"Develop a model to describe how agricultural and food systems function, including the sustainable use of natural resources and the production, processing, and management of food, fiber, and energy."
Environment & Society
"Analyze and interpret data about how different societies (economic and social systems) and cultures use and manage natural resources differently."
Watersheds and Wetlands
"Develop a model to describe how watersheds and wetlands function as systems, including the roles and functions they serve."
Environmental Literacy Skills
Investigating Environmental Issues
"Gather, read, and synthesize information from multiple sources to investigate how Pennsylvania's environmental issues affect Pennsylvania's human and natural systems."
Environmental Experiences
"Collect, analyze, and interpret environmental data to describe a local environment."
Evaluating Solutions
"Obtain and communicate information on how integrated pest management could improve indoor and outdoor environments."

Table 16. Pennsylvania Integrated Standards for Science Environment and Ecology from 2022 Science, Technology, Engineering, Environmental Literacy, and Sustainability Standards (continued)

Sustainability and Stewardship
Environmental Sustainability
"Obtain and communicate information to describe how best management practices and environmental laws are designated to achieve environmental sustainability."
Environmental Stewardship
"Design a solution to an environmental issue in which individuals and societies can engage as stewards of the environment."
Environmental Justice
"Construct an explanation that describes regional environmental conditions and their implications on environmental justice and social equity."

4.1.3 Existing Environmental Justice Frameworks

Critical environmental justice (CEJ) is largely unexplored in education. Pellow (2018) offers a productive framework for CEJ studies that addresses the limitations in the evolving field of EJ and ecojustice and is constructively critical of the United States Environmental Protection Agency's limited vision for environmental justice. Pellow's four pillars of CEJ call for 1) a closer examination of the *intersections* between social identities in the persistence of environmental injustices, 2) the need to use a *multiscalar lens* to study issues of environmental injustice, 3) striving for *transformation* over reform of systems, and 4) the *indispensability* of beings and the natural world that have been historically dominated (Pellow, 2018, p.17-18). Pellow's critical environmental justice framework also illustrates the connection between Dr. Cedric Robinson's idea of racial capitalism and EJ. Racial capitalism is the idea that the political and economic system of capitalism in the United States is inextricably connected to and mutually reinforces systemic racism (Robinson, 2000). Racism is the foundation of environmental injustice, and it sustains and magnifies environmental injustices despite the history of action, resistance, and movements towards environmental justice. The idea of transformative learning in environmental justice education through critical pedagogies is emerging in the field (Cachelin & Nicolosi, 2022; Robinson et al., 2023).

Pellow's notion that reform will not lead to environmental justice is aligned with abolitionist educational scholars who call for transformation over reform in school settings to forefront liberation. Brazilian educator and philosopher Paulo Freire links liberation to rejecting domination (Freire, 1970). Freire reminds educators that "liberation is praxis" that requires action and reflection to transform rather than reform the world (Freire, 1970). Ecojustice scholar Rebecca Martusewicz applies Freire's ideas further through *relationality* among people and nature and the intersecting forms of social and ecological violence that contribute to androcentrism and environmental injustice (Martusewicz, 2018). She argues that environmental justice "self-work" for practitioners and researchers is as important to the EJ movement as advocacy and policy reform (Martusewicz, 2018).

Numerous scholars have worked to develop theoretical frameworks and practical models to understand environmental justice and related concepts like socio-scientific issues (SSI), social justice science education, and ecojustice in different contexts, including community planning (Meenar et al., 2018), economics (Ali, 2001), engineering (Blue et al., 2021), geoenvironmental science (Bose, 2004), green energy (Scott & Smith, 2017), law (Bullard, 1993), public health and nursing (Butterfield & Postma, n.d.; Chircop, 2008; Kreger et al., 2011; Taylor et al., 2007; Wilson, 2009), public policy (Gusti et al., 2019; Neal et al., 2014), social work (Teixera & Krings, 2015), tourism (Whyte, 2010), as well as formal (Dimick, 2012) and informal science education. There is a gap in practical environmental justice frameworks that use a critical lens, especially in the context of education.

For example, Ali describes collective responsibilities in the context of economics and environmental justice (2001). However, they caution that shared responsibilities for addressing environmental injustices must also be differentiated to enable distributive justice given the inequitable impact of and contributions to environmental degradation across lines of difference in race and socioeconomic status (Ali, 2001).

Teixeira and Krings (2015) developed the "Environmental Justice Framework for Social Work Education" tool for social work post-secondary educators to incorporate sustainability and environmental justice-related interventions into training programs for various social work contexts. Their framework illustrates values, perspectives, and skills needed to enact four guiding principles derived from existing global standards for social workers, including 1) "the recognition of the dignity and worth, diversity, and strengths perspective," 2) "the recognition of the interconnectedness among micro, mezzo, and macro systems," 3)" the importance of advocacy and changes in socio-structural, political and economic conditions that disempower, marginalize, and exclude people," 4) "focus on capacity-building and empowerment of individuals, families, groups, organizations, and communities through a human-centered developmental approach" (Teixeira & Krings, 2015, p.4).

In science and STEM (science, technology, engineering, and mathematics) education, frameworks that support student learning around topics related to environmental justice often center on the teaching and learning of socio-scientific issues or social problems that can be connected to science learning through process or concept (Sadler, 2009). The Socio-scientific Issues Teaching and Learning (SSI-TL) model supports the teaching and learning of SSIs through situated learning by providing educators with descriptions of a sequence of suggested learning experiences and learning objectives aligned with the Framework for K-12 Science Education and NGSS (Sadler et al., 2017; Lave & Wenger, 1991). Dimick uses a framework that examines the idea of student empowerment as a mechanism to promote social justice science education in formal education spaces through pedagogies and practices that promote social, political, and academic empowerment (2012).

At the core of CEJ is a recognition that traditional conceptions of EJ can promote or reinforce the status quo. Some researchers have looked for ways to use CEJ frameworks to explain the Black Lives Matter movement (Pellow, 2016), economics (Carrillo & Pellow, 2021), the Israel/Palestine conflict (Pellow, 2018), nursing (LeClair et al., 2021), public policy (Pellow, 2018), and the United States prison system (Pellow, 2018). Like other scholars, Stapleton advocates for a more critical environmental education in the United States and explains the glacial pace of change in environmental education with standpoint theory (2020).

4.2 Critical Environmental Justice for Teaching and Learning

4.2.1 Environmental Racism and Environmental Injustices

Climate change, food insecurity, land degradation, natural resource scarcity, pollution, and exposure to dangerous materials are disproportionately experienced by low-income and minoritized communities worldwide. The students, families, and educators most affected by environmental injustices in the United States often live in communities with historically underfunded school systems. A root cause of inequitable access to educational opportunities is also the root cause of environmental injustices: structural violence rooted in systemic racism (Williams, 2021).

The environmental justice movement is an antiracist social justice movement. However, like many social justice movements in history, its message can be diluted and appropriated for other political agendas. To avoid this common pitfall, it is important to start with and center the root of environmental injustices, environmental racism. The root of environmental racism is violence. In his book *Climate Change is Racist: Race, Privilege, and the Struggle for Climate Justice*, Williams analyzes climate change using Galtung's (1969) peace studies framework to understand the three levels of violence (2021). The levels of violence that contribute to environmental racism are like a tree. The roots or foundation of violence is cultural violence, which is often unconscious and described as white supremacy or male chauvinism (Williams, 2021; see also Galtung, 1969). Structural violence can be compared to water and nutrients flowing from the tree's roots to its visible branches and leaves. This type of violence is legitimized by cultural violence and recognized as patterns of inequality along lines of difference. Visible violent acts at distinct levels, like a police officer shooting an unarmed Black child, government officials flooding poor neighborhoods to protect the homes and businesses of the wealthy during a hurricane or exporting toxic wastes to countries in the Global South, are the final level of direct violence (Williams, 2021; see also Galtung, 1969).

According to Bullard, "environmental racism refers to any policy, practice, or directive that differentially affects or disadvantages (whether intended or unintended) individuals, groups, or communities based on race or color" (Bullard, 1993, p.1037). Tatum describes cultural racism as smog in the air. "Some days it is so thick it is visible, other times it is less apparent, but always, day in and day out, we are breathing it in" (Tatum, 2001, p.125). Figure 14 illustrates the reality of environmental racism and its roots in cultural violence as a gray smog that exerts pressure on the ecosphere, including all living and nonliving things on Earth. This smog of environmental racism causes environmental injustices, including anthropogenic climate change, the global water crisis, environmental degradation, and food insecurity, as illustrated in Figure 15.

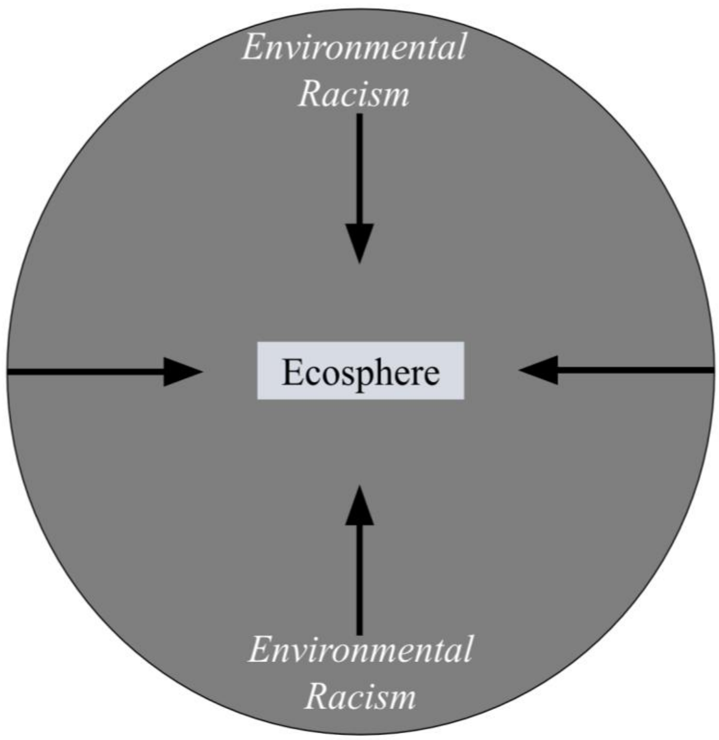


Figure 14. Bottom Layer of the CEJ4T&L Framework- "Environmental Racism as Smog"

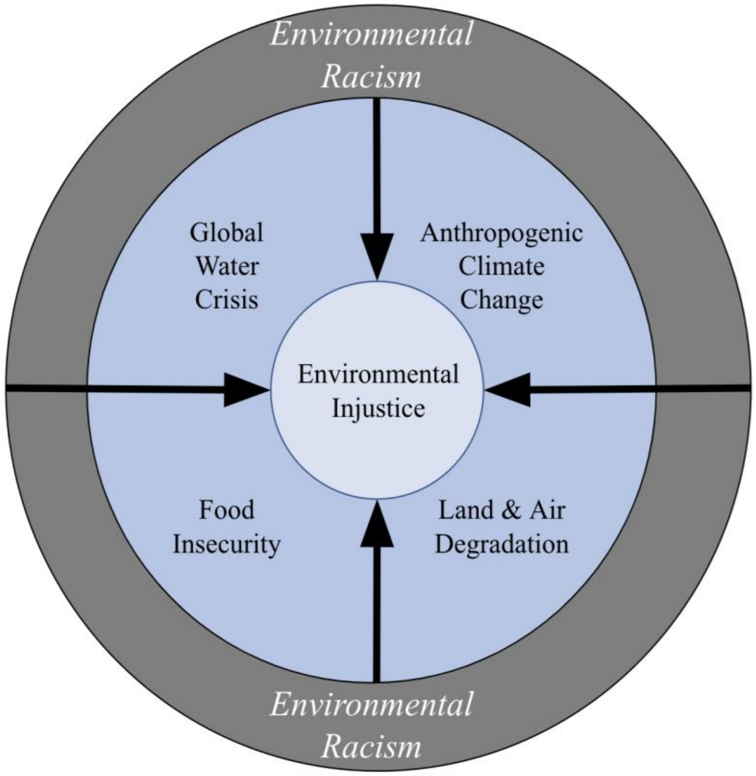


Figure 15. Second Layer of the CEJ4T&L Framework "Environmental Injustices are Fueled by Environmental Racism"

4.2.1.1 Environmental Justice vs. Ecojustice

There is an ongoing debate in the field over language, particularly between scholars who use "environmental justice" (e.g., Bullard, 1994), those who use "ecojustice" (e.g., Bowers, 2002; Martusewicz, 2018; Martusewicz et al., 2014). Martusewicz differentiates the concepts based on the relationship and direction of the environmental injustices either among humans, *environmental justice*, or by humans toward nature, *ecojustice* (2005). Other scholars contend that the two types of justice are deeply intertwined (e.g., Ali, 2001; Gruenewald, 2005; Haluza-DeLay, 2013; Pellow, 2018). Given the purpose of this conceptual framework to support critical teaching and learning at the crossroads of social justice and environmental sustainability, we focus on the human side of environmental justice. However, Pellow's critical environmental justice (2018) and forthcoming discussions of the importance of students' personal connection with nature as a key crosscutting concept in CEJ-T&L will hopefully illustrate the connections between the two forms of justice in teaching and learning.

4.2.2 CEJ4T&L: Core Concepts

The environmental justice literature can be organized into core concepts that respond to environmental injustices that have evolved as the Environmental Justice Movement in the United States has evolved since the 1980s. These core concepts can provide multiscalar entry points for teaching and learning about critical environmental justice. "The environmental justice frame has grown not only horizontally to this range of new issues and countries, but also vertically to an application to broad-based global issues, from the global toxics trade to food sovereignty, to of course, climate justice" (Schlosberg & Collins, 2014, p. 361-362). For this reason, the CEJ4T&L includes core concepts that move beyond the traditional definition of environmental justice.

Scholars point to various locations within which to place environmental justice studies in education, including social studies education, Earth, and Space Science (ESS) courses, elective environmental education (EE) courses, informal learning organizations, or outdoor education (Lewis & Lu, 2017; NSTA, 2023; NRC, 2012). However, access to rigorous, high-quality EE and ESS courses varies significantly from state to state and even district to district. ESS education scholars agree it is the "most neglected area of science education and scientific literacy" (Lewis & Lu, 2017, p. 304; see also American Geological Institute, 2015). How can we hope to prioritize environmental justice studies if they are only connected to limited access, optional informal and outdoor education programs, or when they relate to two science courses that are often deprioritized or eliminated from high school graduation requirements? Integrating environmental justice studies with social studies education is one solution. Still, science educators are uniquely positioned to support learners in understanding how science and engineering practices, crosscutting concepts, and science disciplinary core ideas can be used alongside CEJ4T&L approaches to address our planet's most pressing problems.

While environmental justice studies can and should exist in formal and informal spaces, there are also direct connections to formal Pre-K-12 science education and transdisciplinary learning environments. Often, the scope of environmental justice education in science or formal environmental education, if it is present at all, is limited to inequitable distributions of environmental hazards like toxic waste dumps. However, there are a number of different facets or aspects of critical environmental justice that are intra-generational and exist at multiple scales including but not limited to: the inequitable impact of climate change (e.g. Amorim-Maia et al., 2022; Lombardi, 2022; Svarstad, 2021), unequal protection from natural disasters (e.g. Bullard & Wright, 2012; Meenar et al., 2018), exposure to toxins (e.g. Bullard, 1994; Van Horne et al., 2023), the burden of pollution through displacement (e.g. Dryzek, 1987), environmental health inequities (e.g. Chircop, 2008; Kreger et al., 2011), unequal access to environmental resources (e.g. Dickinson, 2012; Kushmerick et al., 2007; Taylor et al., 2007), inequitable water availability (e.g. Gusti et al., 2019; Neal et al., 2014; Zwarteveen & Boelens, 2014), sacrifice zones and the inequitable burden of sustainability (e.g. Menton et al., 2020; Pellow & Brulee, 2005; Scott & Smith, 2017), land rights issues, and food justice (e.g. Shvartzberg Carrio & Cooper, 2021). Given the broad range of critical environmental justice topics, we categorized each into four overarching categories referred to as CEJ4T&L core concepts that are meant to serve as entry points for teaching and learning that can be easily aligned to NGSS and state learning priorities, including climate justice, collaboration and balance, food sovereignty and sustainable agricultural practices, and water justice. In the following section, each of the four core concepts are defined in the context of CEJ4T&L.

4.2.2.1 Climate Justice

The field of climate justice has seen a meteoric rise in popularity among educational researchers, practitioners, and mainstream media in the last few decades (McGinnis et al., 2017). Anthropogenic climate change is a common topic in environmental education included in the NGSS (NGSS Lead States, 2013). The climate justice movement is the most prominent extension of the EJ movement (Kluttz & Walter, 2018; Schlosberg & Collins, 2014). The foundation of climate justice is the idea that anthropogenic or human-caused climate change and its inequitable impacts on historically marginalized communities can be understood through critical, social justice, and decolonial lenses (Kluttz & Walter, 2018). The climate justice movement has become more than seeking to mitigate and adapt to climate change. It also focuses on "moving to a post-carbon energy system, paying for the ecological and social damage of climate change, and protecting the voice and sovereignty of the most vulnerable" (Schlosberg & Collins, 2014 quoted in Kluttz & Walter, 2018, p.94).

Sea level rise and weather extremes do not discriminate based on racial identity or socioeconomic status; therefore, climate change is not consistently recognized as a key issue in EJ studies. As Amorim-Maia et al. (2022) argue, a critical and intersectional climate justice lens is needed to understand climate change adaptation planning and mitigation and the "overlapping and interdependent systems of disadvantage and oppression that restrict people's adaptive capacity and create new or exacerbate existing social-ecological vulnerabilities" (p.4). Their framework aligns with Pellow's pillars of CEJ, where intersectionality influences vulnerability, resistance, and resilience to the impacts of anthropogenic climate change, and applies multiscalar methodological and theoretical approaches to analyzing needed adaptation and mitigation strategies (Amorim-Maia et al., 2022; Pellow, 2018).

A coalition of nongovernmental organizations known as *Climate Justice Now!* Developed "core climate action principles" that moved beyond keeping fossil fuels in the ground and carbon mitigation to raising awareness that climate change inequitably impacts historically marginalized people and seeking more voice for those historically underrepresented in decision-making (Eaton & Day, 2020; Kluttz & Walter, 2018; Koukouzelis, 2017). Schlosberg and Collins conceptualize climate justice in three ways through the lens of "academic discourse, elite nongovernmental organizations (NGOs), and grassroots movements" (2014, p. 359). They argue that the environmental justice movement and the climate justice movement fused in 2005 post Hurricane Katrina, and the grassroot movement version of climate justice is the only conceptualization that is aligned with the environmental justice movement (Schlosberg & Collins, 2014). For that reason, the CEJ4T&L framework uses this definition of climate justice. Climate justice is part of the larger environmental justice movement and focuses on the "local impacts and experience" of global warming and climate change, the "inequitable vulnerabilities" experienced by historically marginalized people and communities, elevating those voices, and seeking "community sovereignty and functioning" (Schlosberg & Collins, 2014, p. 359).

4.2.2.2 Collaboration and Balance

Environmentalism in the United States had been around since the mid-19th century with texts from John Muir and Henry David Thoreau and the establishment of the national park system. A more modern and mainstream environmentalism movement emerged with the publication of Rachel Carson's *Silent Spring* in 1962 and passage of Congressional Acts including the Clean Air Act, the Wilderness Act, the Endangered Species Act, (Carson, 1962; Kroll, 2001; Schlosberg &

Collins, 2014). The push for preservation and protecting nature, however, harmed and continues to harm Indigenous communities when it is not done so with a critical lens. Issues of and action against inequitable environmental vulnerabilities and harm among historically marginalized communities also did not start with the birth of the modern environmental justice movement in the 1980s.

"Ecological degradation is first and foremost a social violence" (Haluza-DeLay, 2013, p.397), but it takes collaboration and balance to prevent further harm. An important tenet of environmental education is that students can make sense of the traditional arguments and perspectives in the field. For example, should John Muir's argument of preservation or Gifford Pinchot's conservation be used to understand the impact of the United States national park system? Should science educators foreground Western or Indigenous ways of knowing? In the face of climate change, is it more important to discuss mitigation or adaptation solutions? Should equitable access to natural resources be prioritized over the sovereignty of nations? Traditional environmental education programs often focus on the idea of sustainability. However, sustainability in environmental education is a concept that represents an anthropocentric balance between using enough natural resources to meet human needs while ensuring there is also enough to meet the needs of future generations of humans (NAAEE, 2015). What is at stake if we only view environmental justice education through a human versus ecological lens? In order to balance perspectives and successfully address our world's most pressing problems, diverse ways of knowing need to be elevated in environmental decision-making (Robinson et al., 2023). Collaboration and balance are needed to support learners to reconcile seemingly incompatible ideas in environmental education that will support the development of environmental dispositions that can critically analyze benefits and drawbacks of complicated solutions to wicked problems.

4.2.2.3 Food Sovereignty and Sustainable Agricultural Practices:

"The recovery of the people is tied to the recovery of food, since food itself is medicine- not only for the body but also for the soul and for the spiritual connection to history, ancestors and the land" (quoted in Adamson, 2011; LaDuke et al., 2009). Environmental racism among other factors can lead to food injustice where systemic inequities along lines of race, gender, socioeconomic status, and ability are perpetuated within food systems (Glennie & Alkon, 2018). "Food justice movements respond to the lack of decent food and economic opportunities on one hand, but also the idea of autonomy and security on the other" (Schlosberg & Collins, 2014 p. 370). For this reason, food justice is part of the critical environmental justice for teaching and learning core concept of food sovereignty and sustainable agricultural practices which represent mechanisms for food autonomy and security, respectively.

In literature, scholars differentiate between food justice and food sovereignty depending on the context. Food justice is a term more prolific among scholars in the United States, while many Indigenous scholars and activists in the global south use food sovereignty (Adamson, 2011; Glennie & Alkon, 2018; LaDuke et al., 2009; Reynolds & Bradley, 2018). Food sovereignty reflects a fundamental human "right to food" (Adamson, 2011, p. 213). All humans have a right to nutritional, culturally affirming food. Indigenous food systems tend to be smaller scale, more sustainable, and therefore more resilient to climate change (Adamson, 2011; Schlosberg & Collins, 2014). The CEJ4T&L intentionally uses sovereignty to elevate Indigenous human rights and ways of thinking.

Food sovereignty and sustainable agricultural practices are directly tied to the climate justice, because climate change can disrupt small scale and industrial agricultural systems, cause the decline and eventual extinction of crucial pollinators including native bees, accelerate soil depletion and erosion, create food deserts, spread disease, and more (Schlosberg & Collins, 2014; Wade et al., 2020). While the issue of empowering urban youth in environmental justice is at the forefront of the literature due to perceived lack of connection to nature, the idea of environmental justice can seem at odds with the values and livelihoods of rural farming communities where seemingly simple solutions like organic farming practices are thrown at tremendously complicated problems like pest control in food production that also disproportionately impact the livelihoods of agricultural communities.

The intersection of sustainability and agriculture education also serves as a meaningful entry point for practitioners and learners in rural communities. The Pennsylvania Environmental Literacy and Sustainability standards are one example of a possible alignment between agricultural education standards and environmental justice (PDE, 2022; National Council for Agricultural Education, 2015). Education scholars have also explored pedagogical approaches to investigating food sovereignty (LaDuke et al., 2009) and sustainable food practices, e.g. critical place-based pedagogies, arts-based pedagogies, experiential learning, and discovery learning (Harris & Barter, 2015). Food sovereignty and sustainable agricultural practices is an overarching core concept that provides locally relevant and place-based entry points for teaching and learning about critical environmental justice through a lens that moves beyond the priorities of the first generation of the Environmental Justice Movement in the United States.

4.2.2.4 Water Justice:

In school, children learn that the Earth is 71% water and that living things need water to survive. Later, they learn how water is used in energy production and manufacturing processes. Water is the center of many religious ceremonies, cultural traditions, recreational activities, and more. The “hydrosocial cycle” builds on the concept of the hydrologic cycle to include its relationship with society (Linton & Budds, 2014). Access to clean drinking water should be a basic human right, but it is instead an indicator of power and privilege with the power to initiate violent conflict (Gusti et al., 2019). Other than air and shelter, water is the resource human bodies urgently need to survive. Lack of access to water can cause life-threatening health emergencies in a matter of hours to days depending on the climate. Beyond the human body's need for hydration, lack of water can quickly cause widespread sanitation issues that can spread deadly disease and shut down vital industries like food manufacturing, agriculture, hydroelectricity, cooling nuclear power plants, and more. Scholars have proposed various water justice frameworks to make sense of the hydrosocial cycle and the confluence of clean water availability and social justice in formal education and other settings (Davis & Schaeffer, 2020; Handayani et al., 2019; Neal e al., 2014; Sultana, 2018; Zwarteveen & Boelens, 2014)

The water-food-energy nexus is a key topic in sustainable development and within all four of the core concepts in the CEJ4T&L framework. This nexus is described differently among scholars down to the order of three parts of the nexus. The nexus is included in the water justice section with water as the first concept to signify how water is integral to food and energy systems (Al-Saidi & Hussein, 2021). Food systems and energy systems require significant amounts of water, and these systems impact water quality, access, and distribution (Al-Saidi & Hussein, 2021; Schlosberg & Collins, 2014; Wade et al., 2020; Wang & Knobloch, 2018). Energy sovereignty, autonomy, and justice are also included in scholarship about water justice, agricultural sustainability, food sovereignty, and Indigenous land rights (LaDuke et al., 2009). The water-food-energy nexus can be taught through the lens of traditional environmental sustainability practices, but it is ultimately a connection between the four CEJ4T&L core concepts.

CEJ4T&L Framework Core Concepts Application

How might a middle school science teacher in Pennsylvania use the CEJ4T&L Framework core concepts as entry points for student-centered learning that is aligned to the new Pennsylvania environmental literacy and sustainability standards and the Next Generation Science Standards? Table 18 shows an example NGSS and STEELS standard. In this case, middle school students are expected to be able to ask questions and provide evidence to understand climate change over time. There are clear connections to climate justice given the disciplinary core ideas of human impacts on earth systems and global climate change. Teachers can make connections to water justice considering factors like fossil fuel combustion that also pollute water and require significant water for the process itself. Food sovereignty and agricultural sustainability can be brought into learning experiences as extensions to understand how human impact relates back to inequitable distribution of harms because of the changing climate. Collaboration and balance can be incorporated as an extension to understand adaptation and mitigation strategies. This standard also discusses the balance between natural processes and anthropogenic causes. The Pennsylvania standard is open-ended and therefore leaves teachers with the opportunity to choose entry points and core concepts based on connections to local environmental issues salient to their students, their students' career interests, connections to other coursework, etc.

Table 17. Example Next Generation Science Standard and Pennsylvania Science, Technology, Engineering, Environmental Literacy and Sustainability Standard to Illustrate CEJ4T&L Core Concept Application

NGSS Example Standard	MS-ESS3-5	"Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century" (NGSS Lead States, 2013).
Disciplinary Core Idea	ESS3:C Human Impacts on Earth Systems	"Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise" (NGSS Lead States, 2013).
Disciplinary Core Idea	ESS3:D Global Climate Change	"Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities" (NGSS Lead States, 2013).
Clarification Statement		"Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the significant role that human activities play in causing rise in global temperatures" (NGSS Lead States, 2013).
Crosscutting Concept	Cause and Effect	"Cause and effect relationships may be used to predict phenomena in natural or designed systems" (NGSS Lead States, 2013).
Science and Engineering Practices	Connection to Engineering, Technology, and Applications of Science	"All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment" (NGSS Lead States, 2013).

Table 17. Example Next Generation Science Standard and Pennsylvania Science, Technology, Engineering, Environmental Literacy, and Sustainability Standard to Illustrate CEJ4T&L Core Concept Application (continued)

PA Environmental Literacy and Sustainability Standard	3.4.6-8. I Environmental Literacy and Sustainability: Sustainability and Stewardship	"Construct an explanation that describes regional environmental conditions and their implications on environmental justice and social equity" (PDE, 2022).
	Clarifying Statement	"Examples include both current and historical conditions due to systemic inequalities, including but not limited to human health impacted by Superfund sites, air quality, urban heat islands, acid mine drainage, access to green space, biodiversity, and water quality. Explanations could be constructed using primary and secondary sources, both print and digital" (PDE, 2022).
Science and Engineering Practices	Obtaining, Evaluating, and Communicating Information	"Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence" (PDE, 2022).
Disciplinary Core Ideas	LS4.D: Biodiversity and Humans	"Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystems services that humans rely on—for example, water purification and recycling" (PDE, 2022).
Crosscutting Concepts	Cause and Effect	"Cause and effect relationships may be used to predict phenomena in natural or designed systems" (PDE, 2022).
	PA Context	"Examples of Pennsylvania context include but are not limited to Pennsylvania Environmental Justice Area designations or Environmental Health Indicators" (PDE, 2022).

4.2.3 CEJ4T&L: Multifaceted Approaches

The multifaceted approaches to CEJ4T&L support youth empowerment, especially those historically underrepresented and marginalized in STEM. CEJ4T&L is a conceptual framework to support learning in any discipline and especially transdisciplinary learning environments. The motivation for this paper's emphasis on the STEM field and youth who are historically underrepresented in STEM comes from a common problem of practice that inspired the creation of the framework in the first place. Like NGSS, these crosscutting concepts are intellectual tools and connections that can create conditions that support teacher and learner to better understand core ideas of critical environmental justice. Dimick argues that student empowerment can be understood in terms of social empowerment, political empowerment, and academic empowerment (2012). The four darker blue circles in Figure 16 represent multifaceted approaches teachers can use to construct learning environments that empower youth to understand each of the CEJ4T&L core concepts through a critical lens and culturally relevant pedagogies (Ladson-Billings, 1995). The four approaches include (1) transdisciplinary pedagogies (2) social justice values, (3) understanding environmental sustainability practices in STEM, (4) and an authentic connection with nature. The water-energy-food nexus is a common thread that connects CEJ4T&L core concepts and is often central to learning about engineering and environmental sustainability practices. By integrating these approaches, educators and their students can push back on environmental racism towards the goals of water justice, climate justice, food sovereignty, and agricultural stewardship, and a balance between incompatible perspectives. Given the multifaceted nature of these approaches and their capacity to inform liberatory pedagogies, the following section explains the knowledge, skills, and mindsets needed to enact these approaches.

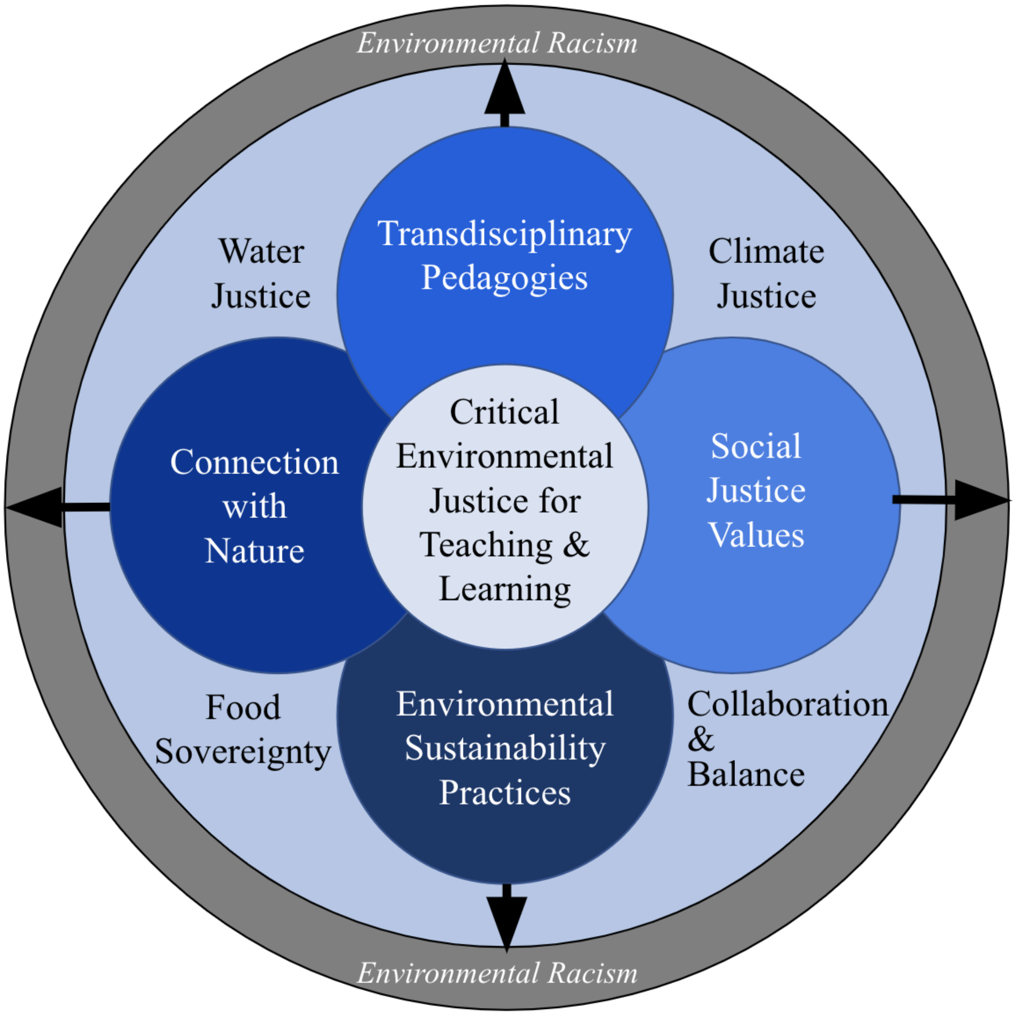


Figure 16. Critical Environmental Justice for Teaching and Learning (CEJ4T&L Conceptual Framework)

4.2.3.1 Transdisciplinary Pedagogies

Due to the current political, educational, and atmospheric climates, STEM educators are tasked with preparing scientifically literate students who can dissolve traditional disciplinary boundaries to address our world's most pressing problems. Transdisciplinary pedagogies in CEJ4T&L are conceptualized as student-centered, problem-solving experiences that intuitively integrate various disciplines in relevant, real-world scenarios (Sengupta et al., 2019). These pedagogies can result in new understandings and the discovery of possible local solutions and ways to address complex, multiscale problems like climate change, resource scarcity, etc. There are some other pedagogical strategies and education frameworks that inform and align with our conception of transdisciplinary strategies. Quigley et al.'s (2017) conceptual model for STEAM (science, technology, engineering, the arts and humanities, mathematics) teaching practices also use transdisciplinary pedagogies to address local, relevant problems.

For example, a teacher might propose a locally relevant (Pang et al., 2021) problem to students about inequitable access to fresh vegetables in their community. Students and their teacher would work collaboratively to understand what disciplines are needed in order to better understand and address the problem. Data science might be organically brought in so that students can examine heat maps with fresh produce sources and their distance to different neighborhoods in the school district. They might need to connect with a local farmer who participates in the community farmer's market or the high school agriculture teacher to understand what goes into producing fresh vegetables. Maybe they might research existing nutrition programs in the school district and community. After students propose solutions based on their research, they might need to engage in the engineering design process to create a hydroponics system for the school. Green argues that experiential learning like this is a pedagogical strategy for youth to engage in social and environmental justice education (2021).

4.2.3.2 Social Justice Values

Each phase of the EJ movement has leveraged core principles informed by collective values to guide decision-making. For example, the "Principles of Environmental Justice" were adopted and used after the first National People of Color Environmental Leadership Summit in 1991 (Dickinson, 2012). Critical environmental justice sits at the intersection of environmental sustainability education and social justice education, emphasizing human impact on the environment and the resulting inequitable impact on humans. Pellow's four pillars of CEJ studies can be used as checkpoints to assess whether EJ studies reach the level of CEJ or not. Abolitionist and decolonial environmental justice take the social justice focus further by seeking to disrupt the root colonial causes of environmental racism (Menton et al., 2020).

A key part of social justice education is striving for consistent cultural relevance, responsiveness, and sustained pedagogy (Ladson-Billings, 2021). Ladson-Billings argues that culturally responsive teaching can support students to "accept and affirm their cultural identity while developing critical perspectives that challenge inequities that schools (and other institutions) perpetuate" (1995, p.469). To engage Pre-K-12 learners in social justice education, educators need to commit to teaching that is abolitionist (Love, 2019) and anti-oppressive (Edwards, 2006) and supports the development of a liberatory consciousness (Love, 2000). Indeed, educators need to work towards abolitionist teaching practices to aspire "towards a more intersectional decolonial framing of environmental justice" proposed by Menton et al. (2020, p. 1625). This framework for environmental justice values transformation over reform.

Before moving to action and accountability, educators need to consider their positionality and what it means to move from being an aspiring social justice ally (Edwards, 2006) to a co-conspirator willing to their comfort and safety on the line in partnership with their students and communities (Lowe, 2023). Once appropriate to action, civic engagement in formal learning spaces can allow students to leverage social justice values to inform real-world decisions that promote equitable participation (Doucette et al., 2023; Frungillo et al., 2022).

4.2.3.3 Environmental Sustainability Practices

Environmental education is often associated with sustainability education. Therefore, environmental education curricula often emphasize the knowledge and skills needed to understand and use environmental sustainability practices. Practices exist at various levels, including reducing carbon emissions, preventing pollution, “reduce-reuse-recycle-reduce” programs, energy reduction, water conservation, and more. Environmental sustainability practices lend themselves well to integrated STEM instruction (Roehrig et al., 2017). Engineering design principles are often incorporated and can center on critical environmental justice in discussing synergies and trade-offs in sustainable development. Environmental education students often learn about the Water-Energy-Food nexus (Menton et al., 2020) and the United Nations' sustainable development goals (United Nations, 2017). Environmental sustainability practices are already represented in Next Generation Science Standards, so this is an aspect of CEJ4T&L that lends itself well to three-dimensional learning, ambitious science teaching through the investigative cycle and incremental sensemaking (Furtak & Penuel, 2018; Windschitl, 2020).

4.2.3.4 Connection with Nature:

Research suggests that childhood nature experiences and outdoor embodied learning influence productive environmental behaviors and feelings (Chen-Hsuan Cheng & Monroe, 2012; Schilhab, 2021; Wells & Lekies, 2006). For example, Wells and Lekies (2006) surveyed 2,000 Americans between 18 and 90. Their results suggested that people who had built an authentic connection with nature through various experiences were likelier to report positive attitudes and behaviors toward the environment. Chen-Hsuan Cheng and Monroe explored youth's affective attitude towards nature. They found four dimensions including: "(a)enjoyment of nature, (b) empathy for creatures, (c) sense of oneness, and (d) sense of responsibility" (2012, p.31). While this index might be more relevant for ecojustice than environmental justice, critical environmental justice blurs the lines between the two. These four dimensions are entry points for further learning and exploration in environmental education spaces. Engaging in didactic nature experiences in formal science education has been found to support students' understanding of science content and processes (Schilhab, 2021).

Scholars point to a number of possible reasons for reduced connection to nature for youth including increased reliance on technology, stranger danger, limited access to green spaces, generational disconnect, fast-paced capitalist culture, and exclusion both implicit and explicit of historically minoritized people (Chen-Hsuan Cheng & Monroe, 2012; Finney, 2014; Scott & Tenneti, 2021; Wells & Lekies, 2006). Additionally, traditional Western STEM classes do not emphasize building an authentic connection with nature. In *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants*, Robin Wall Kimmerer argues that all people can benefit from seeking to understand Native ways of knowing (2013). STEM educators must explore the tensions and synergies between Western science and Indigenous ways of knowing to support students' ability to build authentic, personal connections with nature.

> In the Western tradition, there's a recognized hierarchy of beings, with, of course, the human being on top–the pinnacle of evolution, the darling of Creation– and the plants at the bottom. But in Native ways of knowing, human people are often referred to as "the younger brothers of Creation" (Kimmerer, 2013, p.9).

Kimmerer's storytelling and exploration of Native ways of knowing starkly contrast discussions of the Anthropocene's irreversible damage to the planet. One critique of incorporating ecojustice and environmental justice in especially younger grades is the negative effect on students' emotional well-being. Over the past decade, many scholars have investigated eco-anxiety and climate anxiety (e.g., Brophy et al., 2023; Coffey et al., 2021; Pihkala, 2020). Bright and Earnes (2022) use Boler's (2017) *Pedagogy of Discomfort* framework to understand how New Zealand youth climate activists moved from apathy through climate anxiety to collective action.

CEJ4T&L Framework Multifaceted Approaches Application

How might a middle school science teacher in Pennsylvania use the CEJ4T&L Framework multifaceted approaches to facilitate learning that is aligned to the new Pennsylvania environmental literacy and sustainability standards and the Next Generation Science Standards shown in Table 18. Students asking questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century can be part of a transdisciplinary STEAM scenario where students are solving a local, real-world problem related to climate change adaptation. It is easy for the NGSS example to never move beyond human impact on the environment, but it is important to support students to see how humans inequitably impact the environment and, in turn, humans are inequitably impacted by climate change.

4.3 Implications for Teaching and Learning

This conceptual framework is meant to be a tool for preservice teachers, in-service teachers, teacher educators, and educational researchers to understand the knowledge, skills, and mindsets needed for learning and teaching critical environmental justice. This framework builds on research from Pre-K-12 formal and informal learning environments, but future research is needed to better understand the needs of the teachers as adult learners of CEJ (Kluttz & Walter, 2018).

Few scholars have empirically measured the inclusion of environmental justice, let alone critical environmental justice, in curricular materials, state environmental literacy plans, state science standards, or preservice teacher preparation programs. Kushmerick et al. (2007) examined 224 lessons from mainstream environmental education curricula and found that the curricular materials seldom explicitly addressed environmental justice. In the almost two decades following their study, more curricular resources explicitly address environmental justice, like Frungillo et al.'s (2022) MWEE (Meaningful Watershed Educational Experiences). MWEEs disrupt curricular boundaries and support five learning outcomes for all students, including promoting equity and environmental justice through access, equity-focused discussions, and civic action projects (Frisk & Larson, 2011; Frungillo et al., 2022). MWEEs can be adapted for urban, suburban, and rural contexts. While urban planning and urban sprawl are part of environmental justice scholarship, there is a misconception that is reinforced by some scholars and curriculum resources that environmental justice education is for "urban" or "diverse" youth (Hazula-DeLay, 2013).

Unfortunately, it is unlikely that every state and school district in the United States will suddenly have the capacity or desire to ensure that every student has dedicated time in their Pre-K-12 educational experience to focus on environmental education, let alone environmental justice education. Conversely, using transdisciplinary learning strategies and problem-based learning can make space for CEJ4T&L in other core subjects and electives in formal learning spaces. Educators can also integrate social justice standards into their disciplinary curriculum (Learning for Justice, 2018). Researchers and practitioners have been working together to understand how a justice-centered, integrated curriculum can increase engagement and interest in historically underrepresented youth in STEM (Plank et al., Under Review). The CEJ4T&L framework can therefore be used beyond the scope of science and environmental education contexts. Through transdisciplinary pedagogies, any content can be organically brought in to address a locally relevant problem. There is even space for justice-centered computer science curriculum to be integrated in unlikely places like English Language Arts courses (Chelednik et al., Under Review).

4.4 Conclusion

The challenge of teaching and learning for critical environmental justice is even more urgent now, given threats to our students' scientific understanding and agency through science denial and disinformation (Allchin, 2022; Lombardi, 2022). Not only does environmental education need to start with and center environmental justice in formal, informal, and community-based spaces, but it also needs to be integrated into mainstream courses. As more states add education standards related to environmental literacy and justice, educators will need additional support in developing the knowledge, skills, and dispositions needed to support collective sensemaking, action, and accountability toward an environmentally just future. In states that are not likely to implement Environmental Literacy Plans, environmental education will remain on the periphery of formal education. Educators might need to use strategies like creative insubordination

(Gutiérrez, 2016) to ensure students get the learning experiences they need to address the world's most pressing problems.

The Framework for K-12 Science Education and the shift to three-dimensional learning, including core disciplinary ideas, crosscutting concepts, and science/engineering practices, focuses on student-centered educational experiences where learners participate in "science as practice" (Furtak & Penuel, 2018; NRC 2012). This framework supports educators to design and facilitate experiences that give youth agency and voice, allow them to explore phenomena that matter to them through three-dimensional learning with a justice lens. This article addresses a need for research on educating for environmental justice, but further research is needed. Future research is needed to gauge how the CEJ4T&L framework can address tensions and misalignment between student and teacher conceptualizations of environmental justice.

5.0 Conclusion

The dynamic intersection of global environmental crises with persistent disparities in STEM along lines of difference including race, gender, socioeconomic status underscores the urgent need for a critical and intersectional environmental justice movement. This movement needs to equip young people with social justice mindsets and computational thinking skills essential for addressing the most pressing challenges facing our world. “Dismantling oppressive structures begins with critically examining how they manifest within our habits of mind so we can see beyond them—to capture what was lost, what is hidden, and what could be” (Robinson et al., 2023, p.496). Empowering youth to dismantle systems of oppression cannot happen without also empowering them to dream and collectively build better futures. The formation of a research-practice partnership between a university, a computer science education organization, and various school districts representing diverse contexts reflects a proactive response to this imperative, with a focus on developing justice-centered computer science and STEAM pathways.

Through the partnership’s ongoing projects, including the integration of environmental justice and data science into classroom instructional units, the aim is to create conditions that can empower historically underrepresented youth in STEM and computer science. My dissertation explores the impact of the Environmental Justice Pathways project and its curricular interventions on youth participants, especially those who are historically underrepresented in STEM, across multiple grade levels. My research encompasses a mixed methods approach with two empirical studies exploring the influence of teacher-designed curricula on youth occupational identity and the learning outcomes related to environmental justice. In response to various findings from the Environmental Justice Pathways project, my work on supporting Pennsylvania’s Environmental

Literacy Plan, and a recognized gap in the environmental justice education field, I developed the Critical Environmental Justice for Teaching and Learning (CEJ4T&L) framework. The aim of this framework is to support educators to foster environmental literacy through a critical lens and empower young people to confront environmental racism and seek environmental justice through transformative pedagogies and a commitment to social justice.

In the first empirical study, the quantitative findings suggested that students answered self-efficacy questions more favorably for environmental justice, data science, and computer science compared to their responses for interest, identity, and self-concept. They also answered all questions related to environmental justice more favorably than questions related to computer science and data science. There were statistically significant negative changes in environmental justice identity, data science identity, and computer science interest. However, there were also positive statistically significant changes in environmental justice interest and self-efficacy. These quantitative results guided the qualitative analysis which revealed three overall themes from eight codes including 1) constructing mental models, 2) agency and relevance, and 3) disrupting and reimagining occupations and career pathways.

The first two themes were directly aligned with the a priori coding scheme from the occupational identity development framework or the Environmental Justice Pathway project objectives to produce relevant and agentic, integrated lessons. The last theme and related codes came from examples where students were asked if they thought they would use data science and environmental justice in the future. Most students were able to make a direct connection to their aspirations without changing their chosen career to something related to computer science. Others reimagined careers and pathways to address problems related to environmental justice using computational thinking and data science skills. Students' perspectives helped explain some of the tensions in the quantitative data where students seemed to enjoy environmental justice and feel confident in their ability to use related knowledge and skills in the future without necessarily identifying with it as an occupation. Conversations with students about their dream occupations pushed back on calls to action that would have educators try to convince more historically underrepresented youth to take high school computer science elective courses or pursue computer science occupations. If we empower youth to disrupt and reimagine occupations and career pathways, perhaps we can collectively transform those classes into something students do not need to be convinced to take. The conclusions from the first study informed some of the multifaceted approaches to teaching and learning about critical environmental justice in my CEJ4T&L framework. My most significant conclusion was that students were using a more critical lens when they resisted the premise of occupational identity development in formal schooling toward a specific profession like computer science. So, the instructional practices I developed for the implications are more broad STEM occupational identity development influences.

The findings from the second empirical study were also used to develop layers of the CEJ4T&L framework. One of the major takeaways, though not surprising, was that students' mindsets about environmental justice often mirrored their teachers' whose mindsets heavily influenced their instructional design and facilitation. Teachers who facilitated opportunities to identify personal connections with the curriculum and engage in civic action had higher percentages of students whose conceptualizations of environmental justice moved beyond environmentalism. In this study, I was able to parse out the stages of development that students and teachers went through before reaching the level of conceptual understanding of environmental justice I was looking for. The classes leveraging transdisciplinary problem-solving had more students with a conceptual understanding of environmental justice. Teachers used a variety of entry points related to the core concepts to engage students.

My dissertation covered a broad range of topics from critical environmental justice to Pre-K-12 education to computer science and computational thinking to identity development to STEM representation to research-practice partnerships to designing and implementing integrated curriculum. While these eclectic topics may seem unrelated, my dissertation illustrated throughlines with implications for teacher educators, policy, and practitioners. My ultimate career goal is to focus on reimagining preservice and novice STEM educator training and post-graduation support through research-practice partnerships. As a preservice teacher educator, I was able to use the findings and implications from the three papers to support the next generation of STEM teachers.

5.1 Common Conclusions Across Articles

There are common threads that tie together the conclusions of all three articles. The three themes in the first article are 1) connections to mental models, 2) agency and relevance, and 3) disrupting and reimagining occupations and pathways. The four themes in the second article are 1) teacher mindsets about environmental justice, 2) personal connections, 3) civic action, and 4) transdisciplinary pedagogies. Finally, the four multifaceted approaches for teaching and learning in critical environmental justice include 1) social justice values, 2) environmental sustainability practices, 3) connection with nature, and 4) transdisciplinary pedagogies shown in Figure 17. What is important to notice here is the connection between some of the subthemes in article one, the overall themes in article two, and the multifaceted approaches discussed in the article proposing the CEJ4T&L conceptual framework in article three. One of the subthemes in the first paper is “personal and community connections” while the second paper argues that students need to make personal connections to conceptualize environmental justice beyond environmentalism.

The major contributions of my dissertation included an articulation of environmental justice and computer science occupational identity development influences and barriers with implications for curriculum design and teacher education, and factors that influence students’ conceptual understanding of environmental justice, a review of environmental justice frameworks, and a proposed framework for Critical Environmental Justice in Teaching and Learning (CEJ4T&L). The CEJ4T&L framework can be applied to other key concepts in this dissertation. For example, critical teaching of data science can be done using the CEJ4T&L core concepts as entry points and the CEJ4T&L multifaceted approaches to support transdisciplinary, critical pedagogical practices. The multifaceted approaches to teaching and learning about critical environmental justice also support occupational identity development in ways that are aligned with the students’ push to reimagine occupational pathways through a justice lens. Future research with the CEJ4T&L conceptual framework lends itself well to community engaged research practices including community ethnography (Tan & Calabrese Barton, 2018) and practices for teaching and learning including critical approaches to place-based, community-engaged (Cachelin & Nicolosi, 2022) and extrarational pedagogies (Robinson et al., 2023).

Common Theme	**Article 1**	**Article 2**	**Article 3**
	1) Connections to Mental Models -Personal and Community Connections -Representative Role Models 2) Agency and Relevance -Culturally Relevant Pedagogy 3) Disrupting and Reimagining Occupations and Career Pathways	1) Teacher mindsets about EJ 2) Personal Connections 3) Civic Action 4) Transdisciplinary Pedagogies	1) Social Justice Values 2)Environmental Sustainability Practices 3) Connection with Nature 4) Transdisciplinary Pedagogies
Representative Role Models	Representative role models support occupational identity development among historically underrepresented youth	This was not explicitly included in the framework, but it is an inherent part of culturally responsive pedagogy, which connects back to articles one and three.	Representative role models can build mental models and personal connections that allow students to develop stronger environmental dispositions and accurate conceptualizations of environmental justice.
Personal Connections	Teachers need to find ways to support youth to build and recognize personal connections to integrated curricula whether it be local context, alignment with values, and building a mental model.		
Civic Action	Civic action is often included in culturally relevant pedagogy, which can support occupational identity development. Civic action is also part of social justice values, and it supports students' conceptualization of environmental justice.		
Transdisciplinary Pedagogies	Integrated curriculum does not have to be transdisciplinary. However, students are more likely to experience shifts in their attitudes when they engage with concepts more than once and in different contexts in multidisciplinary contexts or when they can use disciplines as needed to authentically address a locally relevant problem. The ideas of environmental justice, occupational identity, computational thinking, and data science ultimately give students agency to relevant problems.		

Figure 17. Common Themes Across Three Article Findings

In this dissertation, I also illustrated how STEM and computer science education research can be reimagined through research-practice partnerships and how justice-centered curriculum that is relevant and promotes student agency can increase student interest and engage historically underrepresented students in computational thinking practices. Each of the projects in the research-practice partnership have informed the next project and phase of the partnership as shown in Figure 18. For example, I engaged in a previous study called the STEAM Studio Model for Innovation: Building Robust Learning Ecologies and Pathways in Computer Science from the first project in 2020. In this project, our research team explored collaborative problem solving during making activities to promote computational thinking within the computer science and STEAM research-practice partnership. These results informed the content integration decisions for the design of the Environmental Justice Pathway project. The results from the articles in this dissertation have supported my work with the Strength Across Schools: Justice-Focused Computational Thinking in Middle School English Language Arts.

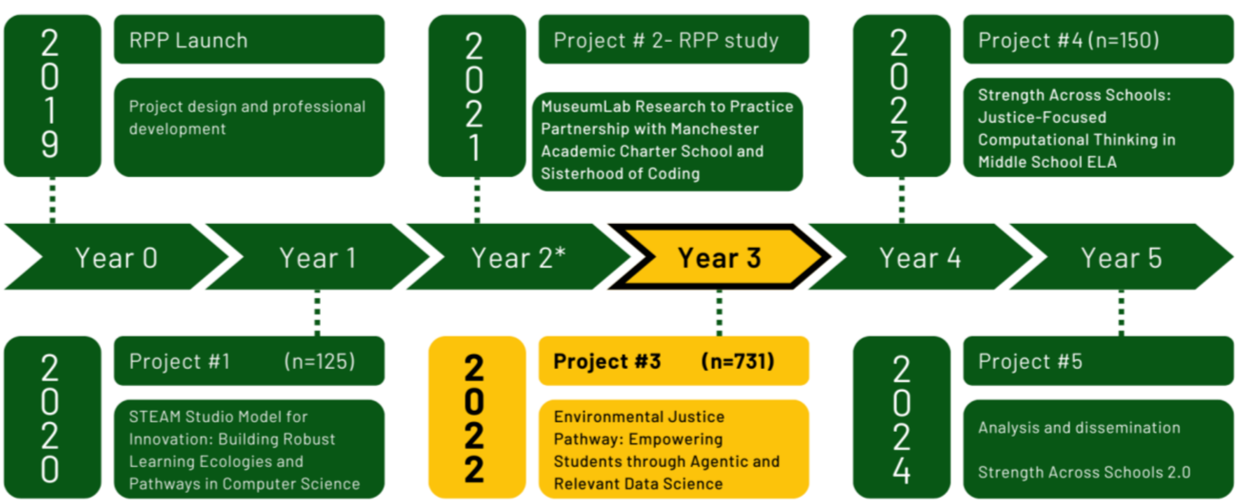


Figure 18. Timeline and Projects of the Computer Science/STEAM Pathways Research-Practice Partnership

Without data science, leaders in the Environmental Justice Movement would not have been able to understand the multiple scales at which environmental injustices exist, nor would they have been able to tell a compelling story for policymakers and voters. Computational thinking practices (including data science) are more than just tools for students and educators to address real problems or communicate their observations in a compelling way. Unfortunately, they can also be wielded as weapons of oppression through disinformation (Lombardi, 2022; Noble, 2018). The controversial politics related to the human impact on the environment standards in the Next Generation Science Standards in many state standards adoption processes is one way this shows up in STEM education. Conversely, they can also be tools of empowerment for educators and youth to dismantle systems of oppression and co-construct a liberatory education for all.

5.2 CEJ4T&L Research to Practice

As a science teacher educator, I have started to use the CEJ4T&L conceptual framework in Appendix E in my work as a practitioner. This complicated framework cannot and should not be introduced all at once. Instead, the layers of the framework serve as a guide for how pre-service and in-service teacher educators can plan for the scope and sequence of teaching and learning about critical environmental justice by itself or integrated into another discipline like traditional science teacher education. The first layer points to the smog of environmental racism and how we breathe it in everyday whether we benefit from white privilege, or the intersection of our identities make us more vulnerable to environmental injustices. For educators to understand our positionality to environmental racism, it is important to understand teacher (Van Lankveld et al., 2017) and racial identity development stages (Seaton et al., 2006; Helms, 2014) for our students and ourselves. The first section of the introductory chapter of my dissertation includes a written reflection of both my positionality regarding environmental justice and that as an educational researcher.

In that process, I constructed an initial model of my evolving understanding of environmental justice and how my socialization and privilege influence my personal connection with nature, human impact on the environment, and environmental injustices. That initial model reflected the evolution of environmental justice conceptualization framework from the second study in my dissertation where I first had a connection to nature with an environmentalism disposition. That mindset evolved into environmental justice as I developed social justice values through awareness and analysis of equity and social justice in the world and my local environment. Finally, I started to develop a critical environmental justice lens when my critiques of the environmental justice movement developed alongside a collective responsibility to act in ways that allow me to co-conspire across lines of difference with people and communities who do not necessarily share my environmental privilege. As a teacher educator, it is important to intentionally reflect on and build awareness my own evolving identity development and positionality before supporting educators and students to do the same.

The second layer of the CEJ4T&L highlights environmental injustices fueled by environmental racism. After building awareness of multiscalar environmental injustices that are locally and globally relevant over time, it is crucial to use a social justice lens to understand how environmental racism fuels injustices and obscures the root cause of those injustices in its smog. The third layer asks learners to critically analyze what it would look like to move from those environmental injustices to corresponding environmental justices. These core concepts emphasize the multiscalar nature of critical environmental justice because they each exist on varying spatial and temporal scales. These core concepts serve as multiscalar entry points from which educators can design locally and globally relevant transdisciplinary collaborative problem-solving scenarios.

The fourth layer shows pedagogical practices that educators can use when designing and facilitating learning experiences about these entry points for students and teachers. Before designing and facilitating for others, educators need to first experience each of these multifaceted approaches as learners.

I recommend starting with analyzing positionality with nature and constructing experiences that allow learners to build an authentic, personal connection to nature. This is the first step in the evolution of environmental justice conceptualization and allows learners to build a mental model they can later view through a social justice lens and revise based on learning connected to sustainability and transdisciplinary collaborative problem-solving experiences connected to core concepts. These multifaceted approaches are in many ways connected to racial identity development and teacher identity development. They also address common barriers that surfaced in the first and second articles in my dissertation.

5.3 Addressing Barriers to CEJ4T&L Implementation

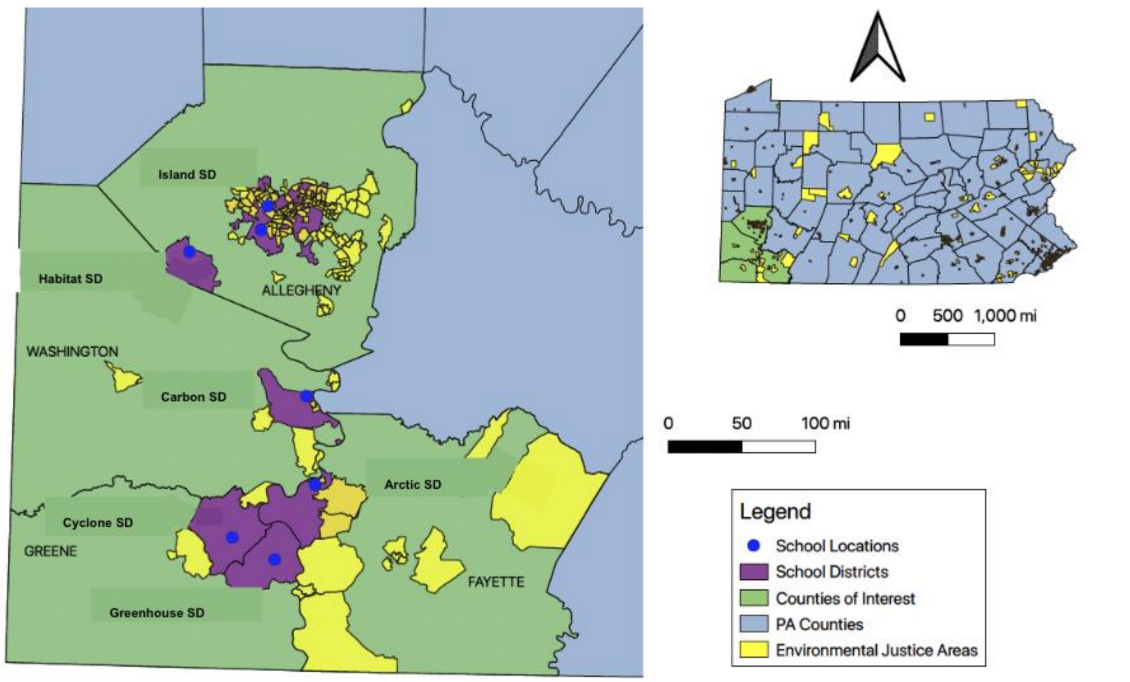
Throughout the Environmental Justice Pathways project and my work with the Computer Science/STEAM Pathways RPP, I have observed and listened to stories of barriers to integrating environmental justice and data science. Callahan et al.'s (2019) conceptual framework for barriers to occupational identity development highlight common barriers like stereotypes, implicit bias, and homophily to STEM occupational identity development. The study's findings suggested that those barriers exist in computer science occupational identity development in formal schooling as well. In the second study, I focused on highlighting what the teachers did that led to more accurate conceptualizations of environmental justice for their students. There was a problem of practice rooted in systems of oppression that loomed throughout the study. Many teachers expressed concern about integrating environmental justice specifically, and some purposefully designed curricula that integrated environmentalism rather than environmental justice. In the interviews, teachers acknowledged fear of retribution from their school districts and communities in times of science denial and fear, as well as increased scrutiny on teachers using critical pedagogies. Many teachers recruited for the study were more interested in the computer science pathway and data science integration than the environmental justice emphasis. In fact, the research team often navigated this challenge using coded language to describe the project as the "Data Science Pathways Project" rather than the "Environmental Justice Pathways Project" in some of the rural and suburban schools.

Another barrier is that teachers often do not have the capacity to redesign or create curricula through a transdisciplinary lens, especially following COVID-19 pandemic. One way we addressed this barrier was to show teachers how state mandated standards can be easily aligned in the transdisciplinary learning experiences and authentic assessments of learning. Teachers also cannot be expected to be an expert in all the disciplines needed to address complex, locally relevant problems. Therefore, it is important for teachers to collaborate with other educators, students' families, and members of the community to connect youth with representative role models and experts that can support their collaborative problem-solving process.

Engaged research like research-practice partnerships are meant to be reciprocal and iterative. It is important for our research team to consider, what is our responsibility as researchers and practitioners ourselves? If I were to go back and redesign the Environmental Justice Pathways project, I would include more time for the RPP team to co-plan, engage in model learning experiences, and revise the curricula before facilitating it for students. I would also want to engage in more touchpoints with the participating teachers before, during, and after facilitating the curricula to support their identity development around environmental justice, especially in a time of science denial and disinformation. Transdisciplinary pedagogies were an existing asset of the RPP. When the ideas of environmental justice, occupational identity, computational thinking, computer science, data science, and engaged research were brought together to address our problem of practice, we were able to overcome some barriers together.

My dissertation has implications for research, practice, and policy implementation. First and foremost, it shows how engaged research like RPPs can be responsive to practitioners' needs. This work also contributes to a growing body of mixed methods research in education. There are also exciting opportunities to use the CEJ4T&L in future teaching and research as well as the adapted frameworks from the first two studies. The alignment between the three-dimensional nature of NGSS and the CEJ4T&L framework will support policy implementation efforts for NGSS and environmental literacy plans. This work also aligns with the National Research Councils' call (2012) for supplementary three-dimensional science and social studies standards and curriculum frameworks aligned with environmental education ideas.

Appendix A Supplementary Materials Referenced in Chapter 1



Data Sources: Western Pennsylvania Regional Data Center (Allegheny County Environmental Justice Regions) PA Department of Environmental Protection GIS (Environmental Justice Areas) Pennsylvania Spatial Data Access (Counties, School Districts) Grable Foundation Grant (School Locations)

Figure 19. Environmental Justice Areas in Relationship to School District Partners in the Computer Science/STEAM Pathways Research-Practice Partnership in Western Pennsylvania

LESSON TITLE

Suggested Grade Level(s):

Overview:

Pathway:

Duration:

Teacher Tip: Suggested Pacing:

Academic Standard Alignment:

List of potential standards aligned to environmental justice and/or data science from Next Generation Science Standards, Common Core, Pennsylvania Academic Standards, Pennsylvania Technical Education Standards, Computer Science Teachers Association K-12 Standards, and the International Society of Technology in Education standards.

Objectives:

Environmental Justice Tie In:

Definition:

Environmental justice is ***the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income****, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (EPA, 2017)*

Environmental Justice Guiding Questions:

1. How can we ensure that everyone has access to a healthy environment to live, learn, and work in?
2. How can we use data to understand where (or how) environmental issues impact communities with high poverty more than other communities?

Figure 20. Integrated Environmental Justice and Data Science Lesson Plan Template Given to Practitioners during the Environmental Justice Institute Professional Development Part 1

3. What environmental injustices exist in my community?
4. How can we ensure everyone has a voice in the conversation about sustainability and protecting the environment?
5. How do citizens use data to advocate for environmental needs in their community?

Computational Thinking Competencies and Practices:

List of Computational Thinking Practices and Competencies

- *Analyzing and Communicating with Data*
- *Collecting and Structuring Data*
- *Creating Algorithms*
- *Creating Computational Models*
- *Understanding Systems*
- *Abstraction*
- *Decomposition*
- *Pattern Recognition*
- *Testing and Debugging*

Computational thinking (CT) is a problem-solving process that includes (but is not limited to) the following characteristics:

1. *Formulating problems in a way that enables us to use a computer and other tools to help solve them.*
2. *Logically organizing and analyzing data*
3. *Representing data through abstractions such as models and simulations.*
4. *Automating solutions through algorithmic thinking (a series of ordered steps)*
5. *Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.*

Essential Questions (Unit/Lesson):

Materials for Students:

Figure 21. Lesson Plan Template Part 2

Students Prior Knowledge:

Teacher Preparation:

Student Artifacts/Evidence:

Habits of mind:

1. *Persisting*
2. *Managing Impulsivity*
3. *Listening to Others with Understanding and Empathy*
4. *Thinking Flexibly*
5. *Thinking About Our Thinking (Metacognition)*
6. *Striving for Accuracy and Precision*
7. *Questioning and Posing Problems*
8. *Applying Past Knowledge to New Situations*
9. *Thinking and Communicating with Clarity and Precision*
10. *Gathering Data Through All Senses*
11. *Creating, Imagining, and Innovating*
12. *Responding with Wonderment and Awe*
13. *Taking Responsible Risks*
14. *Finding Humor*
15. *Thinking Interdependently*
16. *Learning Continuously*

Student agency:

Real life applications and Career Connections:

LESSON SEQUENCE

Planning for engagement with important science ideas:

Eliciting students' ideas (initial model):

Figure 22. Lesson Plan Template Part 3

Supporting ongoing changes in thinking (activities, sense making):

Pressing for evidence-based explanations (assessment):

ADDITIONAL RESOURCES

Activities for Relearning:

Activities for Enrichment:

Resources for Teachers:

https://ambitiousscienceteaching.org/tools-planning/

https://www.sfsdcspathway.org/

Figure 23. Lesson Plan Template Part 4

Table 18. Descriptions of the Environmental Justice and Data Science Integrated Lesson Plans Designed and Implemented in the Environmental Justice Pathways Project

Grade Level	Content Area	Lesson Title	Lesson Summary
K-5	STEAM	Understanding and Educating Others on Environmental Advantages of Reusable Water Bottles	Students collected data on school-wide plastic water bottle savings using information from school water fountains for over two-weeks for the three floors in the school. Students analyzed the data in small groups to identify observations and inferences. Students also conducted research into connections to Environmental Justice issues to form a persuasive argument.
K-5	STEAM	What's All the Buzz About Bees?	Students engaged in a themed unit on the connection between bees and Environmental Justice. They engaged in activities like creating data glyphs, designing bee hives, and coding robots to behave like bees.
3-5	STEAM	Understanding Human Impact on the Environment Using Data Visualization Techniques Through Earth Time	In this lesson, students choose between six significant habitat changes including wildfires, deforestation, city growth, sea levels rising, glaciers melting, and coral bleaching. Once they choose their topic, they use EarthTime to analyze the data in different areas around the world so they can choose an area which they feel is impacted the most by environmental injustices to complete a larger unit project.
3-5	Technology	Coding Nature	In this unit, students can collect audio and visual assets through connecting with Nature. They use those assets and coding skills to create multimedia/multimodal websites to share their observations and experiences with others. They also make explicit connections between the computational thinking activities involved with coding their observations in Nature, and Environmental Justice through narrative storytelling.

Table 18. Description of the Environmental Justice and Data Science Integrated Lesson Plans Designed and Implemented in the Enviornmental Justice Pathways Project (continued)

5	Science	The Love Canal Tragedy: A Case Study in Environmental Justice	In this unit, students use primary and secondary literature and photographs from the Love Canal to understand environmental injustice case studies through storytelling. Students used data to understand the impact of soil contamination on public health. At the end of the lesson, students wrote persuasive letters pertinent to their own context.
6	Science	Community Water: Environmental Impact Using Data Visualization Techniques	Students designed and presented infographics based on data they collected on personal water use over time.
6	STEAM	Environmental Justice: How to Better the Community We Live In	Students designed surveys to understand community needs related to Environmental Justice. In response to the data, students partnered with the agriculture education educator to design an ongoing service-learning project to address the gap in access to fresh fruits and vegetables in the community.
6	Math	Environmental Justice and Data Science Overview and Life Connection	Students explored the top five environmental issues in Western PA and made explicit connections to justice and people doing the work that share aspects of their identity and background. Students used Citizen Science Interactive to understand data analysis related to Environmental Justice.
6-8	Science	Pittsburgh Environment Data Driven Letter	Students designed surveys to understand various needs related to Environmental Justice in their community. They used data and research to craft a persuasive letter to the city mayor, design compelling data visualization, and record a podcast about their chosen issue.

Table 18. Description of the Environmental Justice and Data Science Integrated Lesson Plans Designed and Implemented in the Enviornmental Justice Pathways Project (continued)

6-8	Technology Education	Understanding Environmental Justice Through the Use of MIT App Inventor	Students collected their own data on their households' habits related to recycling, water consumption, consumption of resources, travel, etc. After analyzing the data, students will create story boards to design an app to address the environmental problem they explored. Students will use MIT app inventor to code interactive apps for a designated audience.
7	Science	Sustainability Challenge: Sustainable Agriculture Cultivated by Today's Young Minds	Students engaged in the Chipotle-EarthForce Sustainability Challenge to design sustainable solutions to Environmental Justice related issues in their community. The class worked to implement the three winning designs.
8-12	Computer Science	Using Visualizations to Inspire Curiosity: How Does Our Environment Affect Us?	Students engage in an activity called Looking Ten Times Two in which they work independently then merge into group work. Students also engage in a data talk and use EarthTime to discover the constant burning fire in Braddock, PA, and the environmental justice implications.

Pre- and Post-Survey for Elementary Students- Assent, Demographics, and Short Response

The data from this survey could be used as part of a research study. A research study is a special way to learn about something. We are doing this research study because we are trying to find out more about the way students learn about science, technology, and data. Your teacher is a part of the study, which is why we are asking you to join the study.

Would you like to be a part of this study?

(Yes or no)

First and Last Name

*This information was used to match the pre and post surveys. It was then changed to an identification number.

What is the name of your school?

(Multiple Choice)

What grade are you in?

(Multiple Choice)

What is the name of the teacher giving you this survey?

(Multiple Choice)

Where were you born? (City, State, Country)

How do you describe yourself?

(Girl, Boy, Non-Binary/ Third Gender, prefer to self-describe, prefer not to say)

Choose one or more races that you consider yourself to be:

(White, Black, or African American, Latino/Latinx/Hispanic, Asian/Indian, American Indian/ Alaska Native, Native Hawaiian/Pacific Islander, Multiple Races, Other)

What is Environmental Justice? Why is it important to learn about it?

What is computer science? Why is it important to learn about it?

What is data science? Why is it important to learn about it?

Tell us what you learned in the Data Science/Environmental Justice lesson(s).

(post survey question only)

Tell us what you think about the Data Science/ Environmental Justice lesson.

This might include: What went well for you? What was challenging for you? What would have helped you learn better?

Likert-type questions (see Figures below)

After the Likert-type questions, students are given a constructed response space.

(Optional) Is there anything you would like us to know about your responses in this section?

If you could have any job when you grow up, what would it be? Why?

What career would your parents want you to have when you are older?

What will you do after you graduate from high school?

Describe a problem you wish to address.

(This problem could be at your school, in your community, in our state, in the world…)

Explain why the problem you described is important.

What do you need to learn to address the problem?

In what ways might you help to make sure everybody has a healthy environment?

(A healthy environment means clean air, clean water, clean soil, healthy food, and protection from natural disasters)

In what ways might you use coding or computer science in the future?

(Think about school, your future job, and/or your personal life)

In what ways might you use data science in the future?

(Think about school, your future job, and/or your personal life.)

We are interested in finding out what you think about the environment. NO! means you really disagree. no means you disagree. yes means you agree. YES! means you really agree.

	YES! (Strongly agree)	yes (Somewhat agree)	no (Somewhat disagree)	NO! (Strongly Disagree)
I like learning about how to care for the environment.	○	○	○	○
I am good at caring for the environment.	○	○	○	○
I know more than my friends about how to care for the environment.	○	○	○	○
I can become good at helping the environment.	○	○	○	○
I like the challenge of learning about how to care for the environment.	○	○	○	○
I want to find out more about how to care for the environment.	○	○	○	○
I am an environmentalist.	○	○	○	○
I often ask questions about the environment.	○	○	○	○

Figure 24. Pre/Post Survey Environmental Justice Questions

We are interested in finding out what you think about data science. NO! means you really disagree. no means you disagree. yes means you agree. YES! means you really agree.

	YES! (Strongly agree)	yes (Somewhat agree)	no (Somewhat disagree)	NO! (Strongly Disagree)
I like using data.	○	○	○	○
I am good at making sense of data.	○	○	○	○
I know more than my friends about using data.	○	○	○	○
I can become good at making sense of data.	○	○	○	○
I like the challenge of making sense of data.	○	○	○	○
I want to find out more about data science.	○	○	○	○
I am a data scientist.	○	○	○	○
I often ask questions about data.	○	○	○	○

Figure 25. Pre/Post Survey Data Science Questions

We are interested in finding out what you think about Computer Science. NO! means you really disagree. no means you disagree. yes means you agree. YES! means you really agree.

	YES! (Strongly agree)	yes (Somewhat agree)	no (Somewhat disagree)	NO! (Strongly Disagree)
I like computer science and coding.	○	○	○	○
I am good at computer science and coding.	○	○	○	○
I know more than my friends about computers and coding.	○	○	○	○
I can become good at coding and computer science.	○	○	○	○
I like the challenge of coding and computer science.	○	○	○	○
I want to find out more about coding or computer science.	○	○	○	○
I am a coder or a computer-type person.	○	○	○	○
I often ask questions about computer science and coding.	○	○	○	○
	YES! (Strongly agree)	yes (Somewhat agree)	no (Somewhat disagree)	NO! (Strongly Disagree)

Figure 26. Pre/Post Survey Computer Science Questions

Semi-Structured Interview Protocol for Teachers

Teacher Interview Protocol:

1. How long have you been teaching?
2. How long have you been teaching this grade level and content?
3. How much PD have you had around environmental justice and data science? (preservice and in-service) Teacher preparation context?
4. What does support look like in your context for instructional planning, design, and implementation? Do you collaborate with other teachers here or in another district?
5. How would you define Environmental Justice today? Is this different from how you would have conceptualized it before being part of this grant?
6. How would you define Data Science today? Is this different from how you would have conceptualized it before being part of this grant?
7. Describe your planning process for the lesson/mini unit that we observed. What were some challenges you faced?
8. How did you go about integrating the two contents? (DS and EJ)
9. Did integrating the two contents help or hinder student learning?
10. Did you bring in any other subjects or content?
11. Where would you need more support to integrate the two?
12. Can you describe how students engaged in the lesson? What were their responses? What did they understand, and where are they still struggling?

13. If you were to teach this lesson again next year, what would you change and keep the same?
14. What were your big takeaways from this experience?
15. How has this experience changed your practice? What other applications do you see in the future?
16. If you were to give advice to someone starting out with this, what would it be?

Semi-Structured Interview Protocol for Student Small Groups

Hello, my name is XXXX, and I work at the University of Pittsburgh School of Education. We have been working with your teacher to learn the best way they can teach and learn how you learn. During this interview, I will ask you questions, if you don't want to answer you can simply tell me that. Also, if you want to stop being interviewed, tell me that, and I will stop the interview. No one will be mad at you. Also, this interview will never be shared with your teacher. I will audio record our interview so that I don't make any mistakes about what you say. No one from the school will listen to this audio recording. Your parents have agreed that it is okay for you to talk to me, but that doesn't mean you have to talk to me. Do you have any questions before we begin?

***When you start recording the interview, verbally record the date, location, teacher, and grade level of the observed class. Have each student introduce themselves verbally so it is easier to match their voices with their names when we transcribe the recording. Save the recording with the following format: Date_Teacher_GradeLevel_StudentsNames

This is XXXX. We are at XXX and today is XXX. We are in Mr./Ms./Mx. XXX's Xth grade class at XXX school. I am talking to (have students introduce themselves with first and last names)

Part 1: Questions about the observed lesson

1. Can one of you please describe what you are learning about in class today?

Note: If students are not responding, let them know that they can help each other explain or prompt them with your own notice and wonderings. You can also prompt them to share the goal or objective of the day. This is an important question that will impact student responses to the follow-up question.

2. Why do you think your teacher thought (whatever students described in the first question) was important for you to learn about?

Note: If students successfully describe data and environmental justice (or something similar) you might ask why the teacher decided to teach those two topics together.

3. How did your teacher help you learn (response to question 1)?

Note: The goal of this question is to prompt students to describe the activities and their interpretation of the teachers' pedagogy and practices.

4. What went well in today's lesson for you?

5. What challenged you about today's lesson?

6. If you could give your teacher (and us) advice about how to make the lesson better for you, what would you suggest?

7. Did your teacher include any other subjects in the lesson? (ELA (English Language Arts), SS, Art, Music, Gym, Recess, Math) How?

8. What other subjects does your teacher include in ______ class?

Note: The goal is to understand more about how the teacher integrates other disciplines from the students' perspective.

Part 2: Computer Science

Computer Scientists and Coders use data science, like you did in class today, to address important problems like making the environment cleaner for everyone. I want to know how you feel about computer science.

What is something you think about when you think about computer science?

Note: The goal is a word association or metaphor.

Do you like working with computers, understanding data, and coding? Why?

You said that you (did or did not) like parts of computer science. Would you consider yourself good at computer science? Why or why not?

Note: If the student says they are not good at computer science, follow up and ask if they think they could become good at it if they had help. If time allows, it might be interesting to ask if they think they need to like something to be good at it.

Part 3: Environmental Justice

Why do you think it is important to protect the environment?

Does connecting learning about the environment and fairness (or whatever environmental content objective the teacher used) change how you feel about computer science and learning about data?

What is the most important problem related to the environment that needs to be addressed?

Part 4: Impact of coaching around occupational identity

Note: For this section, we are going to look at individual students' pre-survey response, interview response, and post-survey response to the same question. We are interested to see if there is any change.

What job do you want to do in the future?

What kind of skill does a (insert job here) need?

Note: If the student does not mention skills related to data science, computer science, computational thinking, collaboration, or environmental justice directly probe with one of those examples.

For example- How might an NFL football player use data science? Or- How might an NFL football player support environmental justice (protect the environment, etc.)? Can you think of an example where an NFL football player might need to analyze data? Can you share an example of how you might use these skills in the future outside of your career?

Probe here if they already have an answer. If they do not have an answer yet, provide a potential solution.

Part 5: Additional student identity questions if time permits.

What is your favorite subject to learn about in school? Why?

Describe the way you learn best.

Note: Ask students if they see any connections between their favorite subject, what they want to be when they grow up, their family's expectations, and the problem they want to solve in the world.

If students are not able to answer these questions for themselves, ask the other members of the working group for their ideas. Is this something they have talked about before? If so, when/where?

Appendix B Supplementary Materials Referenced in Chapter 2

Table 19. Environmental Justice Pathways Project Post-Survey Research Participants

	School*	Teacher* & Grade	Subject	*n*
Rural	Greenridge Elementary & Middle (Public)	Polar, 5	STEAM	18
		Ridge, 6 & 7	Computer Science	62
	Forest Hills Elementary (Public)	Fern, 3	STEAM	66
		Primrose, 4	4th Grade General	33
		River, 5	5th Grade General	14
	Skyline Middle (Public)	Plum, 6	Science	54
		Maple, 6	STEAM	
Suburban	Falcon View Elementary & Middle (Public)	Winter, 4 & 5	Technology Literacy	226
		Luna, 4	STEAM	259
		Lotus, 8	Computer Science	80
		Meadow, 7 & 8	Technology Education	78
Urban	Sporting Green Elementary (Public)	Summer, 5	Science	34
	Mountain Vista Middle (Charter)	Dahlia, 6	Math	33
		Rose 7	Science	23
		Wren, 8	Engineering	5

Note. *n* = Number of students who completed the post-survey.
**All school and teacher names have been changed to protect the identity of the individuals*

Table 20. Description of Qualitative Data Analysis Themes, Codes, Related Constructs, and Examples

Occupational Identity Concept	Related Survey Construct	Theme	Codes	Example
Exposure	Self-concept Identity	Mental Models/ Pathways	Schooling Connections	*"It's important to teach kids, especially younger, so they know they shouldn't do these things to the environment.*
			Personal Connections	*"I mean, there are a lot more severe storms now and more flooding which I've seen even recently in [hometown] and stuff. So, I feel like that will get worse.*
			EJ- Desired Career Connections	*"A baker…I'd want to look into information about the environment to see where to put my bakery and with the history of different ingredients to see which are like the best for environment."*
			DS-Desired Career Connections	*"If you plan on making a company, you probably need to advertise and make an app…I want to be a businessperson."*
Stereotypes	Self-concept Identity	Alternative Representations	Real-world role model	*"[Our teacher] told us about her friend and brother-in-law."* *"That dude is the FATHER of Environmental Justice."* *"I am not a terribly creative person, so I'm not normally good at MIT App Inventor."*

Table 20. Description of Qualitative Data Analysis Themes, Codes, Related Constructs, and Examples (continued)

Engagement	Self-efficacy Interest	Knowledge and Skills	Computational thinking (CT) aligned skill.	*"And data science is basically taking those numbers and putting meaning into them, basically."*
			Perceived utility relevance	*"[Our teacher] should keep having us do storyboards so we can have our designs ready… we draw our design on paper and then do MIT App Inventor."*
				"I'd say yes. Because anyone who codes are considered a coder. It doesn't say good coder, it's just coder. You can be bad but you're still a coder. You used code."
			Productive struggle	
Implicit Bias	Self-efficacy Interest	Culturally Relevant Pedagogy	Justice-centered	"*Asthma is a big problem because the pollution is so bad…They can't breathe!"*
			Tailored to cultural identity.	*"All people should be treated equally no matter how much money they have. Because people who don't have enough money always have to live near very polluted areas…People who have more money…have enough money to live away from the polluted areas.*
				"My mom didn't know the sky was blue until she was 12…she lived literally right next to a steel mill, so the air was pumped with pollutants, so the sky was yellow…"
			Tailored to student interest	*"I love photography."*

Note- Student interviews were coded using MAXQDA (VERBI software, 2021)

Appendix C Supplementary Materials Referenced in Chapter 3

ICIDAR

Integrated Content Implementation and Design Assessment Rubric

Indicators	Low (1,2)	Mid (3, 4, 5)	High (6, 7)	Comments (Also note if not observed)
Academic Standard Alignment • Standards chosen are related to the specific class' context ○ Ex: Mandated curriculum, widely accepted academic standards etc. • The standards align in a way that is cohesive and makes sense to students	The standards chosen are not widely accepted academic standards and/or do not represent the specific class' context OR The standards are not addressed during the lesson. OR The standards do not align with the objectives.	The standards chosen are widely accepted academic standards and are representative of the specific class' context. AND The standards inconsistently align with the lesson's objectives. AND/OR Sometimes, the standards are addressed during the lesson.	The standards chosen are widely accepted academic standards and are representative of the specific class' context. AND The standards consistently align with the lesson's objectives. AND Often standards are addressed throughout the lesson.	
Objectives • Explicitly states lesson's goals • Clearly communicates Environmental Justice tie in • Clearly communicates computational thinking competencies and practices • Connections between Environmental Justice and computational thinking are explicitly communicated	The teacher does not provide objectives that are explicitly communicated OR the standards provided do not reinforce EJ or CT. OR The objectives are not referenced or clarified throughout the lesson.	The teacher provides clear goals, but the lesson's purpose does not fully reinforce both EJ and CT goals. OR The teacher provides objectives that reinforce EJ and CT but there is not a clear connection between the two. AND/OR Sometimes, the objectives are referenced and clarified throughout the lesson.	The teacher provides goals that are clear and fully reinforce both EJ and CT. AND Often the objectives are referenced and clarified throughout the lesson.	

Figure 27. Integrated Content Implementation and Design Assessment Rubric (ICIDAR) Part 1

Environmental Justice Tie In The teacher uses guiding questions such as: 1. How can we ensure that everyone has access to a healthy environment to live, learn, and work in? 2. How can we use data to understand where (or how) environmental issues impact communities with high poverty more than other communities? 3. What environmental injustices exist in my community? 4. How can we ensure everyone has a voice in the conversation about sustainability and protecting the environment? 5. How do citizens use data to advocate for environmental needs in their community?	The lesson does not make connections to Environmental Justice OR does not attempt to answer any of the guiding questions.	The lesson sometimes makes connections to environmental issues and attempts to answer any of the guiding questions. OR There is an explicit connection between environmental issues and impacts on humans but not social justice implications. The connection MIGHT approach ideas of fairness for the humans it affects.	The lesson often makes connections to Environmental Justice and explicitly seeks to answer at least one of the guiding questions. AND There is an explicit connection between environmental issues and social justice implications. Race and class (systemic oppression) are centered in the conversation.	The lesson attempts to define EJ = 3 The meaning of EJ is factual recall = 2
Computational Thinking Competencies and Practices 1. Analyzing and communicating with data 2. Collecting and structuring data 3. Creating algorithms 4. Creating computational models 5. Understanding systems 6. Abstraction 7. Decomposition 8. Pattern Recognition 9. Testing and debugging	The teacher does not facilitate building computational thinking competencies and practices. OR The teacher does not infuse age appropropriate opportunities for computational thinking aligned with objectives.	The teacher facilitates computational thinking competencies and practices. AND The teacher infuses age appropriate opportunities for computational thinking aligned with objectives. OR The opportunities provided are not authentically aligned with the objectives.	The teacher facilitates building computational thinking competencies and practices, as well as, infuses age appropriate, **rigorous** opportunities for computational thinking aligned with the objectives. AND/OR The opportunities provided are authentically aligned with the objectives.	
Student Agency • Encourages student-driven approaches • Supports student choice and voice • Aligned with authentic tasks or activities that would mimic the practice in the real world	The teacher does not create a platform for student agency that aligns. with the lesson objectives. OR The opportunities for student agency do not align with the lesson objectives.	The teacher sometimes creates a platform for student agency, and the opportunities for student agency align with lesson objectives. AND Student choice is central to the lesson. AND/OR Student choice and voice MIGHT be meaningful to students AND/OR related	The teacher consistently creates a platform for student agency, and the opportunities for students agency aligned with lesson objectives. Student choice is central to the lesson, and it is meaningful to students or related to an authentic task. There MIGHT be areas where more agency could have been allotted.	

Figure 28. ICIDAR Part 2

Real Life Applications and Career Connections • Applies understanding of diverse student backgrounds and experiences to problem solving context • Provides tasks that are relevant to students' lives and interests • Provides opportunities for considering future professions that are related to the lesson's objectives. • Explicitly designs tasks, which are culturally, geographically, globally or locally relevant.	The teacher approaches the lesson through inauthentic tasks OR The ideas do not provide connections relevant to student backgrounds, experiences, or interests aligned with lesson objectives.	The teacher approaches the lesson by offering students an authentic task(s). OR The tasks provide connections relevant to student backgrounds, experiences, and/or interests aligned with lesson objectives. AND/OR The teacher makes explicit connections between authentic tasks and future professions.	The teacher often approaches the lesson by offering students authentic tasks that provide connections relevant to student backgrounds, experiences, and/or interests aligned with lesson objectives. The teacher makes explicit connections between authentic tasks and future professions AND Content is not approached as an "add-on" but is embedded throughout.	

Figure 29. ICIDAR Part 3

Classroom Descriptions and Teacher Conceptualizations of Environmental Justice for Classroom Cases Not Included in the Comparative Case Analysis.

Ms. Summer, 5th grade science, urban elementary school, Sporting Green elementary school (N/A)

Students collected data on school-wide plastic water bottle savings using information from school water fountains for over two weeks for the three floors in the school. Students analyzed the data in small groups to identify observations and inferences. Students also researched connections to environmental justice issues to form a persuasive argument.

"To be honest with you, when we talked about environmental justice, when this all started, I had to look it up. I did. I looked it up. I was like, what are they referring to, environmental justice? You know, I knew it had to do with the environment, but what do they mean by that? And so, I kind of was ignorant in that I really did not have any exposure or idea. And now, now I do. And it's funny because, I think we kind of put new names on things that have been around for a while. And we are just kind of trying to bring them to the forefront again, and that's how I feel the whole environmental justice title kind of is. Because I remember in the 80s like we did a big environmental push in the classroom to get kids to be aware of, you know Earth Day, and the environmental practices that they should be doing and all that. And now, it seems like it is resurging again as… and I think it is resurging with a little bit more of a strong hold in that, I remember teaching environmental practices to kids at elementary school, but not with the intent that… this is my right. I am entitled to this type of environment, and I am going to demand it. And

so, then I am going to do whatever it takes to make that happen. And I think that is where the difference is. It was more about just getting the word out before, and now it is really getting kids involved in the actual practice of how I can make that environment happen for me and for others around me, and I think that is kind of what I am getting from it."

"I think you have to put it out there that there are things in life that we are entitled to. I am entitled to clean water. I am entitled to fresh air to breathe. Now, is that always going to happen? No. You have to get kids to know that these are the things that they should expect from their environment. And when you are not getting something that you are expecting, you can't complain about it… unless you are going to complain and come up with a solution. And so, I guess, my thing is with kids is to say… what can you do? You're eight. Because that's what they come back with me, a lot of kids. 'Well, I'm just a kid. What do you expect me to do? I can't tell a grown up.' No! We can. We can tell. It's all in the delivery. How we do it. We can. So, it was funny, because even when I sent them with homework like how will you convince your family to go to a refillable water bottle? You know what's going on now. You know the dangers of those plastic bottles. You know the money we could be saving. Now how can you tell your parents? How can you get your parents on board? It's funny because a couple of kids said… 'oh my mom won't listen.' Or 'my dad… I can't tell my dad what to do.' And then we talked about it. You don't have to tell them. You just have to have a conversation about it. You have to make them aware the same way that you became aware. You had your own 'aha' moment when you saw everything, and now bring that aha moment to them."

Ms. Dahlia, 6th grade math, urban middle school, Mountain Vista Middle School (MID-D)

Students explored the top five environmental issues in Western PA and made explicit connections to justice and people doing the work that share aspects of their identity and background. Students used Citizen Science Interactive to understand data analysis related to environmental justice.

"Yeah, definitely. It definitely has changed for me. You know, kind of just looking at the environment, and what are some of the impacts of the environment on different communities and considering how those communities are being treated. If they're being treated fairly. I have had some sprinkles of knowledge about it throughout my life, and even putting together the lessons, I realized there's way more in my personal life than I thought, and I realized. But it definitely opened my eyes to things that I was even kind of aware of, but it's kind of just brought it back to the forefront of my mind. And just that the importance of it is really important and valuable to delve into the lessons."

Ms. Rose, 7th grade science, urban middle school, Mountain Vista Middle School (MID-E)

Students engaged in the Chipotle-EarthForce Sustainability Challenge to design sustainable solutions to environmental justice-related issues in their community. The class worked to implement the three winning designs.

"Before this, it was caring about your environment. You know, talking about it through that project-based lens. Finding that thing that really can bring some passion out of students, and just them understanding that their voice truly matters… Now taking that full circle. How student voice is even more powerful than mine. How can I get students to embrace their content as their own… enough to make a change? But it is what it is. Their voice means more than mine. It's powerful! When a kid says something! You get ten heads to turn around versus with an adult just one. So, just how powerful that youth voice is. So that's what I had before. The piece that I have now, honestly, is incorporating a lot more data. I have the piece where I want students to have this voice and to have this really unique voice in the structure of politics and the structure of society. They have a very very powerful voice that they do not use enough, but I think that we just do not give them enough good, hard facts. We will try to find them this great article instead of, what I loved, instead of having an anchor text to drive my project. I would love to have anchor graphs or anchor data pieces that are from more than one source. That is what would drive our instruction… numbers and graphs and all of that. When you hear a number, that's what makes your jaw drop."

Ms. Wren, 8th grade engineering, urban middle school, Mountain Vista Middle School (MID-B)

Ms. Wren divided up her instructional unit into two main pieces. She tasked her students to go through a process of analyzing environmental justice data through a social justice lens from start to finish. Students were encouraged to collect data of their choice in the community. They had to do their own research, connect with local businesses, research local government, get in tune with local issues, and more. Students designed surveys to understand various needs related to environmental justice in their community. They used data and research to craft a persuasive letter to the city mayor, design compelling data visualization, and record a podcast about their chosen issue.

When Ms. Wren was interviewed after teaching the instructional unit, she was asked about how her definition of environmental justice changed throughout the project. She said, "It means kind of along the same track of what I initially thought, with a deeper understanding of it is in my mind thinking about our kids, a lot of them. Seeing the world that they're in and seeing how their place in the world can affect others, that's a lot of conversations we had with the project that we did. It was how their community is being affected by themselves, being affected by legislation, and how they can take a handle on what they are seeing…and environmental justice is looking at where you are in seeing what exactly is going on and making sure everybody can be on a level playing field… what's happening in the world to what is happening in our neighborhood, they were able to think a lot more about like the small things that they're seeing, they didn't realize wasn't just. But they are still struggling with that more kind of general conceptualization as eighth graders would have. What's effecting the world so as part of this we have had different talks about things *going on in the bigger part of the nation or the entire world, and it's hard for them to conceptualize those big concepts down to their little bubble."*

Ms. Ridge, 6th and 7th grade computer science, rural middle school, Greenridge Middle School (M-F)

After facilitating the instructional unit, Ms. Ridge engaged in an interview. When asked if her understanding of environmental justice shifted throughout the project, Ms. Ridge said, "I don't think that there has been a shift so much it probably in hindsight would have helped me if I had gotten maybe the STEAM teacher or science teacher involved. More Language Arts teachers could have maybe like shifted the stories that they were reading to find something that fit better with what we were doing. We looked at shifts in more awareness when we did the nature walk and the kids were appalled to see all the litter [around the school campus]. And that was around the time it kind of registered for them that they do have a part in trying to keep things clean. I think it's more their responsibility to… like our downtown's pretty dilapidated, although it is improving, like there are some people that re setting up some things. But we've had this little town and then everything else is so country, so we're not seeing things like the kids in [the urban partner districts] are seeing like we don't really have too much air pollution let's say. That is environmental justice, but it is like the smaller things like they might see their parents or siblings throw something out the car window. So, it's like they see themselves as part of the solution, as opposed to part of the problem. And things like that, like they see a little bit more of a personal responsibility, I don't think they're big picture yet. It's just more of an individual thing, but I think that's a good way to start it too."

Appendix D Supplementary Materials Referenced in Chapter 4

Table 21. Next Generation Science Standard and Environmental Literacy Plan Adoption and Implementation Status in the United States as of January 2024

State	(Year) Relationship to NGSS	Environmental Literacy Plan	Sources
Alabama	(2015) Modified NGSS-Aligned Standards	Completed but not adopted	www.alabamaachieves.org
Alaska	(2019) Aligned to NGSS Standards	Completed but not adopted	http://education.alaska.gov
Arizona*	(2018) Modified NGSS-Aligned Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.ade.az.gov
Arkansas*	(2015) NGSS Standards	Process not begun, abandoned, or put on hold indefinitely.	http://ade.arkansas.gov
California*	(2013) NGSS Standards	Implementation Underway	www.cde.ca.gov
Colorado	(2018) Aligned to NGSS Standards	Implementation Underway	www.cde.state.co.us/
Connecticut	(2015) NGSS Standards	Implementation Underway	www.sde.ct.gov
Delaware*	(2013) NGSS Standards	Implementation Underway	www.doe.k12.de.us

Table 21. Next Generation Science Standard and Environmental Literacy Plan Adoption and Implementation Status in the United States as of January 2024 (continued)

Florida	(2008) Little to no influence from NGSS standards	Completed but not adopted	www.fldoe.org
Georgia*	(2016) Modified NGSS-Aligned Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.gadoe.org
Hawaii	(2016) NGSS Standards	Implementation Underway	www.hawaiipublicschools.org
Idaho	(2016) Aligned to NGSS Standards	Completed but not adopted	http://sde.idaho.gov
Illinois*	(2014) NGSS Standards	Implementation Underway	www.isbe.net
Indiana	(2016) Implementation underway of modified NGSS-aligned standards.	Drafting stage or existing plan does not align with NAAEE guidelines	www.doe.in.gov
Iowa*	(2015) NGSS Standards	Process not begun, abandoned, or put on hold indefinitely.	http://educateiowa.gov
Kansas*	(2013) NGSS Standards	Implementation Underway	www.ksde.org
Kentucky*	(2013) NGSS Standards	Implementation Underway	www.education.ky.gov
Louisiana	(2017) Aligned to NGSS Standards	Completed but not adopted	https://www.louisianabelieves.com/resources/library/k-12-science-resources

Table 21. Next Generation Science Standard and Environmental Literacy Plan Adoption and Implementation Status in the United States as of January 2024 (continued)

Maine*	(2019) NGSS Standards	Implementation Underway	www.maine.gov/doe
Maryland*	(2013) NGSS Standards	Implementation Underway	www.marylandpublicschools.org
Michigan*	(2015) NGSS Standards	Completed but not adopted	www.michigan.gov/mde
Minnesota*	(2019) Modified NGSS-Aligned Standards	Implementation Underway	http://education.state.mn.us/mde/index.html
Mississippi	(2017) Modified NGSS-Aligned Standards	Process not begun, abandoned, or put on hold indefinitely	www.mdek12.org
Missouri	(2016) Modified NGSS-Aligned Standards	Implementation Underway	http://dese.mo.gov
Montana*	(2016) Modified NGSS-Aligned Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.opi.mt.gov
Nebraska	(2017) Aligned to NGSS Standards	Adopted but not implemented	www.education.ne.gov
Nevada	(2014) NGSS Standards	Completed but not adopted	www.doe.nv.gov
New Hampshire	(2016) NGSS Standards	Completed but not adopted	www.education.nh.gov
New Jersey*	(2020) NGSS Standards	Implementation underway	www.state.nj.us/education/

Table 21. Next Generation Science Standard and Environmental Literacy Plan Adoption and Implementation Status in the United States as of January 2024. (continued)

New Mexico	(2018) NGSS Standards	Completed but not adopted	https://webnew.ped.state.nm.us
New York*	(2016) Aligned to NGSS Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.nysed.gov
North Carolina*	(2009, 2023) Implementation underway of modified NGSS-aligned standards.	Completed but not adopted	www.ncpublicschools.org
North Dakota	(2019) Aligned to NGSS Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.dpi.state.nd.us
Ohio*	(2019) Modified NGSS-Aligned Standards	Implementation Underway	www.ode.state.oh.us
Oklahoma	(2020) Modified NGSS-Aligned Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.ok.gov/sde
Oregon*	(2014) NGSS Standards	Implementation Underway	www.oregon.gov/ode/pages/default.aspx
Pennsylvania	(2010, 2022) Implementation underway of modified NGSS-aligned standards.	Implementation Underway	www.education.pa.gov
Rhode Island*	(2013) NGSS Standards	Implementation Underway	www.ride.ri.gov
South Carolina	(2014) Modified NGSS-Aligned Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.che.sc.gov

Table 21. Next Generation Science Standard and Environmental Literacy Plan Adoption and Implementation Status in the United States as of January 2024 (continued)

South Dakota*	(2015) Aligned to NGSS Standards	Completed but not adopted	http://doe.sd.gov
Tennessee*	(2016) Modified NGSS-Aligned Standards	Completed but not adopted	www.tn.gov/education
Texas	(2017, 2021) Implementation underway of modified NGSS-aligned standards.	Implementation Underway	www.tea.state.tx.us
Utah	(2019) Aligned to NGSS Standards	Drafting stage or existing plan does not align with NAAEE guidelines	www.schools.utah.gov
Vermont*	(2013) NGSS Standards	Drafting stage or existing plan does not align with NAAEE guidelines.	www.education.vermont.gov
Virginia	(2018, ~) Revision in progress	Implementation Underway	www.doe.virginia.gov
Washington*	(2013) NGSS Standards	Implementation Underway	www.k12.wa.us
West Virginia*	(2015) Aligned to NGSS Standards	Drafting stage or existing plan does not align with NAAEE guidelines	http://wvde.state.wv.us
Wisconsin	(2017) Modified NGSS Aligned Standards	Implementation Underway	http://dpi.wi.gov
Wyoming	(2016) Modified NGSS-Aligned Standards	Process not begun, abandoned, or put on hold indefinitely	http://edu.wyoming.gov
Washington DC	(2013) NGSS Standards	Implementation Underway	http://osse.dc.gov

Note- *Indicates Next Generation Science Lead State, Sources- Individual state department of education websites, NAAEE, NSTA

Table 22. Next Generation Science Standard Adoption and Implementation Status as of January 2024

State	NGSS Status Category	Designation Explanation
Delaware	NGSS	Delaware was one of the original twenty-six states that were considered Next Generation Science Lead States in 2011. The Delaware State Board of Education voted unanimously to adopt NGSS in the Fall of 2013. As of January 2024, it is one of twenty states plus the District of Columbia that adopted and use the NGSS in its entirety. (DOE, 2020; NSTA, 2023)
New York	NGSS- Aligned Standards	New York is part of a group of states that developed its own iteration of the NGSS that is closely aligned with the NRC (2012) recommendations. New York is also one of the original twenty-six states considered Next Generation Science Lead States in 2011, but they were not obligated to adopt the standards. NGSS was used as a guide, and in many cases, the standards are identical. New York's science education standards were adopted in December 2016 and are called the New York State P-12 Science Learning Standards, which replaced 1996 standards. New York made very minor modifications to the NGSS including the addition of early childhood standards and minor rearrangement in the order. The standards will be fully implemented including aligned Regents assessments by June 2026. (NSTA, 2023; NYSED, 2021)

Table 22. Next Generation Science Standard Adoption and Implementation Status as of January 2024 (continued)

Ohio	Modified NGSS-Aligned Standards	Ohio is part of a group of states that developed science education standards after the release of the NRC framework. In this category, there is some alignment to the three-dimensional learning aspect of the NGSS, but there are significant modifications, additions, or deletions compared to NGSS. Ohio's most recent science education standards were adopted by the State Board of Education in early 2018 and called the Learning Standards and Model Curriculum for Science. These standards include curriculum frameworks and place-based examples. The content and science/engineering practices mirror NGSS in many ways, but the standards were not intentionally based on NGSS. Ohio is also one of the original twenty-six states considered Next Generation Science Lead States in 2011, but they were not obligated to adopt the standards. On the Ohio Department of Education and Workforce website, it says "the structure of Ohio's Learning Standards for Science is somewhat different from NGSS, but the research that provided A Framework for K-12 Science Education, from which each was developed, is the same…teachers are encouraged to use NGSS to support classroom instruction." The website also includes a "crosswalk" tool with NGSS. (NSTA, 2023; ODE, 2023)
Virginia	Revision in Progress	Until recently, North Carolina, Ohio, Pennsylvania, Texas, and Virginia would have been in the same category as Florida with standards that had little to no influence from the NGSS. Virginia adopted new science education standards known as the Science Standards of Learning in Fall 2018. These standards show little to no influence from NGSS or the NRC framework. However, there were additional environmental science standards added based on the state's environmental literacy plan implementation plan. Virginia initiated a review process that will result in new Science Standards of Learning in January 2025 with full implementation expected by 2026. This process is expected to support better alignment with NGSS and the NRC framework. (NSTA, 2023; VDOE, 2023)

Table 22. Next Generation Science Standard Adoption and Implementation Status as of January 2024 (continued)

Indiana	Implementation Underway	Indiana is implementing standards aligned with NGSS and the NRC framework. After NGSS was published in 2013, Indiana adopted its Academic Science Standards in 2016. At the time, they would have been in the yellow "Modified NGSS-Aligned Standards" because they were still content focused. There was also an additional environmental science section added. In 2022, the Indiana State Board of Education approved the K-12 Indiana Academic Standards in science and computer science. While these standards are aligned with the 2016 content, they are also aligned with NGSS and the NRC framework. These standards were expected to be implemented by the 2023-2024 school year. (IDOE, 2022; NSTA, 2023)
Florida	Little to No Influence from NGSS	Florida is the only state that has science education standards that have little to no influence from NGSS or the NRC framework that has not begun the revision or implementation of revised standards. The Florida Department of Education released a document called Teaching Science in Florida: Understanding Next Generation Sunshine State Standards or NGSSS. These standards were approved in 2008 and have not been updated since. In this document, PJ Duncan, Secondary Science Program Specialist, argues that "no crosswalk between NGSS and our Florida Next Generation Sunshine State Standards (NGSSS) is possible." (FLDOE, 2017; NSTA, 2023)

Table 23. Pennsylvania Science Standards Revision Timeline

Timeline	Description
2022	Pennsylvania Science and Technology Standards/ Environment and Ecology Standards are adopted. -At the time this was revolutionary because these were the first state standards to mention evolution.
September 2019	The State Board of Education directed the Pennsylvania Department of Education (PDE) to update the Commonwealth science standards
February 2020	Between February and March 2020, there were fourteen stakeholder engagement sessions to comment on needs for the new standards.
April 2020	A revision committee convened over nine full days and thirty additional meetings to review stakeholder feedback, existing frameworks for science education, technology education, agricultural education, environmental education, engineering education, and more.
September 2020	Recommendations from the revision committee were adopted by the Board.
January 2022	The STEELS standards were adopted by the state board of education on January 13, 2022
June 2022	PDE works with stakeholders to create the STEELS Hub along with curriculum frameworks ahead of the final publication
July 2022	The STEELS standards were published as final in the Pennsylvania Bulletin on July 16, 2022, as part of the amendments to 22PaCode Chapter 4
August 2022	PDE works with stakeholders to create resources to support implementation
December 2022	PDE works with stakeholders to reimagine science safety within the framework for Meaningful Watershed Educational Experiences and the STEELS standards
Spring 2023-Spring 2025	PDE works alongside the state Standards Aligned System, regional Intermediate Units, school district leadership, school administrators, and teachers throughout the state to engage in each step of the STEELS Standards Implementation Guide around curriculum, assessment, professional development, leveraging cross-content connections, and communication.

Table 23. Pennsylvania Science Standards Revision Timeline (continued)

June 2025	Former Pennsylvania science standards are sunset on June 30, 2025
July 2025	STEELS standards are to be implemented state-wide for the 2025-2026 academic year following a three-year window for implementation.
2030	Pennsylvania will review the standards every five to ten years.

Students who demonstrate understanding can:

MS-ESS3-5. **Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.** [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. • Ask questions to identify and clarify evidence of an argument.	**ESS3.D: Global Climate Change** • Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.	**Stability and Change** • Stability might be disturbed either by sudden events or gradual changes that accumulate over time.

Connections to other DCIs in this grade-band:
MS.PS3.A

Articulation of DCIs across grade-bands
HS.PS3.B ; **HS.PS4.B** ; **HS.ESS2.A** ; **HS.ESS2.D** ; **HS.ESS3.C** ; **HS.ESS3.D**

Common Core State Standards Connections:

ELA/Literacy -

RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts. (MS-ESS3-5)

Mathematics -

MP.2	Reason abstractly and quantitatively. *(MS-ESS3-5)*
6.EE.B.6	Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set. *(MS-ESS3-5)*
7.EE.B.4	Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. *(MS-ESS3-5)*

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

The section entitled "Disciplinary Core Ideas" is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*. Integrated and reprinted with permission from the National Academy of Sciences.

Figure 30. Three Dimensions of MS-ESS3-5 Earth and Human Activity Standard

Science, Technology & Engineering, and Environment Literacy & Sustainability (STEELS)

Grades 6–8

3.4.6-8.I Environmental Literacy and Sustainability: Sustainability and Stewardship

Students who demonstrate understanding can *construct an explanation that describes regional environmental conditions and their implications on environmental justice and social equity.*

Clarifying Statement: Examples include both current and historical conditions due to systemic inequalities, including but not limited to human health impacted by Superfund sites, air quality, urban heat islands, acid mine drainage, access to green space, biodiversity, and water quality. Explanations could be constructed using primary and secondary sources, both print and digital.

Assessment Boundary: N/A

Science and Engineering Practices (SEP)	Disciplinary Core Ideas (DCI)	Crosscutting Concepts (CCC)
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods. • Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.	**LS4.D: Biodiversity and Humans** • Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Pennsylvania Context: Examples of Pennsylvania context include but are not limited to Pennsylvania Environmental Justice Area designations or Environmental Health Indicators.

PA Career Ready Skills: Explain how expressive communication strategies can affect others.

Connections to Other Standards Content and Practices

Standard Source	Possible Connections to Other Standard(s) or Practice(s)
Agriculture (AFNR)	CS.04.01.02.c: Evaluate sustainability policies and plans and prepare summary of potential improvements for AFNR businesses or organizations.
Science, Environmental Literacy and Sustainability (NAAEE)	5-8 Strand 2.3.A. Human-environment interactions: Learners describe human-caused changes that affect the immediate environment as well as other places, other people, and future times.
PA Core Standards: ELA	CC.3.6.6-8.H: Draw evidence from informational texts to support analysis reflection, and research.

Figure 31. Pennsylvania Science, Technology & Engineering, and Environmental Literacy & Sustainability standard on Environmental Justice- PA 3.4.6-8.I

Appendix E Supplementary Material Referenced in Chapter 5

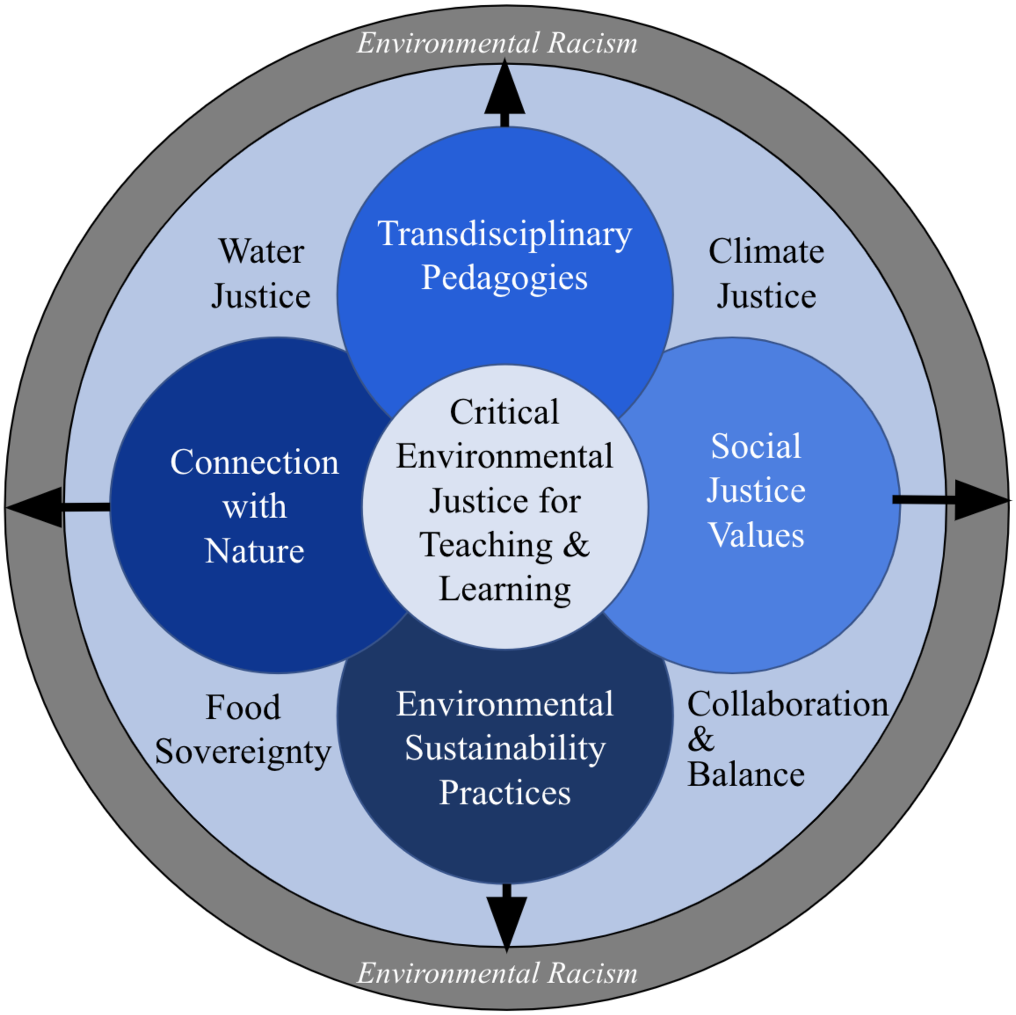


Figure 32. Critical Environmental Justice for Teaching and Learning Conceptual Framework

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