DESIGNING AND IMPLEMENTING PROFESSIONAL DEVELOPMENT TO SUPPORT CRITICAL SCIENCE CONSCIOUSNESS AMONG SCIENCE EDUCATORS

by

Lenora M. Crabtree

A dissertation submitted to the faculty of
the University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in
Curriculum and Instruction

Charlotte

2020

Approved by:

_____
Dr. Michelle Stephan

_____
Dr. Chance Lewis

_____
Dr. Troy Sadler

_____
Dr. Adam Reitzel

_____
Dr. Jae Hoon Lim

ABSTRACT

LENORA MOSLEY CRABTREE. Designing and implementing professional development to support critical science consciousness among science educators.
(Under the direction of DR. MICHELLE STEPHAN).

Justice-oriented pedagogies support students' socio-political, or critical, consciousness. Research reveals, however, that science educators, the majority of whom are white, struggle to enact these practices. The purpose of this Design-based Research study is to explore the implementation of a professional development innovation designed to support practicing science teachers' development of critical consciousness and content specific critical science consciousness. Teachers that possess critical science consciousness are aware that inequities in society influence science, and cognizant of the role science plays in the creation and perpetuation of systemic oppression. This research illuminates two significant findings: 1) Certain science content can be leveraged to increase practicing teachers' critical consciousness and critical science consciousness, and 2) Situating instructional materials in the history and current realities of the place individuals inhabit can support development of critical consciousness and critical science consciousness. This research also has implications for science curriculum and instruction: 1) Science practices are valuable tools to investigate the epigenetic impact of systemic inequities that create disparate health outcomes among marginalized groups, 2) Science teacher educators and professional development providers need to explicitly address the social construction of race and the role of science in the creation of notions of White Supremacy, and 3) Enacting culturally relevant practices has the potential to liberate teachers as well as students.

DEDICATION

This dissertation is dedicated to Ella May, who risked everything to disrupt the order of things as given, the teachers of Gaston County who dare to follow in her footsteps, and the students of B144 who inspire me to do the same.

ACKNOWLEDGEMENTS

At every stage in this research process, Dr. Michelle Stephan's mentorship has been invaluable to this process. Dr. Stephan, the joy, intellect, and commitment you bring to your work inspires me to do the same. After each of our meetings, I want to be a better researcher, scholar, and person. Tai, this dissertation happened because of your gesture of friendship. You and your peers are going to change the world. To Adam Reitzel, I continue to be inspired by your curiosity, brilliance, and decency. Thank you for answering a million questions and asking a thousand more. Dr. Chance Lewis, your focus on solution-oriented scholarship challenges me to carry on that legacy. Dr. Jae Hoon Lim, thank you for listening, prompting, and supporting me as a scholar, writer, and teacher educator. Dr. Troy Sadler, I am grateful to have this opportunity to learn from your knowledge and experience. Your interest in this work motivates me to attend more closely to what has been uncovered through science education research as I seek to find my place in an ongoing conversation.

The workshop at the core of this research would not exist without an incredible team of designers, movers, and shakers. In addition to Dr. Stephan and Dr. Reitzel, I am indebted to Dr. Luke Reinke, Dr. Monica High, Dr. Prem Pugalenthi, Eli Davis, and Bianca Yavelak for the passion and clarity they brought to this work. Thank you for embracing my commitment to the unique place the participants live and teach and reminding me that science practices can be powerful tools to investigate inequities.

Dr. Bettie Butler, without your prompting, I would not have begun this journey. Thank you for speaking with boldness and honesty. To Dr. Greg Wiggan, my consciousness was stirred by every reading and reflection you assigned. On behalf of my colleagues, thank you for turning our worlds upside down, literally. I am also grateful to Dr. Jennifer Warner who guided me

through the Capstone project which served as a catalyst for this dissertation and encouraged me to bring my teacher identity to this research. Opportunities to apprentice with Dr. Warren DiBiase and Dr. Daniel Alston transformed my perspective of science teacher education and gave me a glimpse into an exciting future in virtual and face to face classrooms.

To those with me on this Urban Education journey, especially Dr. Dymilah Hewitt, your friendship brought much joy to a long process. To my sister, co-author, and friend, Dr. Sonyia Richardson, when I lack courage, I remember the words you spoke over me and I press on. Dr. Amanda Casto and Dr. Katie Wagner, sharing the lessons our students taught us helped me find my voice in Urban Education. Thank you for walking that road with me. I am confident that the advocacy, scholarship, and passion of Dr. Joseph Allen, James E. Ford, Brittany Hunt, Michelle Pass, Portia York, Alicia Davis, Nikki Kincaid, Jimmeka Anderson, Deneen Dixon, and so many others will transform classrooms, schools, and most importantly, systems in the years to come.

The ideas that permeate this dissertation emerged in the classrooms in which I have been privileged to learn from my students. One of my greatest joys as a teacher is to watch my students grow into adulthood. I am especially grateful to Angie Hernandez, Sabahat Siddiq, Tierra Pressley, Kelli Hunnicutt, Jessica Capers, Coleman Mack, David Benton, and Allison Cummings for their encouragement. And Caroline Brooks, many of these words would literally not be on the page without your generous gifts of time, humor, and grace.

One does not leave a cherished profession to become a graduate student during the sixth decade of life without great trepidation. Scott Crabtree's love and unwavering support when the journey grew long and arduous is one of the greatest gifts I have ever received. My mother, Vivian Mosley's abiding faith that this dissertation could come to pass propelled me forward in the hopes of hearing her say "Glory!" when the task was complete. I am also deeply grateful to

Jan Mosley Hill and Melody Mosley Morris for their encouragement and listening ear. Without the space to think and write that Wislaine Gauchette, Kathy Nutter, and Robin Pratt provided this dissertation could not have happened. Thank you for sharing your friendship, support, and expertise with mom and me through the ups and downs of this long journey.

Taylor, Meredith, Seth, Amanda, and Sam Crabtree, you have given your mom and mother-in-law room to grow and I am grateful. To my beautiful, amazing goddaughter, Malaya, you, and your god-nephews are my "why" for this work. Owen, Russell, Jude, and Samuel, thank you for reminding Lala that doctoral studies and dissertations can wait while we take a walk, throw stones in a creek, pick blueberries, or feed carrot tops to a rabbit.

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CHAPTER I: INTRODUCTION

Equitable science education is essential in a diverse democratic society. As the United States and other developed nations shift from manufacturing to knowledge-based economies, equitable access to science and engineering education ensures that employment opportunities in the growing STEM (Science, Technology, Engineering and Mathematics) workforce are available to all persons (National Academy of Sciences, 2011). Of equal importance to the diversification of the STEM workforce is the development of a scientifically literate public. In order to confront challenges as varied as global climate change, microbial resistance to antibiotics, rising disparities in health status, and an aging transportation infrastructure, collective knowledge of basic science concepts is essential (Agre & Leschner, 2010; Varner, 2014; Watts et al., 2015). Initiatives to broaden participation in STEM have received expanded attention and funding over the last two decades. Despite this emphasis, research examining STEM interest and engagement continues to reveal persistent and widening gaps between White, high socioeconomic status (SES) males and groups that have been traditionally underrepresented in STEM including persons who identify as female, Black, Latinx, and students experiencing poverty (Saw et al., 2018).

To address this persistent challenge, a growing body of research indicates that students from groups underrepresented in STEM benefit from instruction that emphasizes issues of concern for marginalized communities (Campbell et al., 2015; Garibay, 2015; Thoman et al., 2015). Since the 1980s, appeals for more relevant science education have led to adaptations in curriculum and practice that acknowledge connections between Science, Technology, and Society (Bennett et al., 2006), and incorporate a socio-scientific issues approach (Sadler, 2004;

Zeidler et al., 2005). These responses, however, fall short of adopting an explicitly critical perspective to address inequity and injustice through science content instruction. A "sociopolitical turn" in science education is needed (Tolbert & Bazzul, 2017, p. 323). This transition necessitates a willingness on the part of science educators, the majority of whom are White (Banilower et al., 2018), to address issues of oppression, power, and identity inherent in science content, as well as in classrooms and school structures. Recognizing that persons from dominant groups struggle to understand the perspective of those who have experienced discrimination and oppression (Howard, 2016), research is needed to explore how science educators might be supported to examine science content and pedagogy through a critical lens. The studies that were conducted through this research address that need.

Theoretical Framework

This research is bolstered by critical theory and its emphasis on the potential for individuals and groups to recognize and overcome oppressive societal forces. Critical theorists reject ahistorical, value-free, positivist methods of research and emphasize critique of science, technology, and culture (deMarrais & LeCompte, 1999). According to Gramsci (2017), revolutionary change is possible when organic intellectuals emerge from the masses and provoke others to become active learners who acknowledge and address oppression. Two specific tenets of critical theory as it relates to education guide this work: the classroom as a space for political action and the role of teachers as agents of change (Sadnovik, 2007).

In addition, this research draws on critical race theory and the reality that race remains the most significant factor determining inequities in American society (Bell, 1992; Ladson Billings & Tate, 1995). Critical race theory emerged within critical legal studies; however, it is deeply rooted in the Black intellectual tradition (DuBois, 1903; Woodson, 1933). Although race

is an ideologized, social construct, the racialized nature of society and its impact on "raced" persons must be acknowledged and addressed (Ladson-Billings & Tate, 1995, p. 48). Storytelling as counter-narrative, and the power of "stories by people of color" to "catalyze the necessary cognitive conflict to jar dysconscious racism" (Ladson-Billings & Tate, 1995, p. 58) is a guiding principle of this research.

Pedagogical Approaches Grounded in Critical Theory

This research is also informed by two pedagogical approaches that emerged as applications of critical theory and critical race theory. Weaving critical theory with praxis, critical pedagogy (Freire, 1970) emphasizes the creation of a democratic classroom in which teachers assume the role of teacher-learners and students become learner-teachers. According to Freire (1970), critical approaches to instruction acknowledge inequities, promote emancipatory knowledge, and reject the banking model of education; in contrast, the problem-posing model engages students and teachers in ongoing inquiry. Through active dialogue between teachers and students, students learn to read the world, developing critical consciousness and an awareness of situated reality.

More recently, Ladson-Billings's (1995) research described successful teachers of African American students as those who hold high expectations for all students, encourage cultural competence, and support students' development of socio-political consciousness. She challenged teachers to permit students to move beyond issues including "saving the rainforest" and "animal rights" to probe more volatile topics (Ladson-Billings, 1999). Developing students' cultural competence and socio-political consciousness became major tenets of what she termed Culturally Relevant Pedagogy (CRP). Fifteen years after her seminal research, she described the role of the teacher in supporting socio-political, or critical, consciousness as the "neglected

dimension of CRP" (Ladson Billings, 2017, p. 145). According to Ladson-Billings (2011), while teachers embrace the ideals of high expectations and are willing to incorporate aspects of students' home cultures into curriculum and instruction, they are either unwilling or unable to support sociopolitical consciousness development, a deficiency she attributes to the harsh reality that "most of the teachers I encounter have not developed a sociopolitical consciousness of their own" (p. 41). Data from interviews with Science Teacher Educators revealed that those charged with preparing pre-service teachers lack an understanding of the socio-political, or critical, aspects of CRP (Underwood & Mensah, 2018). According to Howard (2016), teachers cannot teach what they do not know.

Statement of the Problem

Although Critical Pedagogy and CRP are powerful instructional approaches that push teachers to treat culture as assets in the classroom, limited attention has been given to the relationship between CRP and discipline-specific content, such as science. According to Parsons (2014), science education research is characterized by an emphasis on students as individuals as opposed to members of groups with shared experiences and an almost exclusive focus on the present that ignores the racism and oppression embedded in the history of scientific endeavors. The subsequent failure to address systemic issues leaves practicing teachers ill-equipped to address important topics including race in the science classroom (Mutegi, 2011; Sheth, 2019).

It is an open question as to how to teach science with a critical lens, not to mention the characteristics of teachers' beliefs and practices that are necessary to engage their students in critical science inquiry. In a study conducted prior to the work centered in this dissertation, the author served as a co-instructor of a seminar during which teachers were introduced to a novel science concept, epigenetics, through the lens of social justice. Interviews with three practicing

science teachers were conducted in the final three weeks of the seminar and six months after it concluded. Findings that emerged from analysis of the interview data study revealed that instead of learning *science* through the lens of social justice, the science content provoked teachers' critical consciousness. In addition, some of the teachers were able to adopt a more critical perspective of science-specific content and practices. Drawing on the findings of this study in addition to the literature discussed previously, I posit that in order to employ a critical approach to science education, teachers, at minimum, must possess an awareness of systemic oppression. This dissertation work involved designing a professional development experience that engaged in-service science teachers in critical science inquiry to enhance their development of critical consciousness. The PD experience invited teachers to explore science content through critical pedagogies using structured instructional materials, journal writing, and discussion. Thus, the dissertation aims to explore what types of PD experiences can enhance science teachers' critical consciousness and content-specific critical consciousness.

Purpose

This dissertation draws from Freire's (1970) construct *critical consciousness* and Ladson-Billings's (1995) *sociopolitical consciousness* and integrates science content more explicitly, which my colleagues and I call critical *science* consciousness. Critical science consciousness (CSC) is an awareness of the role that science can play in both liberating and disenfranchising marginalized groups in society. Teachers who possess CSC encourage students to question structural inequalities and injustices evident in science content. For example, teachers may provide opportunities for their students to explore environmental justice issues, including the disproportionate exposure to hazardous wastes and air pollution experienced by people of color and those living in poverty. Teachers may integrate racism and the historical impact this has had

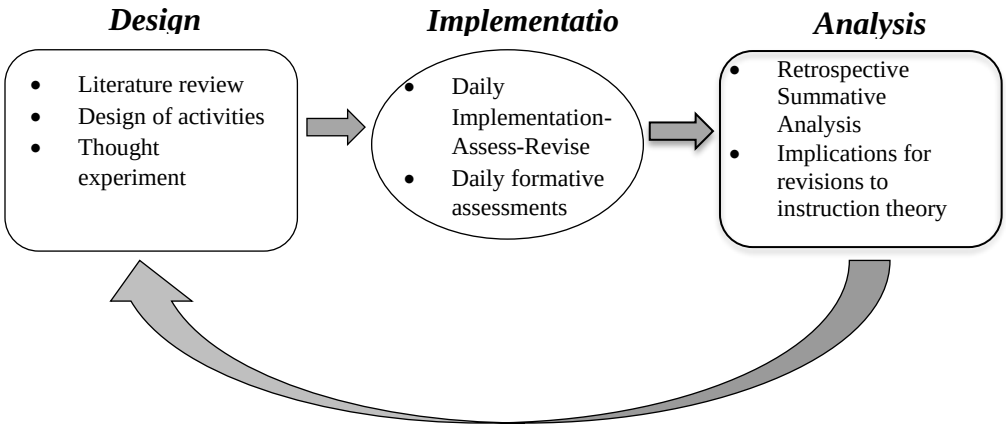
on the development of key science ideas including genetics research. To be able to support K-12 students' learning opportunities, teachers must have sophisticated CSC. Thus, the purpose of this dissertation is to explore how a PD experience can support teachers' development of CSC through a critical exploration of science content.

Research Methodology: Design Research

Design Research has gained prominence in the last two decades in mathematics and science education and varies in its purposes and educational settings (Cobb et al., 2003; Corcoran et al., 2009; Daro et al., 2011). The main activity of researchers in this approach is highly interventionist in that the researcher proactively alters the instructional context and strives for change. The goal is not to test if the design worked, but rather to explore the implementation to provide an analysis of the way in which the design was realized for those who might wish to adapt the design in their own contexts (Cobb et al., 2003). Design Research is conducted in multiple macro-cycles of design, implementation, and analysis (see Figure 1). One macro-cycle involves the designer(s) exploring relevant research in order to design the innovation. The designer also engages in a thought experiment, envisioning how the instructional innovation may be realized with potential participants. In the next part of the cycle, the designer(s) implement the innovation, collecting data along the way for retrospective analysis. The end of the cycle involves the in-depth analysis of the data as a way to inform revisions to the innovation. Ideally, the revised design would serve as the material for a second cycle and multiple cycles would occur until a stable instructional innovation is ready for adaption in other settings.

Figure 1

One Macro-Cycle in Design Research.



Note. Adapted from Stephan & Cobb (2013).

A cycle (i.e., macro-cycle) consisted of designing an innovation (the PD materials and experience), implementing it, analyzing the results, and making revisions grounded in the analysis. The research for this dissertation occurred as one cycle of Design Research that included the design, implementation, and analysis of a four-day summer intensive educator workshop conducted for high school science teachers in county-wide public school district. One of the findings that emerged from the earlier study was that, although teachers who had limited backgrounds in science developed critical consciousness related to racism and societal inequities, their lack of science content knowledge constrained their growth in CSC. This finding informed the design of the second study which involved seven teachers in an exploration of science content through critical pedagogies.

A design team was recruited that met four times prior to the innovation. During these meetings, instructional materials and activities were developed, critiqued, and revised. Design team members included University of North Carolina at Charlotte Cato College of Education

faculty members with expertise in critical methods and Design-based Research, a faculty member from the Biological Sciences Department who served as the co-instructor in the pilot study, the Science Curriculum Specialist in Gaston County, and two teachers who participated in the pilot study.

The instructional materials and activities were implemented during a professional development workshop over the course of four days in July 2019. At the end of each day, the researcher, curriculum specialist, and available members of the design team met to discuss the opportunities and challenges of that day and revised the materials and activities accordingly. In this way, the design team engaged in daily micro-cycles of design/analysis/revision which informed the materials and activities used on subsequent days. While these micro-cycles occurred during the experimentation daily, the research project itself followed a more general macro-cycle of design, implementation, analysis, and revision.

Following the four-day workshop, the design team met to discuss the innovation at the macro level to document any insights to be considered during a full-blown analysis of data. An analysis of the teachers' learning experiences, including any growth in CSC, and ways that the instructional materials supported learning is described in the first manuscript. The second manuscript includes a broader analysis of the design and implementation phases. This analysis also reveals ways the design of the innovation supported and constrained teacher development of CSC. The analyses, along with insights from the design team, inform revisions to the innovation. Ideally, another cycle of design research would occur until a stable PD innovation emerges, but the scope of this dissertation involves only the results of the first cycle.

Research Themes and Questions

The overarching theme of this dissertation is the emergence and development of in-service science teachers' CSC as they engage in a four-day PD experience. As a multi-article dissertation, each manuscript employs a different methodology to explore CSC and elucidate the processes that promote and constrain science educators' development of critical consciousness. The dissertation is divided into three manuscripts. Two manuscripts report empirical research surrounding Professional Development experiences. The fourth manuscript describes a case study which anchored the Professional Development innovation reported in first two manuscripts.

The first manuscript, *We were raised to believe that everything belongs to us: An analysis of emerging critical science consciousness in a professional development setting,* examined evidence of emerging critical consciousness and CSC across a four-day professional development innovation to document the specific ways in which the PD experience enabled and constrained teachers' growth in critical science consciousness. This manuscript examines the following research questions:

1) What evidence of the teachers' collective consciousness emerges during a Professional Development workshop that incorporates science practices and a critical place-based framework to examine disparate health outcomes?

2) What instructional experiences enable and constrain the high school teachers' collective consciousness during a summer intensive Professional Development workshop that incorporates science practices and a critical place-based framework to examine disparate health outcomes?

The second article, *Is it possible to teach just science: Designing professional development for critical science consciousness,* reports an analysis of the design of the four day workshop that employed science practices and a critical place-based lens to explore historic and current health disparities germane to the region in which participants live and teach. This manuscript examines the following research questions:

1) In what ways did the design of the professional development experience enable and constrain the high school teachers' emerging critical consciousness and critical science consciousness?
2) What revisions to the instructional sequence are indicated by an analysis of the design and implementation of the professional development experience?

The third manuscript, *Using critical case studies to cultivate in-service teachers' critical science consciousness,* describes the critical inquiry case study, *Mill Mothers' Lament,* that anchored the summer intensive professional development experience. The manuscript also reports ways this specific case study supported teachers' growth in critical science consciousness.

Data Corpus and Analysis Methods

Data collection for this dissertation began during the spring of 2019 and continued through the summer and fall of 2019. Data included audio recordings of design team meetings and workshop sessions, pre- and post-innovation teacher interviews, participant reflections, field notes, and workshop artifacts.

Audio Recordings of Workshop Sessions

Large group discussions during workshop sessions were audio-recorded and transcribed for analysis. When possible, small group discussions were also recorded. Audio recordings of the

workshop sessions served as the primary data source to document the teachers' collective learning during the workshop. Themes and findings were triangulated with other sources of data, including reflective writings by teachers and recordings of workshop sessions and participant interviews. In addition, the researcher recorded reflections following workshop sessions that were transcribed as an additional data source.

Pre and Post-PD Interviews

During the three weeks preceding the workshop, interviews were conducted with participating teachers to explore their awareness of ways that science can potentially disenfranchise or liberate marginalized groups. Following the workshop, teacher participants were interviewed to uncover ways in which the seminar content promoted and constrained their development of CSC. Interviews were audio-recorded and transcribed. Themes and findings were triangulated with other sources of data including reflective writings by teachers and recordings of workshop sessions and design team meetings.

Audio Recordings of Design Team Meetings

All design team meetings were audio-recorded and analyzed to reveal pre-innovation design decisions, alterations to the original design, justifications for those changes, and outcomes of the innovation. Daily meetings between the researcher, curriculum specialist, and available design team members were also audio-recorded. Recordings were transcribed and analyzed. The data analysis process was ongoing from the initiation of the process through the culmination of the full cycle of design research. Consequently, ongoing analysis contributed to changes made during the micro-cycles as well as to final adjustments made to the CSC construct. Themes that emerged from the data were triangulated with other sources, including reflective writings by teachers, observation notes by the researcher, and participant interviews.

Document Collection

At the end of each workshop day, teachers were asked to reflect on the experiences from that day and share their "joys and concerns" in a brief reflective writing. These were collected each day. Flip chart drawings and other visuals teachers created to present collaborative work to the entire cohort were also collected for analysis.

Summary

Exploring science content through a critical lens is a promising way to acknowledge and support the development of teacher and student critical science consciousness. To engage in this emancipatory form of instruction, teachers must possess the ability to evaluate content through a critical lens and a desire to support students as agents of change. Professional development that provokes critical consciousness among in-service teachers represents an unexplored opportunity in science education research. The studies conducted through this research have the potential to expand our knowledge regarding how to support teachers as they become critical pedagogues and change agents in their areas of influence now and in the future.

Subjectivity Statement

Subjectivity is embedded in all layers of qualitative research (Ravitch & Carl, 2016). My own subjectivities are woven into the fiber of this dissertation and emerge from experiences as a white female science teacher residing in the county in which the workshop central to this study was conducted. My identity as a former teacher in the district allowed me to position myself as a co-learner with participants. Simultaneously, my role as a graduate student researcher/instructor distinguished me as one who "left the classroom" in a community of teachers that places high value on longevity of service to the school system.

As a high school science teacher, I became aware of the ways public education perpetuates inequitable economic and social systems. I also experienced the dissonance of having freedom to experiment pedagogically while teaching in a system driven by standardized curricula and high stakes testing. Other experiences that inform my perspective include impressions formed as a student in K12 science classrooms, undergraduate, and graduate programs in which race, racism, and systemic inequities were ignored.

As a graduate student with a specialization in urban education, I have had the opportunity to gain clarity around these experiences. While the workshop conducted as part of this research was designed to support teachers' critical consciousness through science content and practices, it was imperative that my personal commitment to critical pedagogies in science teaching and learning not cloud how data was collected and analyzed. At the same time, my experiences in the community and its schools enhanced my ability to support open and honest discourse during the workshop and to elicit rich conversations with participants during interviews.

CHAPTER II [ARTICLE 3]: WE WERE RAISED TO BELIEVE THAT EVERYTHING BELONGS TO US: AN ANALYSIS OF EMERGING CRITICAL SCIENCE CONSCIOUSNESS IN A PROFESSIONAL DEVELOPMENT SETTING

Lenora M. Crabtree and Michelle Stephan

Abstract

Recents events reveal the impact of systemic inequities on communities marginalized by race and poverty and highlight the importance of critical and culturally relevant frameworks in science education. Education theorists and current research suggest that a lack of socio-political, or critical, consciousness among science educators limits their ability to engage students in culturally relevant teaching and learning; provoking critical consciousness among white educators is an especially daunting task. In this article, we present results of a Design-based experiment that supported practicing science teachers' development of critical consciousness, and content-specific critical *science* consciousness. The experiment was conducted to test and revise a hypothetical learning trajectory and instructional sequence grounded in critical place-based pedagogies and opportunities to engage in authentic science practices. An analysis of teacher learning that occurred over the course of the workshop offers insight into the potential for innovative professional development to support teachers' understanding of systemic oppression, racism, and the possibilities inherent in teaching for liberation.

We were raised to believe that everything belongs to us: An analysis of emerging Critical Science Consciousness in a Professional Development setting

Equity in science education is paramount in a rapidly changing world. At the time of this writing a global pandemic and reckoning with racism are occurring simultaneously. Together, these events reveal the impact systemic racial and socioeconomic inequities have on the health and safety of marginalized communities, an unveiling that presents challenges and opportunities for science educators. In recent studies conducted to broaden participation in science and engineering fields, students who identified with groups traditionally underrepresented in science expressed desire to address issues relevant to marginalized communities through their education and research (Campbell et al., 2014; Thoman et al., 2015). These findings echo 100 years of education literature (e.g. Banks, 1993; DuBois, 1903; Gay, 2002; Ladson-Billings, 1995; Paris & Alim, 2017; Sleeter, 2011), including research in the field of science education (Atwater & Riley, 1993; Brown et al., 2018; Barton, 2003; Emdin, 2010; Rodriguez, 1998).

While asset-approaches attend to the importance of culture and community in varied ways, the role of the teacher in helping students "recognize, understand, and critique current social inequities" is most clearly addressed in the theoretical framework of Culturally Relevant Pedagogy (CRP) (Ladson-Billings, 1995, p. 476). CRP emphasizes the importance of holding high expectations for all students, promoting cultural competence, and supporting socio-political consciousness (Ladson-Billings, 1995). Although classroom teachers readily acknowledge student learning and cultural competence as important facets of classroom instruction, Ladson-Billings (2011) describes attending to students' sociopolitical consciousness as "the much harder sell," a challenge she attributes to the reality that "most teachers… have not developed a sociopolitical consciousness of their own" (p. 41). Surveys and interviews conducted with

science teacher educators reveal a lack of understanding of the critical aspects of CRP on the part of those charged with preparing future K12 science teachers (Underwood & Mensah, 2018). In a review of equity-focused professional development (PD) literature, Bancroft and Nyirenda (2020) conclude that transforming science educators' deficit perspectives and practices into those that value and leverage students' diverse experiences remains a vexing challenge. According to Howard (2016), teachers cannot teach what they do not know.

The question of how to support practicing science teachers' development of socio-political consciousness remains an open one. In her seminal work, Ladson-Billings (1995) recommended educators look to models of cultural critique including those of Freire (1970; 1973) and other critical pedagogues (Giroux, 2011; hooks, 2003). In this article, we report the results of a Design-Based Research project (Cobb et al., 2003) in which a Professional Development (PD) workshop for practicing high school science teachers was conducted. The aim of the experiment was to study the implementation of an instructional sequence that employed a critical place-based framework and science practices to support teachers' development of critical consciousness. In this article, we report an analysis of the teachers' discourse that occurred over the four-day workshop and describe three themes that emerged. Findings suggest that professional development that provides opportunities for teachers to engage in science practices to study inequities within the context of a local community holds promise to support content-specific critical consciousness.

Conceptual Framework: Critical Consciousness

While CRP is rooted in the African American struggle for Civil Rights in the United States, critical pedagogy emerged from efforts to overcome class oppression in Latin America (Horton & Freire, 1990). *Pedagogy of the Oppressed,* the seminal work of Brazilian priest and

educator, Paulo Freire (1970), describes the intersections of emerging critical consciousness and literacy among Brazilian farm workers. According to Freire (1970), critical approaches to instruction engage teachers and students in problem-posing education, active dialogue, and emancipatory learning. Through reflexive praxis, teachers and students develop critical awareness as they learn to "read the world" and become conscious of their situated reality (Freire, 1970, p. 80). While banking models of education characterized by direct instruction and passive learning conceal facts and anesthetize students' consciousness, problem posing models evoke critical consciousness. As students develop an ability to perceive their existence in a world that is constantly changing, they become aware of their capacity to transform their world.

According to Banilower et al., (2018), 90% of secondary science teachers identify as white. Developing critical consciousness is not a simple task for members of the dominant group who desire to engage in a struggle for liberation with the oppressed (Freire, 1970). Although those in the oppressor class may truly desire to change an unjust system, they often adopt deficit frameworks and perceive those who are oppressed to be unable "to think, to want, and to know;" in contrast, "a real humanist can be identified more by his trust in the people, which engages him in their struggle, than by a thousand actions in their favor without that trust" (Freire, 1970, p. 60).

Systems of oppression are complex and varied. Dimensions including race, gender, class, and sexual identity play important roles in a three dimensional "matrix of domination" that provides a useful model for understanding the complexities of oppression:

> All groups possess varying amounts of penalty and privilege in one historically created system. …For example, white women are penalized by their gender but privileged by their race. Depending on the context, an individual may be an oppressor, a member of an oppressed group, or simultaneously oppressor and oppressed (Collins, 2017, p. 415).

Oppression may be experienced at the personal, group, or institutional level, however, "sites of domination" are also "potential sites of resistance" (Collins, 2017, p. 416). According to Collins

(2017), while oppressive systems respond to human agency, changes in consciousness are essential to accomplish institutional and social change.

Socio-scientific issues and Science Education for Social Justice

A socio-scientific issues (SSI) approach to science instruction presents intriguing opportunities to incorporate a critical lens, particularly in its emphasis on discourse, ethics, and character development. SSIs are social dilemmas and ill-structured problems with connections to science (Sadler, 2004). Among the issues that might inform a critical approach, investigators have examined how SSI support students' informal reasoning (Sadler, 2004; Sadler & Zeidler, 2005), reflective judgment (Zeidler, et al., 2009), and situated learning (Sadler, 2009). In a review of literature related to SSI and informal reasoning, Sadler (2004) found that the incorporation of local issues of immediate concern in students' communities supported students in making connections between personal experience and science knowledge.

Justice-centered Science Pedagogy employs Social Justice Science Issues (SJSI), "issues of social injustice that are important to students and their communities," as generative themes in a merger of SSI and Freire's critical praxis (Morales-Doyle, 2017, p.1036). In a retrospective case study, Morales-Doyle (2017) examined the justice-oriented science curricula he created and enacted within a secondary Chemistry course; findings indicate that the unit prompted students to take on the role of transformative intellectuals (Morales-Doyle, 2017). Engaging students in addressing locally relevant issues of oppression through Justice-centered Science Pedagogy holds tremendous promise, however, research is needed to explore how in-service teachers might be prepared to enact justice-centered approaches (Morales-Doyle, 2017).

Critical Approaches and Science Education Research

Research supports the value of CRP and other justice-oriented pedagogies approaches in classrooms and informal science education spaces to support students' socio-political or critical consciousness (Boutte et al., 2010; Barton & Tan, 2020; Upadhyay et al., 2020). Studies of professional development (PD) experiences that support teachers as critical pedagogues provide evidence of their transformative potential (Chinn, 2007; Johnson, 2011; Grimberg & Gummer, 2013). The research literature also underscores the persistence of deficit frameworks that may impede practicing teachers' abilities to create and enact curriculum that supports social action (Bancroft & Nyrenda, 2020; Brown & Crippen, 2017; Suriel & Atwater, 2012).

Echoing Ladson-Billings' emphasis, Tolbert and Bazzul (2017) have called for a "sociopolitical turn" in science education that centers issues of "structural oppression, power, and identity within culturally responsive, critical, and activist pedagogies" (p. 324). Like Morales-Doyle (2017), their appeal for a more socially just, activist science education is rooted in praxis, specifically one author's partnership with a science teacher whose students investigated the impact of coal mining on the community's access to clean water. Sociopolitical consciousness is also the emphasis of Madkins and de Royston's (2019) case study of an exemplar Black male science educator's political clarity enacted through attentiveness to the lives of his students and science content. While these cases provide evidence for the transformative potential of critical approaches in science education, studies that explicitly address the how science teacher educators might support development of the sociopolitical, or critical, consciousness among practicing science educators are rare. According to Brown and Crippen (2017), research is needed to uncover how science educators develop sociocultural and critical consciousness and explore how they can be supported in the development of curricula that incorporate critical and culturally relevant methods. Science teachers also need support in

the practice of "grappling with racism" to "disrupt the historical and contemporary legacy of racism in science and science education" (Sheth, 2019, p. 56).

In the pilot study portion of this Design Research, the first author investigated how acquisition of new content knowledge by practicing science teachers might be supported through critical pedagogies. Findings suggested that an emphasis on social justice supported teachers' interest and engagement when learning novel science content. Data analysis also revealed that the use of a critical approach provoked new and deepening awareness of structural inequities by teacher participants, particularly those who identify as white and those who identified as belonging to middle and upper socio-economic classes. During post-seminar interviews, teachers described increased awareness of the impact of food insecurity, environmental injustice, and historical trauma impact on their students and communities. In short, the science content supported teachers' development of critical consciousness (Crabtree & Lim, in process).

Evidence also emerged of additional intersections between critical consciousness and the discipline of science. As teachers employed a critical lens to examine science content discussions shifted to critique ways scientific knowledge is generated. An essential aspect of the nature of science is that it is a social endeavor (Erduran & Dagher, 2014). As such, the acquisition of knowledge through science processes is subject to the influence of racial, gender, and class biases present in broader society (Gould, 1996; Marks, 2017). The results of the pilot study led us to wonder if science content itself could be leveraged to support teachers' critical consciousness. We have identified this new construct as critical science consciousness, a content-specific form of critical consciousness. We introduce this term below as we describe the research methodology used to design the science professional development.

Design-based Research Methodology

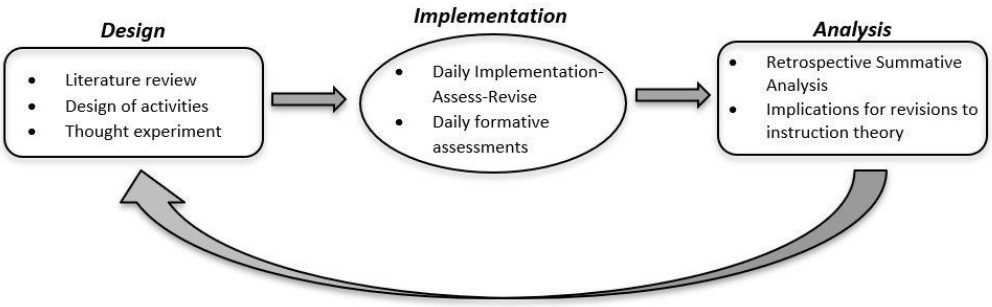
Design-based Research (DBR) has gained prominence in the last two decades in mathematics and science education and differs in its purposes and educational settings (Cobb et al. 2003; Corcoran et al. 2009; Daro et al. 2011). A design research team includes an instructor who implements an instructional sequence analyzed and revised during three phases of design research (Cobb, 2000; Confrey and Lachance 2000). During the *Design Phase*, members of the design team identify a practical or theoretical need, conduct a literature search on the need, and design a potential instructional innovation. In the *Implementation Phase*, the team implements the innovation in a setting meant for eventual scale. During implementation, the team conducts informal analyses of learning, makes on-the-spot revisions, and implements them. The final phase of DBR, the *Analysis Phase*, formal, retrospective analyses are conducted using data collected during implementation (Figure 1). The goal of this phase is to use the findings from a formal analysis of learning to make data-based revisions to the original innovation which then inform a new cycle of DBR. The findings described in this article can be considered a part of the Analysis Phase as we attempt to document the learning that occurred during the PD workshop. Our analysis will inform the redesign of the instructional sequence and after a few more cycles of DBR, a stable instructional sequence should emerge.

The appeal of Design Research lies in the fact that, while much educational research is divorced from practical problems, DBR is *necessarily* located in the practical settings of which it is designed to study. The main activity of researchers in using DBR is highly interventionist in that the researchers proactively alter the instructional context at the same time they are exploring the viability of the innovation. The goal is not to test if the design worked but rather to explore the implementation to provide an analysis of the way in which the design was

realized and the means of supporting that realization for those who might wish to adapt the design in their own contexts (Cobb et al., 2003).

Figure 1

One macro-cycle in design research.



Note. Adapted from Stephan & Cobb (2013).

Although Design-Based Research can be conducted at a range of levels, the work we report here is Teacher Development-Design Research, an adaptation of the Teacher Development Experiment (Simon, 2000). In particular, the research reported in this article involves a Professional Development (PD) workshop designed to enhance science educators' critical consciousness and *content-specific* critical consciousness, a new construct we are calling critical *science* consciousness (CSC). Individuals with enhanced CSC recognize ways that the tools of science can be used to identify, study, and understand systemic inequities. In addition, CSC involves awareness of the role that science education may play in creating, reinforcing, or dismantling systems of oppression. The specific research questions we sought to answer through this experience include:

1) What evidence of the teachers' collective consciousness emerges during a Professional Development workshop that incorporates science practices and a critical place-based framework to examine disparate health outcomes?

2) What instructional experiences enable and constrain the high school teachers' collective consciousness during a summer intensive Professional Development workshop that incorporates science practices and a critical place-based framework to examine disparate health outcomes?

Our focus on white high school science teachers who work with diverse populations of students in a Southeastern United States rurban (Stephens, 2019) school district, adds an additional layer of complexity to this work. To design this innovation, we drew on the Social Justice Science Issues framework described by Morales-Doyle (2017) and others who assert that culturally relevant approaches can transform science teaching and learning (Brown, 2019; Johnson, 2011). Central to our work with practicing teachers in this school district is our belief, informed by Ladson-Billings (2011; 2017), that teachers cannot support students' socio-political, or critical, consciousness if they do not possess critical consciousness themselves. In the next sections, we elaborate on the participants of the TD-DBR that took place in a 4-day summer PD experience. We then describe the design heuristics that were used to create the instructional sequence used with teachers.

The Context

The instructional sequence was implemented during a four- day (Monday – Thursday) summer professional development for high school science educators in a county-wide school district in the Southeastern United States. The district serves approximately 32,000 students in grades pre – K through 12, 66% of whom qualify for the federal Free and Reduced Priced Lunch (FRPL) program. Among students who attend county schools, a majority, 61%, identify as White; 21% identify as Black, 12% Hispanic, 4% Multiracial, and 1% Asian (U.S. Dept. of Education, 2020). High school students in the district attend one of twelve high schools, two of

which are limited to students that meet specific academic requirements. The remaining high schools serve students that live in geographically large, but contiguous school zones that include urban characteristic (Milner, 2012), as well as suburban and rural spaces, resulting in intersectional school climates Stephens (2019) has described as rurban.

In the county in which this study took place, textile manufacturing was the dominant industry until the late 1990's. Rising wages of mill employees coupled with an influx of new residents created a middle class in the 1960's and 1970's; the divide between descendants of those who worked in the textile mills and those who owned or managed them, however, continues to permeate the area. In comparison to the school population, a larger percentage of county residents (78%) identify as White (United States Census Bureau, 2020). Residents describe their region as politically and religiously conservative. Sixty-five percent of county residents who participated in the 2016 presidential election voted for the Republican nominee for president (Politico, 2020).

Seven high school science teachers, all of whom identify as white, registered for the workshop. Five of the educators teach at four of the county's large public high schools and two teach at an Early College program. Four of the participants identify as female and three as male. Years of experience in the high school science classroom among this group of teachers range from 2 – 27; courses taught include Earth Science, Physics, Biology, Chemistry, Anatomy and Physiology, and Forensic Science. Science teachers in this state follow state-mandated Essential Standards to guide instruction, however the state has not adopted the Next Generation Science Standards framework.

The PD workshop was conducted by the first author, a doctoral candidate at the time of the experiment. The first author had been a graduate student and university instructor for five

years at the time of the experiment but had previously been employed as a high school science teacher in the focus district. The high school science curriculum specialist for the county served as co-instructor and was present for all workshop sessions. The instructional sequence was developed in conjunction with an interdisciplinary design team that consisted of the first author, the second author (a math education researcher with expertise in design research), an additional math education researcher, an engineering education researcher, a biologist, the county curriculum specialist, a high school classroom Environmental Science educator, and a secondary special education teacher. The role of the design team was to analyze and respond to the emerging instructional sequence and advise the instructor on pedagogical strategies associated with the use of an inquiry approach.

The first author conducted pre- and post-workshop interviews with six of the seven participating teachers. One participant did not respond to email requests to schedule interviews but did sign consent materials and actively participated in the workshop. During the interviews, the researcher sought to assess the degree to which teachers were comfortable discussing issues of social justice, equity, and race, as well as specific ways they address these topics through their curriculum and instruction. In addition, interview questions explored participants' understandings of how science and issues of social justice intersect. Pre-workshop interviews revealed a pervasive reluctance to discuss race, curiosity regarding how social justice and equity might be explored through science content, and a desire to teach science in more inclusive ways.

Design Phase

Two design heuristics undergird the instructional sequence: critical place-based education and an understanding of science as a dynamic, inquiry-driven discipline. The incorporation of

these two ideas reflects a desire to engage participants in both content and pedagogy relevant to their roles as science educators teaching in a specific context.

Critical Pedagogies of Place

Critical pedagogies of place (Gruenewald, 2003) combine the critique of inequitable systems inherent in critical pedagogies with the local, ecological focus of place-based education. According to Gruenewald (2003), through a critical pedagogy of place students and teachers engage in the interconnected processes of decolonization and the unlearning of dominant ideologies taught in schools, with re-inhabitation, learning to live in ways that are socially just *and* ecologically sustainable. Central to this concept is the recognition that social, as well as environmental, concerns have a geographical context and that experience is heavily influenced by place. This heuristic informed the design of the instructional sequence through an emphasis on the impact of cotton monoculture and inequitable labor practices on short and long-term health disparities in the region**.**

Science Inquiry

The instructional sequence was designed to support participants' learning through active inquiry, methods that align with the problem-posing approach inherent in critical pedagogies Freire (1970). Recent re-conceptualizations of the nature of science place greater emphasis on its social aspects than previous models; new frameworks recommend that teachers emphasize ways in which practicing scientists work with others and seek consensus about new knowledge (Erduran & Dagher, 2014). We identified four science practices outlined in *The NGSS Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NGSS Lead States, 2013) that were most suitable for use with the primary source materials and emphases of the PD workshop: Asking Questions and Defining Problems; Analyzing and

Interpreting Data; Constructing Explanations; Obtaining, Evaluating, and Communicating Information. Accordingly, the tools and activities described below were designed to engage participants in authentic science practices and encourage critical discourse.

The Hypothetical Learning Trajectory

During the initial phase of the research reported in this article, the designers engaged in a thought experiment, anticipating how workshop participants might engage in science practices to explore systemic inequities. According to Simon (1995), the product of this thought experiment can be referred to as a *hypothetical learning trajectory* (HLT), a designer's prediction of the path along which learning may proceed for a group of students, or, in this case, teachers. An HLT includes three components: the learning goals around which activities are designed, potential discourse in which teachers might engage as they participate in those activities, and the specific artifacts that may mediate their learning (Clements & Sarama, 2004). Three learning goals developed for the PD workshop guided the design of the HLT (Table 1).

Throughout the Design Phase, an HLT was developed and revised as the design team reacted to various iterations (Table 2). The HLT has been divided into phases which correspond to shifts in teachers' critical science consciousness the workshop is designed to support. For each phase, the topic, learning goals (LG), instructional materials, science activities/practices, and potential topics of discourse are identified and described below.

Table 1

Learning Goals

Learning Goal 1: *Participants develop awareness of ways that inequities in society impact the scientific enterprise and science education.*
• Social, economic, and political systems influence science curriculum and instruction (Green, 2014). • Social, economic, and political systems shape the questions scientists ask and how they seek to answer those questions (Duster, 2015; Gould, 1996; Marks, 2017). • Aspects of identity and experience influence whose contributions are recognized, and whose knowledge is considered scientific. (Bang & Marin, 2015; Carlone, Haun-Frank, & Webb, 2011; Glasson et al., 2010)
Learning Goal 2: *Participants become more aware of ways that the scientific enterprise and science education contribute to systemic inequities in broader society.*
• Failure to address issues of importance to marginalized communities through science curriculum and instruction perpetuates notions of Science as White Property (Mensah & Jackson, 2018). • Western science perpetuated the fallacy that racial categories have a biological basis (Kendi, 2016; Gould, 1996). • Science curriculum and instruction continues to reinforce erroneous notions about race (Donovan, 2014; 2016; Morning, 2011). • False conjectures about human categories prompt researchers to seek answers to health disparities in gene sequences, while ignoring the social and cultural history of groups with varied experiences (Duster, 2015; Lorusso, 2011).
Learning Goal 3: *Participants recognize the potential for critically conscious science education to contribute to the liberation of individuals, groups, and society.*
• In the early 20th century, high incidences of disease among persons experiencing poverty were heralded as examples of genetic inferiority; as nutritional causes for diseases were uncovered, cures were developed (Etheridge, 1972; Gould, 1996). • In the 1990's, studies in the field of human genomics revealed a higher degree of genetic similarity *between* socially constructed racial categories than *within* them (Ash & Wiggan, 2018). • Researchers in the field of epigenetics have uncovered mechanisms through which varied environmental conditions impact health outcomes (Waterland & Jirtle, 2003). • An understanding of epigenetics can equip future scientists and policy makers to address inequities at their root cause. (Duster, 2015; Sullivan, 2013) • Exploring issues at the intersection of science and social justice through curriculum and instruction equips students and teachers to be agents of change in schools and communities.

Table 2

Hypothetical Learning Trajectory

Topic	Learning Goals	Tools	Activities/ Science Practices (NGSS, 2013)	Possible Topics of Discourse
Investigating Pellagra	1 2 3	Historical case study: • Ella May biography (2-page handout) • Narratives: History of pellagra • Original scientific publications • Diagrams of cellular respiration • Map: Pellagra in the United States • Graph: Pellagra deaths from 1915 – 1930	Constructing a timeline; reading historical summaries; analyzing graphs and maps; forming hypotheses; analyzing experiments and surveys; creating graphs; presenting findings Asking questions; analyzing and interpreting data; using mathematics and computational thinking; developing and using models; constructing explanations; evaluating and communicating information	•The impact of non-sustainable agriculture •The silence around Ella May's murder and the 1929 textile workers' strike •What is pellagra? •Possible causes of pellagra •Bias in scientific investigations •The ethics of conducting experiments in prisons •Connections between pellagra and poverty •Implications of the high rates of pellagra among females and specifically Black females
Pellagra, Diabetes and Obesity	1	Maps: Pellagra (Marks, 2003) and Diabetes Type II (Center for Disease Control website)	Evaluating maps Analyzing and interpreting data; constructing explanations	•Similarities between the pellagra and diabetes/ obesity epidemic •Factors that contribute to high incidence of diabetes

Addressing Food Inequity Today		Data from ethnographic study of a food distribution center (Kolavalli, 2019)	Gallery Crawl and discussion Evaluating and communicating information	• Perceptions that food distribution volunteers have of food aid recipients • Underlying causes of food insecurity
Sickle cell anemia (SCA) as a model of a "raced" disease	2 3	Maps: Global distribution of SCA Visual: current education research on genetics instruction	Analyzing maps, re-evaluating previous conceptions re: SCA; Discussing current research Using models; analyzing and interpreting data; engaging in argument from evidence	• SCA as a disease with African origins • Human migration and sickle cell genes • New knowledge of multiple haplotypes alters conceptualization of SCA as "raced" disease • Framing genetics instruction in non-raced ways • Curriculum standards and testing
Defining race	2 3	Diagrams: the evolution of skin color; 18th and 19th century; craniometry classification systems Images: Enslavement and Colonization	Pair and share conversations; large group discussion Engaging in argument from evidence; obtaining, evaluating, and communicating information	• What is race? • Does discussing race in a science classroom reinforce race as a biological construct? White supremacy in society today
Engaging Students in Justice Issues	3	Guiding questions	Analyzing NGSS or state Standards; cooperative lesson planning; presenting participant-designed units	• Connections between NGSS or state standards and science-oriented justice issues • Topics that engage students and acknowledge/support them as agents of change

Linking the Past and the Present: Epigenetics	1 3	Diagrams of epigenetic mechanisms Video: Epigenetics Images, data and maps: A new perspective on Diabetes and the Pima	Evaluating and discussing historical events and recent scientific findings Using models, analyzing and interpreting data, constructing explanations	• Epigenetics is a confusing concept • Connections between famine in previous generations the current diabetes epidemic
Investigating Inequitable Access to Advanced Courses	2 3	Department of Education Office of Civil Rights website	Finding and analyzing equity data for individual schools and districts; presenting findings; brainstorming solutions Analyzing and interpreting data; constructing explanations	• Racial inequities in access to advanced science and math coursework • Potential ways to raise awareness and increase opportunities for marginalized students • Other areas of inequity (discipline disproportionality)

The instructional sequence

A historical case study designed to support teachers' awareness of systemic factors that contribute to health disparities anchors the first phase of the HLT. To launch the case study and support teachers' engagement in the activity, a brief (two page) biography was developed for participants to construct a timeline of the life of Ella May, a local mill worker. Ella May left the Appalachian Mountains with her family when employment in the logging industry was no longer available and became a leader in the textile labor movement; she was murdered by a white mob during attempts to integrate a historically significant strike (Horton, 2017). According to family accounts, prior to her murder she gave birth to nine children, two of whom died of pellagra (Horton, 2017). We anticipated teachers would discuss the impact non-sustainable practices had on the Southern Appalachian region and Ella May's family. In the county in which participants teach, Ella May's murder and the labor movement are rarely acknowledged controversial subjects and we expected some teachers might question why they were unaware of this incident while others would be hesitant to discuss it. We predicted that few, if any, participants would be familiar with pellagra, prompting a taken-as-shared goal to learn about more about the disease and its connections to the textile industry.

Pellagra first appeared in the U.S. in 1902 and by 1907 scientists and medical practitioners throughout the Southeastern U.S. were seeking its cause (Etheridge, 1972). We developed narratives describing early investigations of pellagra, and designed questions to prompt participants to discuss the role that investigators' previous experience and funding sources played in their research (LG 1). Original reports of investigations by public health researchers were incorporated into the case study (Goldberger, 1916; Goldberger et al., 1915; Goldberger & Wheeler, 1920). As participants analyzed historic experiments and presented their

findings, we anticipated that discussions about the identity of persons experiencing pellagra and the ethics of conducting medical research in prisons, mental hospitals, and orphanages might occur (LG 1). Public health survey data offer additional evidence about the pellagra outbreak. We predicted teachers would question sampling methods that excluded non-white individuals from public health studies (LG 2). An activity was designed for participants to transfer historical data to electronic spreadsheets. We expected that graphs created during this exercise would prompt discussions about the negative correlation between income and incidence of pellagra (LG3).

In 1937, niacin was identified as the nutritional factor missing in the diet of those experiencing pellagra. We anticipated teachers would use models of cellular respiration to discuss how nutritional deficiency produced symptoms of pellagra and the role that fortification of wheat and cornmeal played in ending the epidemic (LG3). We designed the final portion of the case study to include a map detailing the extent of pellagra across the Southeast and a graph revealing the disparate rates of pellagra-related death for Black females and Black males (Marks, 2003). We hypothesized teachers would make connections between these data and racialized economic disparities in the Southeastern U.S. during the Jim Crow era (LG3).

The second phase of the HLT was designed for teachers to compare the map from the previous activity with maps related to the current epidemic of Diabetes Type II. This activity was developed to support teachers' awareness of persistent patterns in health disparities across the Southeastern United States. We predicted that teachers would recognize similarities in the geographic and ethnic distribution of pellagra and Diabetes Type II. We also anticipated they would wrestle with the fact that pellagra was caused by nutritional insufficiency, but Diabetes Type II is thought to be influenced by a combination of genetic and environmental factors

including excessive caloric intake. We expected teachers might discuss this contradiction and question whether other conditions endemic to the Southeastern United States might link these two diseases.

Building on predicted discourse linking pellagra and the diabetes epidemic, the next phase of the HLT encourages participants to think critically about efforts to alleviate food insecurity (LG 3). Accordingly, this phase of the HLT incorporated a task to challenge teachers' perceptions of individuals seeking food aid. Vignettes excerpted from an ethnographic study of a food aid program (Kolavalli, 2019) were mounted on poster paper and displayed around the room. For example, one vignette described a conversation between a food aid recipient and a food aid volunteer during a mandatory class on nutrition. When asked to develop a healthy eating goal, the seventy-year old African American male food seeker stated "My goal is to get a quarter of a million dollars. Then I can eat what I want!" (Kolavalli, 2019, p. 104). We envisioned that this activity would challenge teachers' perceptions of individuals seeking food assistance and predicted teachers might engage in discourse about their varied perspectives.

The subsequent phase of the HLT was designed to support teachers' awareness of the role identity plays in who is recognized and celebrated as a scientist (LG 1). We designed an open inquiry exercise in which teachers would use the internet to find facts about James Watson and Ernest Just. Over the last thirty years, Watson, a white male known for his role as the co-discoverer of the double helix structure of DNA, has made numerous pejorative statements about intelligence, genetics, and persons of African descent. We expected few high school teachers would be familiar with these statements and might discuss how this information affects their perception of a once-heralded scientist. We also predicted that few teachers would be familiar with Ernest Just, an African American marine biologist whose ground-breaking research in the

early 20th century has not been recognized widely (Manning, 1985). We anticipated that teachers would discuss their lack of knowledge about Ernest Just and might wrestle with how to discuss James Watson's statements with students.

The next phase of the HLT incorporates visual diagrams to support teachers' understanding of epigenetics. Current findings suggest that environmentally induced changes in the epigenome may be passed on to subsequent generations (Waterland & Jirtle, 2003). We expected participants, especially those who teach Biology, to discuss ways recent discoveries contradict state mandated content standards. Building on this introduction, we incorporated maps and data to tell the story of the Pima, a Native American tribe whose high rates of Diabetes Type II have been linked to famine in the early 20th century (Duster, 2015). In a previous study, teachers with limited science knowledge struggled to understand the concept of epigenetics framed in an environmental justice context. This portion of the HLT was intentionally designed to make the connection between epigenetics and an environmental factor more explicit and to capitalize on participants' recent introduction to food inequities in the Southeastern U.S. We anticipated that teachers might make connections between periods of famine and populations experiencing high rates of diabetes and question narratives that attribute Diabetes Type II solely to individual and group behaviors (LG2).

The environmental justice movement began in the state in which participants teach, however, environmental justice, like labor movements and pellagra, is rarely discussed in schools or classrooms in this area. The next phase of the HLT engages teachers in tasks designed to support incorporation of environmental justice topics into classroom instruction (LG3). Accordingly, we designed a visual presentation to introduce teachers to the event that sparked the movement birth of the environmental justice movement in a nearby county (McGurty, 1997).

The contamination of local drinking water by coal ash is a current topic of concern; we anticipated that teachers might make connections between these topics. A subsequent task was developed to provide opportunities for teachers to design lessons addressing issues of environmental justice through content instruction. This phase of the HLT was intentionally designed to increase teachers' knowledge of the intersections between standards-based curriculum and social justice. We expected teachers might discuss opportunities to engage students in learning about social justice issues through science instruction.

Up to this point, race was not a specific focus of any portion of the workshop . Race is central to the creation of inequities (Bell, 1992, Ladson-Billings & Tate, 1995), and raising awareness of inequities created and supported by the scientific enterprise is a central emphasis of CSC. Accordingly, the final parts of the HLT was designed to provoke discourse around science teachers' conceptualizations of race. The first activities that centered race were developed to disrupt false ideas about sickle cell anemia (SCA), a disease often framed as an "African," "African American," or "Black" disorder in textbooks and classroom instruction (Donovan, 2014; Morning, 2011) (LG2). To elicit and correct misconceptions of SCA as a "raced" disease, our design incorporated a sequence of maps to be revealed in a pre-determined order. We anticipated that this information would disrupt previous frameworks and provoke discourse regarding how revised instruction about SCA might impact students' ideas about race. To confront science teachers' discomfort when discussing race, a task was designed with data from a study by Sheth (2019). Teachers would be told about an incident that occurred in a classroom during which a Biology teacher was asked, "Why are we not all of the same race?" (p. 37). We designed a task in which participants would share their own answer to the student's question

with a partner to elicit teachers' thoughts and create a platform in which a discussion about the social construction of race could occur.

Data Analysis

Atwater (1996) describes social constructivism as an important lens through which those conducting research involving "culture, class, disability, ethnicity, race, discrimination and power in science classrooms" can focus on the "making of meaning by those engaged in science learning and teaching" (p. 830). Accordingly, we draw on theories of social constructivism to make sense of the possible growth in collective critical consciousness and CSC during the workshop and understand how the instructional sequence was realized. Theories of social constructivism acknowledge that learning is an organic, auto-regulated series of re-organizations (Steffe, von Glasersfeld, Richards, & Cobb, 1983; Glasersfeld, 1995) occurs as individuals participate in and contribute to the learning of the classroom community (Bauersfeld, 1992; Cobb & Yackel, 1996). Specifically, we draw on a theoretical framework developed by Cobb & Yackel (1996) called the emergent perspective, which casts learning as both an individual and social accomplishment simultaneously. From the Emergent Perspective, researchers describe the collective learning of a classroom community by documenting the classroom mathematics practices that emerge as teachers and students interactively constitute the mathematical ideas that become taken-as-shared. An analysis of collective learning is complemented by an analysis of individual student's learning as they participated in and contributed to the emerging mathematical practices. For the purposes of this article, we adapted the Emergent Perspective framework to document how a group of science teachers developed taken-as-shared ideas rather than mathematics practices.

Data Collection

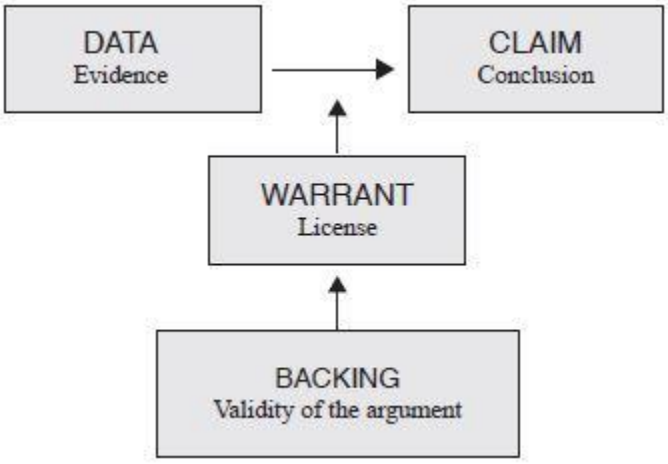
Data collected during the PD workshop informs the findings reported in this article. Group discussions involving all participants were audio recorded. Transcripts of these discussions were analyzed using the method described below. Discussions among small groups of participants were also recorded when possible. Transcripts of small group discussions, pre- and post-workshop interviews, design team meetings, and written participant reflections along with other workshop artifacts were reviewed to confirm and clarify the themes outlined below.

Analysis Method

The method we used to analyze the collective development of critical awareness among this group teachers employs an adaptation of Toulmin's (1958) argumentation model to document the structure and function of the utterances that occur across an extended period of instruction (Rasmussen & Stephan, 2008; Stephan & Akyuz, 2012). The simple structure of Toulmin's (1958) model is pictured in Figure 1. According to Toulmin (1958), an argument consists of three parts: 1) a claim; 2) data provided as evidence for the claim; 3) a warrant or explanation (often unspoken) that connects the data to the claim. If a claim is challenged or the speaker perceives that her argument may be challenged, backing may be needed to clarify the validity of the argument in the face of the challenge. In addition, qualifiers may be added to clarify, extend, or limit the scope of a claim.

Figure 2

Toulmin's (1958) model of argumentation.



While Toulmin (1958) described the components of an individual's argument, analyzing group conversations is more complex. Revising Toulmin's (1958) model, Krummheurer (1995) developed a model to evaluate mathematical arguments. Stephan and Rasmussen (2002) further adapted this model to analyze collective student discourse across several periods of instruction. To assess the viability of an instructional theory, Cobb et al., (2003) recommend that researchers examine the understandings that emerge within a group as well as the way that individual students (in our case teacher participants) participate in and contribute to the discourse. Case studies of the development of critical awareness among individual participants are forthcoming, but space prevents us from including them here. In this article, we report an analysis of the discourse that occurred as we implemented the HLT and discuss evidence of the emergence of critical consciousness and critical science consciousness among this group of teachers.

Following the method described by Stephan and Rasmussen (2002), we created transcripts of all small and large group conversations that occurred across the four days of the workshop and analyzed the transcripts in three phases. First, we coded all large group

discussions using claims, data, warrants, and backings. We examined the conversations for challenges and noted those along with the claim under challenge. Phase 1 produced a 49-page argumentation log summarizing the structure of the large group discussions that occurred across the four days. The argumentation log created in Phase 1 was taken as data in Phase 2. We analyzed the log to determine when or if 1) claims were no longer challenged; 2) claims changed position within the argument scheme and were employed as data or backing for a new claim; and 3) warrants or backing no longer needed to be made. According to Stephan and Rasmussen (2002), these shifts in discourse reveal that an idea has become taken as shared by the group. Across the course of the four-day workshop, teachers returned to several themes. In Phase 3, we reviewed the taken as shared ideas and organized them within categories in chronological order. Grouping the conversations in this way revealed three themes (Table 3) which we discuss below.

In this article, we document the collective critical consciousness development of this group of teacher participants as we implemented the HLT described previously. In addition, we describe our analysis of the data that will feedback to inform revisions of the instructional sequence. Applying the methodology described by Rasmussen & Stephan (2008), we propose that the taken as shared ideas provide a picture of the actualized learning trajectory as the HLT occurred in practice. We acknowledge that this analysis of collective learning is only reliable if participants can engage in discourse that welcomes questions, disagreements, and alternative explanations. The participants' familiarity with the setting, each other, the curriculum specialist, and instructor appeared to support open discourse during the workshop. Science teachers in this district meet regularly throughout the year and have a collegial relationship with the curriculum specialist who has been employed by this district for fifteen years in varying roles. This group of teachers had engaged in a separate workshop with a larger group during the week prior to this

PD experience and demonstrated familiarity with each other and the setting. At the beginning of each CSC workshop session, this group engaged in reflective, creative warm-up activities to support the place-based emphasis and create an atmosphere conducive to open discourse. Finally, as a former teacher in the district, the instructor shared a common experience with participants and positioned herself as a co-learner within this group of science educators.

Table 3

Taken as shared ideas

Theme	Taken-as-shared Ideas	Contested Ideas, not Taken-as-Shared
Individuals or Systems?	Females were more likely than males to experience nutritional deficiencies due to the impact of gendered roles on food access. The combined effects of gendered roles and racial discrimination contributed to high rates of nutritional deficiencies for Black women.	Oppressive economic systems, as opposed to individual behaviors, create disparate health outcomes for marginalized groups.
Defining and Acknowledging Race	Race is not just about skin color. The creation of racial categories is a form of oppression that has impacted groups and individuals in ways that should not be ignored.	
Teaching as Liberation	People who identify as white struggle to understand racial oppression because they have not been subject to it. Students may know and understand more about oppression than their teachers; differences between teachers and students in how oppression is experienced may create tension in classrooms. Teachers can support students and challenge systems by addressing economic and racial oppression through their science instruction.	

Findings

Three themes emerged during the process of data analysis (Table 3). In this section, we describe ideas that became taken-as-shared relative to each theme. In addition, we note concepts that elicited sustained discourse, yet lack sufficient evidence to state that the idea became taken-as-shared. For select ideas, we include a portion of the large group conversation and our analysis of the claim(s), data, warrants, and challenges to give the reader a deeper understanding of how we came to consider an idea to be taken-as-shared among this group of teachers.

Theme 1: Individuals or Systems?

To initiate the instructional sequence, participants were introduced to a textile worker, mother, and union organizer whose murder ended a six-month long labor uprising. Although her death made international headlines, only one participant in this study acknowledged knowing the story of Ella May. A task during which teachers constructed a timeline of her life using a brief (2 page) biography as a tool was designed to support the critical place-based structure of the workshop and disrupt the silence among area residents about labor issues and racial division. This task was also designed to launch an interrupted case study during which participants engaged in science practices to explore the pellagra epidemic. During each part of the case study, teachers collaborated in small groups to form hypotheses, analyze and interpret data, and construct explanations that they communicated to the larger group before moving on to the next section. As participants grappled with disparate impacts of pellagra among varied groups, and reflected on their significance in broader contexts, the following ideas emerged:

- Females were more likely than males to experience nutritional deficiencies due to the impact of gendered roles on food access.
- The combined effects of gendered roles and racial discrimination contributed to high rates of nutritional deficiencies for Black women.

- Oppressive economic systems, as opposed to individual behaviors, create disparate health outcomes for marginalized groups.

Females were more likely than males to experience nutritional deficiencies due to the impact of gendered roles on food access. During an activity designed to reveal the effects of income and gender disparities on the incidence of pellagra, participants transferred tabular data from historic public health surveys into an electronic spreadsheet to produce a graph for analysis (Figure 3). When asked to describe what the graph revealed, a teacher shared an interpretation that income, as opposed to gender, was the important variable.

Charles: The point is, regardless of gender, as income goes up, rates of pellagra seem to go down… Income seems to be the defining variable here, not gender.

Instructor: So the trend line goes down. Is there a difference in gender?

Charles: Actually, yes. Females showed a more dramatic drop. Females started high and then they got very, very low. Males started lower, but they still went down.

Regina: I think that… for the mom, you know, they would make sure that their children were fed so they would definitely be more malnourished than the rest of the family.

Marie: So why were the men lower?

Regina: Culture… It reminds me of Southern Baptist church events. You know, where you would go and the men would eat first, and then the children, and then the women.

Charles: I thought the custom was, even though women had no rights, women always came first, though.

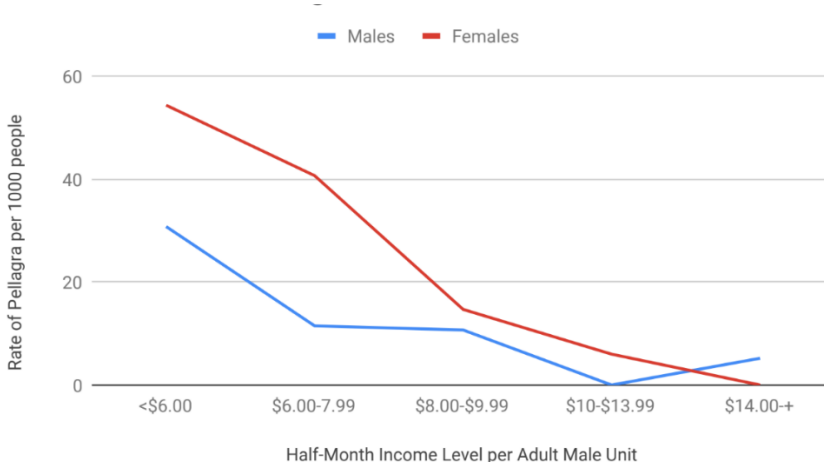
Regina: Not in my experience, but that could be wrong.

Charles: Ok. ‘Cause like the male was always expected to give up their seat for women.

Regina: Yeah, seats and things (laughing).

Figure 3

Rates of Pellagra as a Function of Gender and Income



In terms of Toulmin's argumentation scheme, we interpret Charles to be making a claim that the defining variable determining rates of pellagra is income, not gender. As data to back this claim, Charles pointed out that the slope of the trend lines for both genders is negative ("as income goes up, pellagra goes down"). The Instructor's question ("is there a difference in gender?") required Charles to provide further data and led him to reconsider his original claim. At this point, Regina introduced a new claim: females experienced pellagra at higher rates than males due to cultural norms. In response to Marie's question ("so why were the men lower?"), Regina offered personal experiences with gendered practices as data. In addition, Regina's statement that women might be malnourished because they provide food for their children before feeding themselves served as a warrant connecting gendered cultural practices to the incidence of pellagra. Charles issued a challenge, citing practices sometimes referred to as chivalry that prompted Regina to provide additional data that although a man might give up a seat to a woman, that doesn't mean she receives the same amount of food.

As the conversation continued, the Instructor suggested they review a picture of a family dinner table from an earlier part of the case study (Figure 4). As the group examined the picture, a participant pointed out that the mother appeared to be distracted by a child she is feeding. Charles acknowledged that the father was "just eating." Consequently, the picture became data to support Regina's claim in this region access to food among females was limited by cultural practices. In subsequent discussions, the concept that *women experienced pellagra at higher rates due to gendered practices* was incorporated into the discourse as data, confirming that this idea had become taken-as-shared by participants. Tools that supported this idea becoming taken as shared were the graph created by participants and the historical photograph.

Figure 4

Family Meal in a Mill Village Home, c. 1920

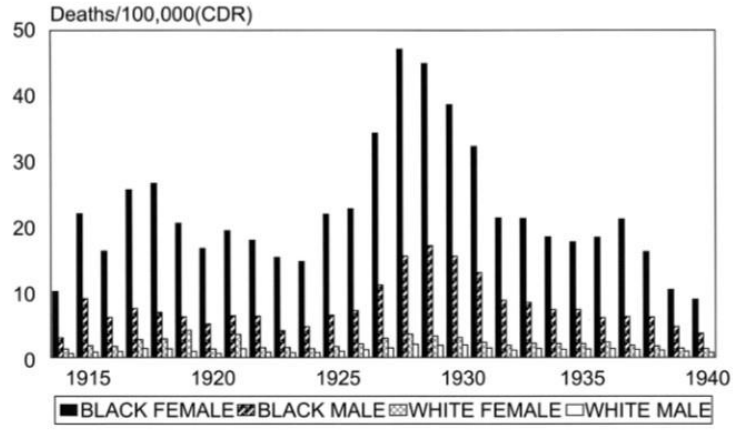
Note. Retrieved from U.S. National Library of Medicine, 2020 (https://www.nlm.nih.gov/exhibition/phs_history/contributions.html) In the public domain.

The combined effects of gendered roles and racial discrimination contributed to high rates of pellagra for Black women. In the final section of the case study, teachers were provided

with data from a recent study by Marks (2003). This literature includes a graph (Figure 5) constructed from Census data that reveals that among four groups, Black females, Black males, white females, and white males, Black women experienced the highest number of deaths per 100,000 individuals. Deaths from pellagra occurred among white females and males at much lower rates than Black persons of either gender. Analysis of small group discourse offers insight into the impact of this tool on the groups' collective learning. While similar discourse occurred in both groups, only one of the conversations is included for brevity.

Figure 5

Crude Death Rate (CDR) from Pellagra by Race and Gender



Note. U.S. Census Bureau Records, Mortality Statistics, 1914-1940. Marks, (2003).

Charles: I'm guessing the increase among the black population is due to segregation, and less access to resources, and poor conditions.

Patrick: Oh, without a doubt. Yeah. I mean, even in the mill villages, they were segregated and… the [sharecroppers] still lived in the tenement shacks… So there was segregation.

Instructor: (Joins the group and points to the graph) What's happening here?

Charles: Well, it seems they all increased and decreased at the same rate, just the Blacks are just always higher…. Although the whites are so low, it's kind of hard to tell.

Regina: I'm wondering what specifically about the Black females made them have such a higher mortality rate.

Patrick: Remember we talked about how they ate last or either they fed the babies first.

Charles: We already determined that the females had a higher rate of [pellagra] and that on top of that they're (pausing to whisper) *black.* It just compounded it.

Patrick: Yeah, yeah. Looking at graphs and everything.

Charles: That's what I would say - just societal things and how they were treated. So basically, the black females were members of two groups that are discriminated or treated lesser.

In response to the Instructor's question ("what's happening here?"), Charles statement that "they all increased and decreased at the same rate, just the Blacks are always higher" constitutes a claim for which the participants' reasoning with the graph provides evidence, or data. It is interesting to note that unlike the previous discourse in which Charles focused exclusively on the downward trend for both males and females, he now notes that although the deaths for all groups follow the same trendline, one racial category is "always higher." Prior to the Instructor's query, Patrick and Charles offered warrants linking the data to the claim as they acknowledged that racial segregation included inequitable access to resources. Regina's statement (I'm wondering…) led Charles to posit an additional claim that "black females were members of two groups that are discriminated." Both Patrick and Charles offered as data the taken-as-shared idea that gendered practices restricted females' access to food established earlier. The impact of race on Black women's access to resources also served as data to support a similar claim in the large group conversation a few minutes later:

Instructor: Why were black women dying at these [high] rates?

Trey: Lowest paid.

Patrick: Well, we also started talking about… Who said that the women ate less generally if they had children because they would be feeding their children?

Elena: And other people's children.

Patrick: Plus, maybe they were working.

Elena: And not in every mill, just thinking of those employed by mills, not every mill employed African Americans period.

In this exchange, Trey claimed that Black women experienced high rates of pellagra due to low pay (data) and Patrick reminded the group of their previous conversation about gendered roles (additional data for the claim). Elena's comment "other people's children," a reference to the positionality of Black women as caretakers of white children, and her statement that "not every mill employed African Americans" provide a qualifier to the claim, and taken-as-shared understanding, *the combined effects of gendered roles and racial discrimination contributed to high rates of pellagra for Black women.*

A broader concept that underscored the discussions described above is the idea that *oppressive economic systems, as opposed to individual behaviors, create disparate health outcomes among marginalized groups.* Analysis reveals, however, that although this idea provoked robust discussion and shifts in teachers' thinking, given the criteria described in the Method section it is not possible to state that it became taken-as-shared among participants. As described earlier, graphs created by the participants revealed a strong negative correlation between income and incidence of pellagra for white males and females (Figure 2); we anticipated this tool would provide visual evidence to support the idea that poverty which occurred due to low wages led to health disparities including pellagra. As the group assembled to describe their

findings, the Instructor was surprised to hear a teacher say that the graph made it appear that poor people cause pellagra.

Instructor: But could you say poverty causes it?

Trey: Yeah, I mean absolutely. It just depends on how you interpret the graph and who is saying it – what science literacy you have to interpret the graph, right?

Instructor: So, you're saying that somebody could look at this graph and say that poor people are causing [pellagra].

Lindsay: So, they stay away from poor people. They're dirty, or whatever.

Marie: It would perpetuate the divisiveness.

The participant's statement that "it looks like poor people cause pellagra" constituted a claim challenged by the Instructor's question, "Could you say that poverty causes it?" Warrants connecting the data (the graph showing an inverse relationship between income and incidence of pellagra) to their colleagues' initial claim were offered by other participants. In addition, the participants' claim that poor people "caused" pellagra revealed a misinterpretation of a causal, as opposed to correlative, relationship between the variables, an inaccuracy reinforced by the instructor when she asked "could you say poverty *causes* it?"

During the subsequent section of the case study, teachers learned through the case narrative that as cotton prices increased following World War I, incidence of pellagra decreased. When prices fell, a resurgence of pellagra prompted an appeal by the U.S. President to Congress to provide aid to famine-ravaged Southern states. This offer of aid was rejected by Southern leaders who argued that the increase in cases of pellagra was due to excessive regulations and ignorance about the importance of a well-balanced diet among those experiencing poverty (Etheridge, 1972). Teachers were prompted to consider if pellagra was a disease of ignorance,

the economy, or both. Following small group discussions, Patrick's group made a claim that pellagra is caused by both ignorance and the economy:

> Patrick: We agreed the economy ***and*** ignorance, which was brought in by Charles talking about the poor people. They didn't know what pellagra was, nor did they know where it came from – which, ignorance again.
>
> Trey: They would just do what people told them like, "don't eat corn."

In the epidemic's early years, scientists speculated that spoiled corn might be the cause. Trey provided data to back the group's claim, suggesting that Southerners who lacked knowledge believed erroneous claims and acted out of ignorance. As the discussion continued, a counter claim was made:

> Lindsay: What do you do? There's no other food. I mean, you're starving. You've got to eat. You have to eat. I've gotta feed my children. This is all I have. I mean, even if I as a mother knew… I have a hungry child that's crying… I'm still gonna feed my child.
>
> Charles: If they knew what it was though, and they knew that it was serious. I'm sure they could've re-evaluated their way of thinking.

Lindsay invoked her personal experiences as a mother to support her claim that parents will do what they need to keep children alive. Charles' challenge, however, provided further backing to Patrick's initial claim. At this point, the participants seemed unable to reach consensus. Remembering a conversation that occurred prior to the large group discussion, the Instructor elicited another response:

> Instructor: What are you thinking, Marie? I see your wheels turning.
>
> Marie: I mean, I'm thinking like what you said, Charles, they know that diet… is an issue. You need to eat a more varied diet…
>
> Trey: That exists today.
>
> Marie: Yeah, that exists today. Because we were talking about that earlier. I don't know if y'all heard. But if… I'm at work all day teaching and I go home, I could cook a meal for my family. But if I'm poor, I'm going to maybe go

> straight to a second job because I need more money and I spend no time at home so I can't make food even though I know I need to feed my children healthy things. I can't. Like there's still a barrier even though you know that it's bad for you. There's still some economic barriers that keep people from being able to do the right thing or feeling like they could ever do the right thing because they don't have the money. They don't have the time.

Patrick: A liter of soft drink is as cheap as a liter of milk.

Charles: Don't you think it's a matter of what you value and what you feel is important?

In addition to providing a claim that "economic barriers" prevent parents from preparing healthy meals, Trey and Marie shifted the discussion from the past to the present. Echoing Lindsay, Marie personalized the discourse, offering as data a contrast between her own circumstances and those of a parent experiencing poverty. Patrick invoked the cost of soft drinks and milk as additional data to support the claim that economic barriers prevent persons from purchasing health food. This claim, however, was again challenged by Charles. Later, the focus returned to individual behavior as Lindsay suggested that some persons experience nutritional deficiencies because "[they] are so picky that they only eat certain things." While several participants offered additional data to support Marie's claim, others vacillated, emphasizing that knowledgeable persons make good food choices regardless of income. In view of these challenges, we cannot state that among this group of teachers the idea that *oppressive economic systems, as opposed to individual behaviors, create disparate health outcomes among marginalized groups* became taken as shared.

Theme 2: Defining and acknowledging race

In an examination of inequitable systems, race and racism are central constructs (Bell, 1992; Ladson-Billings & Tate, 1995). Accordingly, the tools and tasks employed throughout the workshop provoked multiple conversations around these issues. Analysis of participants'

discussions over the course of the PD experience provide evidence that the following ideas became taken-as-shared:

- Race is not just about skin color.
- The creation of racial categories is a form of oppression that has impacted groups and individuals in ways that should not be ignored.

Race is not just about skin color. Although a design decision was made to address the social construction of race on the final day of the workshop, a conversation about the origins of racial categories occurred on Day 2 when a teacher noted that the term "negro" was present in the case materials. As participants discussed how they might address this term in their classrooms, one teacher expressed discomfort with the concepts of "Black" and "white:" "I have a hard time when we classify people as Black or white… I think it's stupid… Why do we do that? …excuse me, we are all humans." Seeking to elicit participants' understanding of the construction of racial categories, the Instructor asked the group, "What is white?"

> Lindsay: What is white? …explain to me.
>
> Elena: The absence of color.
>
> Lindsay: Excuse me, if you saw my DNA I have more Black in me than I do white… So it gets very complicated. It's what you choose, you know, your culture, how you're brought up.

In response to the Instructor's question ("what is white?"), Lindsay made a claim that "race is something you choose," offering as data results from a personal DNA kit that contradicted the racial classification by which she is identified and employing the notion of culture and "how you are brought up" as warrants to explain the apparent contradiction between her claim and the data. Hoping to clarify these contradictions, the Instructor probed further in the whole group discussion:

> Instructor: Is it biological?
>
> Lindsay: Is race biological? No. Race is not biological.

Trey: I would say it's mostly not. I mean there's some biological aspects to it… but when we say black and white terms - like black and white and mulatto – just like all the different levels were culturally developed to kind of give how much of a person you were… like what was your level in society.

Lindsay: Absolutely. It is a thing we developed so we can put people someplace and say this is who you are.

In this discussion, Lindsay made a claim that "race is not biological." Trey's statement, "it's mostly not," suggests a qualifier to her claim. The idea that racial classifications were created to determine a person's "level in society" is offered by both teachers as data. At this point in the workshop, the Instructor acknowledged that the construction of Whiteness was tied to the Atlantic Slave Trade and then, after assuring participants they would return to this complex topic later in the week, shifted the conversation to a different subject,.

On the final day of the workshop, using maps that depict the global distribution of multiple gene variants associated with sickle cell anemia (SCA), participants discussed SCA as a "raced" disease. The instructor also described findings from research that examines how genetics instruction impacts students' conceptions of race (Donovan, 2014; 2016). As a final activity, the instructor asked participants to consider how they might respond to a classroom situation described by Sheth (2019) in which a Biology teacher is asked by a student, "Why are we not all of the same race?" (p. 37):

Instructor: "Well then, why aren't we just all considered to be one race?" My question is - how would you respond to [a] student if that question is asked to you this Fall? …turn to your job alike [partners] group and discuss what you would say to that student.

After several minutes of paired conversation, the instructor solicited ideas from participants. One pair shared a website containing extensive information about the evolution of skin color. As other pairs shared similar ideas, the instructor posed an additional question:

Instructor: [The student] asked ‘why aren’t we all one race’ and what have we answered… What have we addressed?

Trey: We’ve answered… just skin color.

Elena: But not race.

During the conversation that followed, participants returned to various explanations for why race exists, noting different “norms” and “values” among cultures and the practice of differentiating persons by skin color for “millenia” that began as soon “as people began noticing a difference.” As the conversation slowed, the instructor projected a collage of images from slave auctions and the colonization of Africa onto the screen at the front of the room. The discussion paused as participants studied the images. Using these images as a backdrop, the instructor explained that the constructs of Black and White were created by Europeans and European Americans, including those in the sciences, to justify the Trans-Atlantic Slave Trade and colonization of the Southern Hemisphere (Kendi, 2016; Memmi, 2000). She acknowledged that it is not wrong to discuss the evolution of skin color with students, but it is an incomplete answer to the question posed by the student. Paraphrasing Coates (2015), she clarified that race is the offspring of racism, not the parent. Trey agreed, stating “As a Biology teacher, [addressing the social construction of race is] within our locus of control. This is what we can give [students], we can offer them… knowledge and guide them through.” Trey’s claim that teachers can provide students with important knowledge by addressing the social construction of race was not challenged by his peers. During post-interviews, teachers discussed race in varied and complex ways indicating that the idea that *race is not just about skin color* had become taken as shared.

The creation of racial categories is a form of oppression that has impacted groups and individuals in ways that should not be ignored. On Day 2, as the instructor sought to shift the conversation away from the unplanned discussion on the construction of race and back to the case study (described above), she was interrupted:

Regina: It's too late to ignore it.

Instructor: Oh, tell me what you mean.

Regina: We can't just do away with it right? We can't just say we're just people… I've said that so many times… but I think there becomes a point where it's ignoring what people have experienced… We are all just human,but ignoring the classifications that have systematically oppressed people for thousands of years. At some point if we just ignore, it becomes even more harmful than those classifications themselves.

Applying Toulmin's framework, the claim was made that "ignoring the classifications that have systematically oppressed people" is harmful. Regina's claim was not challenged, however, limited discourse occurred around her assertion as the instructor prompted a conversation around an issue raised by a participant on the previous day. On the first day of the workshop, a participant was asked to expand on his statement that he hoped to learn how to create a more inclusive classroom during this workshop. In response, he explained that the school where he teaches sits at the base of a hill on which a private landowner flies a large Confederate flag visible to all students who arrive by bus. Trey's school setting did not become a topic of discourse when he first described it, but on the second day of the workshop, the instructor returned to the symbol above Trey's school:

Instructor: [Trey] made that connection between "I want an inclusive classroom" and [the Confederate] flag… What does that flag… what role does it play?

Trey: So, coming and going from this place every day, it's like telling them that this is a place that they're not welcome.

Instructor: Who's they?

Trey: People who were oppressed when it was the Confederacy. In that sort of time and age and ideals. That's what it represents to them and to some other people as well. But… that is what I would assume that they might think.

Instructor: So are we back to [intent and impact]? I mean …we don't know the intent of the person who lives in the home who has the large flag.

Trey: I don't know what color they are.

Lindsay: This goes back to the assumptions. And you gotta be very careful about that… I try not to assume anything until you talk to them.

Instructor: So talking to that individual, hold on. Before we go there. Trey, you said you don't feel that they, you said "persons who feel oppressed," feel welcome. …What do you guys think? Do you think that we're making a huge assumption to say that that flag may make some of the children that attend [that high school] uncomfortable?

Lindsay: I don't think it's an out of bounds assumption. …I'm sure that person has a reason that isn't 100% innocent for having that flag there.

Marie: Well, what's more important? Intent or impact?

Charles: I think it might be a little unfair to assume that just because they have it up they're trying to make a statement against Black people… I had a kid in my class who …frequently [wore a shirt displaying the Confederate Flag] and half my class is Black, and no one ever said anything. In fact, they all got along really well.

Instructor: But …I think that the flag for me was more a symbol of "I want my classroom to be more inclusive" and I know there's places that I'm wrestling with that happening… Marie… what are you thinking about impact?

Marie: Yeah. Somewhat aside from the flag situation, if somebody says something that hurts someone else's feelings, but that person truly had no malicious intent whatsoever, should that person be reprimanded because someone else's feelings were hurt?

In response to the instructor's question, Trey made the claim that a large Confederate flag mounted on private property above a high school might make some students feel unwelcome. He offered as data that the flag represents oppression for some students at the school. Raising the question of intent versus impact, the instructor inadvertently directed the conversation toward of the property owner and away from the students entering their high school in view of a symbol of racial oppression. Charles' description of a class in which students who wore Confederate flags on their shirts and Black students "all got along really well" challenged Trey's claim that some students might feel unwelcome in the presence of a Confederate flag. Marie's challenge

minimized the potentially traumatizing situation, describing a circumstance “somewhat aside from the flag” in which “someone else’s feelings were hurt.”

On the final day of the workshop, following more extended discussions around the social construction of race described above, the instructor returned to the topic of whether teachers should address race in the science classroom.

Instructor: But if race is only a social invention… should we then ignore it and view all the students in our class as if you know they are all the same? Everybody is the same…

Regina: No! …Absolutely not. These power structures have been put in place and oppressed people for how long now? It is too late in the game to just say we’re good – we’re all the same.

Trey: “I don’t see color.”

Regina: Yeah, I don’t see color.

Elena: That’s the worst thing you can say!

Instructor: How?

Trey: You are just not acknowledging the issue. You are not acknowledging the issues that [persons of color] have had to deal with because of it.

Instructor: And can I throw another thing in there? [By avoiding race] we're not acknowledging oppression, but are we also [missing the opportunity to acknowledge] some incredible, beautiful things about the different cultures in the classroom?

Regina: Yeah.

Elena: I had not thought about that word, colorblind, and a student taught me this… [Another teacher] made the reference [in my classroom] to just being color blind. [She said,] “I just see all people, I just see you as a person. I'm just color blind. I don't care what color you are.” And a student who just has the richest complexion, I mean, just beautiful skin, she whipped around and said, “Well that's a crying shame because you're missing all this richness!”

Once again, the claim is made that it is too late to ignore race and Regina provides data that systems of oppression have had an impact on racial minorities that should not be ignored. Trey and Elena made an additional claim, asserting that the statement "I don't see color" is "the worst thing you can say," and Elena's provided data in the form of a student's response to a "colorblind" teacher to support their claim. During this discourse, no challenges occurred. In post-workshop interviews, participants discussed the importance of acknowledging the experiences of students of color. In addition, participants discussed personal experiences with race that they had not revealed during pre-interviews, providing additional evidence that among this group of teachers the idea that *the creation of racial categories is a form of oppression that has impacted groups and individuals in ways that should not be ignored* had become taken-as-shared.

Theme 3: Teaching as Liberation

As the teachers engaged in conversations around race, inequity, and oppression, they began to voice questions about how they might act on this new knowledge. Analysis of discourse around these topics indicates that the following ideas became taken as shared:

- People who identify as white struggle to understand oppression.
- Differences in personal knowledge and understanding of oppression between students and white teachers can create tensions in classrooms.
- Teachers should teach in ways that equip students to challenge oppression.

People who identify as white struggle to understand oppression.

On the second day of the workshop, as participants discussed what they had learned during their study of the pellagra epidemic, the impact of nutritional deficiencies on health outcomes became a springboard for participants to think about how economic and education systems may operate in tandem:

Instructor: So the millers… started [fortifying flour and corn meal with niacin] voluntarily by the end of the 1930s. And then… it became a USDA requirement based on what was going on in 1943.

Patrick: The War.

Instructor: Yeah. And we needed strong, healthy folks working in the defense factories. So then [it became] a federal requirement that all corn and… Marie?

Marie: But it still seems like, let's just give them just enough to get what we need out of them.

Regina: Well, we're still doing that today, I mean.

Elena: Right, I agree.

Marie: Clearly, like it's save all the money you can or just get what you can out of the people by giving them the bare minimum resources to get to where we need…

Regina: How can we minimize resources to maximize profits?

Lindsay: Because the rich want to stay rich and we are going to keep the poor, poor.

Instructor: So, that intrigues me. Just that idea of keeping the poor, poor. Can you draw any parallels to education?

Lindsay: Keep people uneducated. We don't let them... Don't let them... know too much.

Marie: Or be able to gain positions of power.

Elena: Yeah. 'Cause you don't know what you don't know.

Regina's claim ("we're still doing that today") echoed Marie's prior statement and was not challenged. In addition, the Instructor's question ("can you draw parallels to education?") elicited a claim that "we don't let [the poor]… know too much" or "gain positions of power," an assertion that was also not challenged. Although discourse around this idea was not sufficient to say that *controlling access to education maintains systems of oppression* became taken as shared, participants returned to this idea through a different lens later in the workshop.

On the final day of the workshop, as participants viewed images of a slave auction block and a map of Africa as colonized by European powers, the instructor encouraged them to

consider ways that depictions in popular culture of Africa as an uncivilized jungle influenced ideas about race. In response, they drew connections between systems of oppression and Whiteness:

> Marie: A lot of this is… hitting me so hard right now. And it's like, why did I never think this way? Because that's the way that white people in general are brought up is that… we're not exposed. We don't understand… We weren't brought up oppressed because we had the power.
>
> Elena: We were raised to believe that everything belongs to us.
>
> Marie: Yeah. And then when you think of the perspectives of the women in the food charity [activity]…
>
> Elena: The grandparents of the African American kid in my fourth period did not grow up [like I did].
>
> Marie: Like this is not news to groups of people that we consider minorities. This is not new. These are not new ideas. These are not new revelations. But they're new for me.

Marie supported her claim that we (implying white people) "don't understand [oppression]…because we had the power" with data that included her own lack of knowledge about oppression. Elena's corresponding claim that "[white people] were raised to believe everything belongs to us," incorporated data in the form of the depictions of slave auctions on a screen visible to participants. Neither claim was challenged, and the group built on these ideas in subsequent discourse, indicating that the idea that *people who identify as white struggle to understand oppression* had become taken-as-shared by this group of teachers.

Differences in personal knowledge and understanding of oppression between students and white teachers can create tensions in classrooms. As participants reviewed what Western science had discovered about SCA, the instructor highlighted Harvey Itano's role in the crucial discovery of an abnormal polypeptide chain. When she noted that Itano was unable to attend his own college graduation because he was interred by the U.S. government, Elena remarked that

she had recently learned about Japanese internment camps through a daughter's school assignment. Elena's frustration about this omission in her own education emerged as the teachers continued to discuss Whiteness and oppression:

Elena: …like we've talked about the educational standards. I mean we're told what…

Lindsay: [interrupting] to teach!

Elena: [continuing] …needs to be taught because some person in a windowless [room] decides, they just decide that students need to know this thing. Do they?

Instructor: And somebody decides that people don't need to know this thing.

Elena: Exactly! Like I'm a forty-seven-year old learning about Japanese internment camps!

Instructor: Marie, you said…Ooh, Elena, do you think that if you were a forty-seven-year old Japanese American, you would know about internment camps?

Elena: Absolutely, because I probably would have had grandparents in them.

Instructor: …Okay. And Marie you just said, 'This is new to me, but it's not new to...'

Marie: …groups of people that have been oppressed.

Instructor: So do we have children in our classrooms who are...

Marie: [sighing] in those groups of people.

Instructor: Do they know more about [oppression] than you and I?

Elena: Of course, of course
.

Instructor: Do you think that ever creates tension in our classrooms?

Regina: Absolutely.

Instructor: Tell me what you're thinking.

Regina: I'm just thinking …that some communities have a very different idea of the American dream and if it's accessible to them, and so that for them being told, 'Education is the way out' when they know otherwise does nothing for them. And then [teachers] being frustrated with them for not prioritizing an education

> when they have seen that it does not make a difference in the way that they're treated compounds the situation even more.

In response to the instructor's question, Regina made a claim that differences in knowledge about oppression between students and teachers creates tension in classrooms. Statements by Elena and Marie regarding knowledge that may be possessed by students who have experienced oppression served as data supporting this claim. The contrast Regina drew between the perceptions students may have of "the American dream and if it's accessible to them" and the frustration teachers experience when students fail to prioritize their education provided a warrant connecting the data (students have more knowledge about oppression than their white teachers) to the claim (these differences lead to tension in classrooms). Following Regina's lead, the instructor asked participants to consider what the statement, "Education is the way out," might communicate to students about their community. Regina's initial claim was not challenged and the subsequent discussion around "education as a way out" provided further support that the idea that *differences in personal knowledge and understanding of oppression between students and white teachers can create tensions in classrooms* was taken-as-shared by participants.

Teachers can support students and challenge systems by acknowledging economic and racial oppression in their science instruction. As participants debated the messages conveyed to students when education is characterized as a "way out," the instructor asked if it might be possible to frame education as a vehicle to change oppressive systems within communities as opposed to a way out of a student's community.

> Lindsay: How do you change the system? …you've got to have money and you've got to have power.
>
> Marie: So we need to change the people that have the money.
>
> Lindsay: Well, how are you going to do that?

Instructor: Great question to a bunch of educators.
Lindsay: Yes, because we don't have money or power.
Marie: Put this fire that we're all feeling in those children.
Lindsay: …you do your part in your classroom.
Marie: That's bringing it back to our locus of control.
Lindsay: Bringing it back to why I stay in the classroom.
Marie: Try to light some of these flames in your kids.
Regina: And also try to influence not only our kids but our peers to think this way as well.
Marie: Yeah.
Trey: Which isn't always easy.
Regina: No it's not.
Marie: …the solution is simple, but it's hard. I mean it's simple. Change the power, but it's hard.

In response to her own question, (how do you change the system?), Lindsay claimed that it takes both money and power to change the system. Marie's challenge ("so we need to change the people that have the money") led to an additional question (how do you change the people that have the money?) and a new claim by Marie that teachers have power to change the system by lighting "this fire" in our students. Both Lindsay and Marie offered data that this action is within a teacher's locus of control. Regina attempted to make an addendum to the claim, encouraging other participants to "try to influence …our peers to think this way as well." This addendum was challenged by Trey ("which isn't always easy"). The group did not challenge Marie's claim that teachers can encourage students to change systems and subsequent discourse suggests that the idea became taken as shared. The notion that participants might also prompt their colleagues to do the same, however, did not become taken as shared.

As participants continued to discuss systems of oppression rooted in economics and race, the instructor sought to bring the discussion back to science curriculum and instruction:

Instructor: Do these issues belong in the science class?
Marie: Yes.
Instructor: Are they in our curriculum?
Regina: No.
Elena: I think it's disguised.
Lindsay: I think it connects …with ethics. Definitely, to me …ethics, absolutely.
Trey: There's the opportunity for... If you read in between the lines for a lot of this. Now they won't have a standardized test question about racial social constructs, but we can justify the teaching.
Instructor: How can we justify it?
Trey: Well, we can use our teaching standards that [involve diversity]…
Instructor: So, we are evaluated on these issues even if they're not part of our [the testing system]?
Lindsay: [State Standard] 2.1: Analyze the interdependence of living organisms within their environments. We're all interdependent on each other.

In response to the instructor's question, Marie's affirmative answer constitutes a claim that economic and racial oppression can be addressed in the science classroom. Lindsay assertion that ethics and interdependence are in the curriculum and state standards, along with Trey's statement that teachers are evaluated on how they support diverse students provided data. No challenges were raised. Our analysis indicates that the combined idea that *teachers can support students and challenge systems by addressing economic and racial oppression through their science instruction* became taken as shared by this group of teachers.

Discussion and Implications for Future Research

Our goal for this PD workshop was to test an HLT designed to support practicing science teachers' critical consciousness and CSC. We drew on critical pedagogical frameworks and

research that reveals limited capacity among science teachers to address systemic inequities in and through curriculum and instruction. Input from the design team and previous experiences informed our decision to design an instructional sequence to explore systemic origins of disparate health outcomes. Our findings suggest that employing science practices and a place-based lens to provoke CSC has great potential. Through an analysis of teacher discourse across the workshop, we identified seven ideas that came to be taken as shared by participants. Here we discuss three themes that emerged from our analysis of participants' collective discourse relative to critical consciousness and CSC and describe ways the design heuristics supported or constrained development of critical consciousness and CSC. We also identify implications for teacher education and future research.

The first theme, "Individuals or Systems?" reflects a recurring debate central to the development of critical consciousness: do disparate outcomes reflect differences in choices and behaviors by individuals or the existence of systems that privilege some while oppressing others? For this group of teachers, the idea that oppressive gender norms resulted in higher rates of pellagra among females became taken as shared as they analyzed data and debated explanations for trends observed in participant-generated graphs. Engaging in science practices also supported participants' understanding of intersectionality, the compounded impact of gender and racial oppression experienced by Black women (Crenshaw, 1990). Evidence from post-workshop interviews indicates that geographic proximity to the textile mills in primary source materials heightened teachers' engagement in the case study portion of the instructional sequence.

Incorporating science practices and a place-based approach did not support critical consciousness and CSC in all instances. The HLT was written to support teachers' understanding of gender, racial, and economic oppression. Our analysis reveals, however, that

when participant-generated graphs showed an inverse relationship between income and incidence of pellagra, some teachers placed blame on the oppressed as opposed to the oppressor. As teachers debated the extent to which an individual's values and behavior determine health outcomes, discourse echoed the debate that occurred 100 years earlier. We propose two possible explanations for this finding. According to Freire (1970), acknowledging oppressive systems disrupts the myth of a meritocracy; consequently, it is difficult for those who benefit from these systems to accept their existence. It is also important to acknowledge, however, that systems of oppression are complex (Collins, 2017). While white males are often privileged by their gender and race, they may be marginalized by class or sexual orientation. Future iterations of this research should be designed to support broad and inclusive conversations around systemic oppression.

The second theme, "Defining and Acknowledging Race," highlights this group of teachers' growing awareness about the origins of racial categories. Race is the primary factor determining inequalities in the U.S., including those that influence and are influenced by science (Bell, 1992; Ladson Billings and Tate, 1995); understanding how race, racism, and White Supremacy originated is central to the development of CSC. Our findings indicate that participants began to discuss the construction of racial categories long before the topic was introduced in the HLT. Engaging in science practices that reveal the fallacy of thinking about SCA as a "black" disease supported the teachers' emerging critical awareness, findings that are congruent with Donovan's (2014; 2016) research. Discussing data from the Human Genome Project further disrupted notions of race as a genetic construct. Ultimately, images of enslavement and colonization became powerful metaphors for ways in which the *invention* of racialized categories created an oppressive hierarchy.

The idea that race and racial oppression should not be ignored in classrooms also emerged early in the workshop but became taken as shared as discussions and activities increased teachers' awareness of ways notions of White Supremacy impact students' lives. While evidence indicates growth in teachers' understanding of race as a social construction, we acknowledge that we did not address the role scientists played in creation of hierarchical racial categories adequately. In future iterations of this TD-DR, we will design tasks to support teachers' understanding of the role Western Science played in the creation and perpetuation of notions of White Supremacy. Developing theory around how teacher educators might support pre-service and in-service science teachers as anti-racist educators is a central goal of this research.

In the era of COVID-19, an additional lesson emerges from these findings. Lived experiences influence how data is interpreted. Evidence that clearly reveals the impact of systemic inequities to one observer may be interpreted differently by another. Our finding that some practicing science teachers continue to perceive race as a biological construct is especially troubling. Providing opportunities for implicit notions to be made explicit so that they can be contested is essential (Mezirow, 1991). PD is warranted to support science educators and students as they analyze information and construct explanations for the disparate rates of COVID-19 when data is disaggregated by race.

The repositioning of teachers as learners and students as teachers, an essential facet of critical pedagogies and emancipatory learning (Freire, 1970), emerged as a powerful framework for the third theme, "Teaching as Liberation." As they examined the region's history of economic and racial violence, participants voiced ways that their own education had been limited. Our evidence reveals mounting frustration among this group of teachers as they became

more aware that notions of White Supremacy impact their own thinking. The reality that students may possess more knowledge than their teachers was an important breakthrough. This realization reflects Freire's (1970) description of problem-posing education as a dialogue in which "the teacher-of-the-student and students-of-the-teachers cease to exist" and the collective group becomes "teacher-student with student-teachers" (p. 80). The taken as shared idea that differences in personal experience with oppression creates tensions in classrooms between teachers and students suggests how powerful this reframing was. While science educators are often uncomfortable responding "I don't know" to a student's question, in this admission there is emancipation and the opportunity to inspire students to find their own answers.

Employing Collins's (2017) model of a "matrix of domination," teachers, along with students, exist in an oppressive system; consciousness of oppression, however, can provoke powerful acts of resistance (p. 415). Growing awareness of oppressive systems prompted this group of teachers to question who determines what students need to learn in science classrooms. A desire to disrupt inequitable systems provoked awareness of the knowledge present within students, the power classroom teachers possess to challenge inequities, and an admission that systemic change will not occur without significant effort.

Conclusion

The purpose of this experiment was to test and revise an instructional sequence designed to support practicing teachers' development of critical consciousness and critical science consciousness. To design our workshop experience, we drew on the work of others who have observed teachers succeeding and failing in attempts to engage students in culturally relevant instruction and our own previous experiences teaching science content through a critical lens. We merged a critical place-based focus with science inquiry to explore how this approach might

increase teachers' awareness of the potential for science education to perpetuate or disrupt systems of oppression. Our findings suggest that grounding a professional development workshop in science inquiry and interdisciplinary critical pedagogies of place and has great promise. Findings from the analysis of group discussions, as well as data from post-workshop interviews, provide evidence of ways instructional tasks and materials supported teachers' collective consciousness relative to three CSC Learning Goals. In addition, our findings indicate that science content and practices may serve as powerful tools to support critical consciousness as evidenced by an increased awareness among this group of teachers of their agency to address systems of oppression through science teaching and learning.

References

Anderson, J. (1988). *The education of Blacks in the South, 1860-1935*. The University of North Carolina Press.

Ash, A. & Wiggan. G (2018). Race, multi-culturalisms and the role of science in teaching diversity: Towards a critical post-modern science pedagogy. *Multicultural Education Review, 10*(2), 94-120. https://doi.org/10.1080/2005615X.2018.1460894

Atwater, M. M., & Riley, J. P. (1993). Multicultural science education: Perspectives, definitions, and research agenda. *Science Education, 77*(6), 661-668.

Bancroft, S. & Nyirenda, E. (2020). Equity-focused K-12 science teacher professional development: A review of the literature 2001-2017. *Journal of Science Teacher Education, 31*(2), 151-207. https://doi.org/10.1080/1046560X.2019.1685629

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching, 52*(4), 530-544. https://doi.org/10.1002/tea.21204

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. Horizon Research, Inc.

Banks, J. A. (1993). Multicultural education: Historical development, dimensions, and practice. *Review of research in education, 19*(1), 3-49.

Barton, A. C. (2003). *Teaching science for social justice*. Teachers College Press.

Bell, D. (1992). *Faces at the bottom of the well: The permanence of racism*. Basic Books.

Boutte, G., Kelly-Jackson, C., & Johnson, G. L. (2010). Culturally relevant teaching in science classrooms: Addressing academic achievement, cultural competence, and critical

consciousness. *International Journal of Multicultural Education*, *12*(2). https://doi.org/10.18251/ijme.v12i2.343

Brown, B. A. (2019). *Science in the city: Culturally relevant STEM education*. Harvard Education Press.

Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2018). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. *Urban Education.* https://doi.org/10.1177/0042085918794802

Brown, J. C., & Crippen, K. J. (2017). The knowledge and practices of high school science teachers in pursuit of cultural responsiveness. *Science Education*, *101*(1), 99-133. https://doi.org/10.1002/sce.21250

Campbell, A., Skvirsky, R., Wortis, H., Thomas, S., Kawachi, I., & Hohmann, C. (2014). NEST 2014: Views from the trainees - Talking about what matters in efforts to diversify the STEM workforce. *CBE-Life Sciences Education*, *13*(4), 587-592. https://doi.org/10.1187/cbe.14-04-0068

Carlone, H. B., Haun-Frank, J., & Webb, A. (2011). Assessing equity beyond knowledge-and skills-based outcomes: A comparative ethnography of two fourth-grade reform-based science classrooms. *Journal of Research in Science Teaching*, *48*(5), 459-485. https://doi.org/10.1002/tea.20413

Chinn, P. W. U. (2007). Decolonizing methodologies and indigenous knowledge: The role of culture, place, and personal experience in professional development. *Journal of Research in Science Teaching*, *44*(9), 1247-1248. https://doi.org/10.1002/tea.20192

Clements, D., & Sarama, J. (2004). Learning trajectories in mathematics education. *Mathematical Thinking and Learning, 6*(2), 81–89.

Coates, T. N. (2015). *Between the world and me*. Text publishing.

Cobb, P. (2000). Conducting teaching experiments in collaboration with teachers. In A. Kelly, E. Anthony, & R. Lesh, (Eds.), *Handbook of Research Design in Mathematics and Science Education* (pp. 307-333), Lawrence Erlbaum.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.

Cobb, P., & Yackel, E. (1996). Constructivist, emergent, and sociocultural perspectives in the context of developmental research. *Educational Psychologist, 31*, 175–190. https://doi.org/10.1080/00461520.1996.9653265

Collins, P. H. (2017). Black feminist thought in the matrix of domination. In C. Lemert (Ed.), *Social theory: The multicultural, global, and classic readings* (pp. 413-421). Westview Press.

Confrey, J., & Lachance, A. (2000). *Transformative Teaching Experiments through Conjecture-Driven Research Design.* In A. Kelly, E. Anthony, & R. Lesh, (Eds.), *Handbook of Research Design in Mathematics and Science Education* (pp. 231-265). Lawrence Erlbaum.

Corcoran, T. B., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: An evidence-based approach to reform.* CPRE Research Reports. https://doi.org/10.12698/cpre.2009.rr63

Crabtree, L. & Lim, J. H. (under review). Learning and teaching science through critical pedagogies: A multiple case study.

Crenshaw, K. W. (1990). Mapping the margins: Intersectionality, identity politics, and violence against women of color. *Stanford Law Review*, *43*, 1241. https://doi.org/10.2307/1229039

Daro, P., Mosher, F. A., & Corcoran, T. B. (2011). *Learning trajectories in mathematics: A foundation for standards, curriculum, assessment, and instruction*. CPRE Research Reports. https://doi.org/10.12698/cpre.2011.rr68

Dennis, R. M. (1995). Social Darwinism, scientific racism, and the metaphysics of race. *Journal of Negro Education*, 243-252. https://doi.org/10.2307/2967206

DiAngelo, R. (2018). *White fragility: Why it's so hard for white people to talk about racism*. Beacon Press.

Donovan, B. M. (2014). Playing with fire? The impact of the hidden curriculum in school genetics on essentialist conceptions of race. *Journal of Research in Science Teaching*, *51*(4), 462-496. https://doi.org/10.1002/tea.21138

Donovan, B. M. (2016). Framing the genetics curriculum for social justice: an experimental exploration of how the biology curriculum influences beliefs about racial difference. *Science Education*, *100*(3), 586-616. https://doi.org/10.1002/sce.21221

DuBois, W.E.B. (1903). *The souls of black folk*. Millenium Publications.

Duster, T. (2015). A post-genomic surprise. The molecular reinscription of race in science, law and medicine. *The British Journal of Sociology*, *66*(1), 1-27. https://doi.org/10.1111/1468-4446.12118

Emdin, C. (2010). *Urban science education for the hip-hop generation*. Brill Sense.

Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the Nature of Science for Science Education*. Dordrecht, The Netherlands: Springer. https://doi.org/10.1007/s11191-015-9800-8

Etheridge, E. (1972). *The butterfly caste: A social history of pellagra in the South*. Greenwood.

Freire, P. (1970). *Pedagogy of the oppressed.* Bloomsbury Publishing.

Freire, P. (1973). *Education for critical consciousness.* Bloomsbury Publishing.

Gay, G. (2002). Preparing for culturally responsive teaching. *Journal of teacher education, 53*(2), 106-116. https://doi.org/10.1177/0022487102053002003

Giroux, H. (2011). *On Critical Pedagogy.* New York, NY: Bloomsbury.

Glasersfeld, E.V. (1995). *Radical constructivism: A way of knowing and learning*. The Falmer Press.

Glasson, G. E., Mhango, N., Phiri, A., & Lanier, M. (2010). Sustainability science education in Africa: Negotiating indigenous ways of living with nature in the third space. *International Journal of Science Education, 32*(1), 125-141. https://doi.org/10.1080/09500690902981269

Goldberger, J. (1916). The transmissibility of pellagra: Experimental attempts at transmission to the human subjects. *Public Health Reports, 31*(46) 3159-3173. https://doi.org/10.2307/4574262

Goldberger, J., Waring, C. H., & Willets, D. G. (1915). The prevention of pellagra: a test of diet among institutional inmates. *Public Health Reports (1896-1970)*, 3117-3131. https://doi.org/10.2307/4572932

Goldberger, J., & Wheeler, G. A. (1920). The experimental production of pellagra in human subjects by means of diet. In J. Goldberger (Ed.), *Goldberger on pellagra*. (pp. 54-94). Baton Rouge, LA: Louisiana State University Press.

Gould, S. J. (1996*). The mismeasure of man.* New York, NY: Norton.

Green, A. (2014). The systematic misuse of science. In M. Butler, M. Atwater, & M. Russell (Eds.) Multicultural science education: Preparing teachers for equity and social justice (pp. 11-28). Springer. https://doi.org/10.1007/978-94-007-7651-7_2

Grimberg, B. I., & Gummer, E. (2013). Teaching science from cultural points of intersection. *Journal of Research in Science Teaching*, *50*(1), 12-32. https://doi.org/10.1002/tea.21066

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational researcher*, *32*(4), 3-12. https://doi.org/10.3102/0013189X032004003

Hooks, B. (2003). *Teaching community: A pedagogy of hope*. Hove, UK: Psychology Press.

Horton, M. & Freire, P. (1990). *We make the road by walking.* Temple Press.

Horton, K. (2017). *Martyr of Loray Mill: Ella May and the 1929 textile workers strike in Gastonia, North Carolina.* Jefferson, NC: McFarland and Company, Inc.

Howard, G. R. (2016). *We can't teach what we don't know: White teachers, multiracial schools*. Teachers College Press.

Howard, J. (2018). The white kid can do whatever he wants: The racial socialization of a gifted education program. *Educational Studies*, *54*(5), 553-568. https://doi.org/10.1080/00131946.2018.1453512

Johnson, C. C. (2011). The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *Journal of Research in Science Teaching*, *48*(2), 170-198. https://doi.org/10.1002/tea.20405

Kendi, I. X. (2016). *Stamped from the beginning: The definitive history of racist ideas in America*. Random House.

King, J. E. (1991). Dysconscious racism: Ideology, identity, and the miseducation of teachers. *The Journal of Negro Education*, 60(2) 133-146. https://doi.org/10.2307/2295605

Kolavalli, C. (2019). Whiteness and Food Charity: Experiences of Food Insecure African-American Kansas City Residents Navigating Nutrition Education Programs. *Human Organization*, *78*(2), 99-109.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (2011). Yes, but how do we do it? Practicing culturally relevant pedagogy. In J. Landsman & C. Lewis (Eds.), *White teachers/diverse classrooms: Creating inclusive schools, building on students' diversity and providing true educational equity.* (pp. 33-46). Stylus.

Ladson-Billings, G. (2017). The (R)evolution will not be standardized: Teacher education, hip hop pedagogy, and culturally relevant pedagogy 2.0. In Paris, D., & Alim, H. S. (Eds.), *Culturally sustaining pedagogies: Teaching and learning for justice in a changing world*. (pp. 141-156). Teachers College Press.

Ladson-Billings, G. & Tate IV, W. (1995). Toward a critical race theory of education. *Teacher's College Record*, *97*(1), 47-68.

Lorusso, L. (2011). The justification of race in biological explanation. *Journal of Medical Ethics, 37*, 535-539. http://dx.doi.org/10.1136/jme.2011.043752

Madkins, T., & de Royston, M. (2019). Illuminating political clarity in culturally relevant science instruction. *Science Education, 103*(6), 1319-1346. https://doi.org/10.1002/sce.21542

Manning, K. R. (1985). *Black Apollo of science: the life of Ernest Everett Just*. Oxford University Press.

Marks, H. (2003). Epidemiologists explain pellagra: gender, race, and political economy in the work of Edgar Sydenstricker. *Journal of the History of Medicine and Allied Sciences, 58*(1), 34-55. https://doi.org/10.1093/jhmas/58.1.34

Marks, J. (2017). *Is science racist?* Cambridge, UK: Polity

McGurty, E. (1997). Transforming environmentalism: Warren County, PCBs, and the Origins of Environmental Justice. Rutgers University Press.

Memmi, A. (2000). *Racism*. University of Minnesota Press.

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science teacher education. *Teachers College Record*, *120*(1), 1-38.

Mezirow, J. (1991). *Transformative dimensions of adult learning*. Jossey-Bass.

Milner, R. (2012). But what is urban education? *Urban education, 47*(3) 556-561. https://doi.org/10.1177/0042085912447516

Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education*, *101*(6), 1034-1060. https://doi.org/10.1002/sce.21305

Morning, A. (2011). *The nature of race: How scientists think and teach about human difference*. Los Angeles, CA: Univ of California Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press.

Paris, D, & Alim, S. (2017). Culturally sustaining pedagogies: Teaching and learning for justice in a changing world. Teachers College Press.

Parsons, E. C. (2014). Unpacking and critically synthesizing the literature on race and ethnicity in science education. *Handbook of research in science education*, 167-183.

Politico. (2020, July 8). *2016 North Carolina presidential election results*. https://www.politico.com/2016-election/results/map/president/north-carolina/

Rasmussen, C. & Stephan, M. (2008). A methodology for documenting collective activity. In A.E. Kelly, R.A. Lesh, & J.T. Baek (Eds.), Handbook of design research methods in education: Innovations in science , technology, engineering and mathematics learning and teaching (pp. 195-215). Routledge.

Rodriguez, A. J. (1998). Strategies for counter-resistance: Toward socio-transformative constructivism and learning to teach science for diversity and for understanding. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *35*(6), 589-622. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6<589::AID-TEA2>3.0.CO;2-I

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *41*(5), 513-536. https://doi.org/10.1002/tea.20009

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in science Education*, *45*(1), 1-42. https://doi.org/10.1080/03057260802681839

Sadler, T. D., & Zeidler, D. L. (2005). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education*, *89*(1), 71-93. https://doi.org/10.1002/sce.20023

Sheth, M. J. (2019). Grappling with racism as foundational practice of science teaching. *Science Education*, *103*(1), 37-60. https://doi.org/10.1002/sce.21450

Simon, M. A. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for research in mathematics education*, 114-145. https://doi.org/10.2307/749205

Simon, M. (2000). Research on mathematics teacher development: The teacher development experiment. In *Handbook of research design in mathematics and science education* (pp. 335-359). Lawrence Erlbaum Associates Publishers.

Sleeter, C. (2011). *Professional development for culturally responsive and relationship-based pedagogy*. Peter Lang.

Stephan, M., & Akyuz, D. (2012). A proposed instructional theory for integer addition and subtraction. *Journal for Research in Mathematics Education*, *43*(4), 428-464. https://doi.org/10.5951/jresematheduc.43.4.0428

Stephan, M., & Rasmussen C. (2002). Classroom mathematical practices in differential equations. *Journal of Mathematical Behavior*, 21, 459–490. https://doi.org/10.1016/S0732-3123(02)00145-1

Stephens, J. T. (2019). Teaching Critically Where Rural and Nonrural Cultures Intersect. *American Educational Research Journal*, *56*(6), 2043-2076. https://doi.org/10.3102/0002831219839311

Sullivan, S. (2013). Inheriting racist disparities in health: Epigenetics and the transgenerational effects of white racism. *Critical Philosophy of Race*, *1*(2), 190-218. https://doi.org/10.5325/critphilrace.1.2.0190

Suriel, R. L., & Atwater, M. M. (2012). From the contribution to the action approach: White teachers' experiences influencing the development of multicultural science

curricula. *Journal of Research in Science Teaching*, *49*(10), 1271-1295. https://doi.org/10.1002/tea.21057

Thoman, D.B., Brown, E.R., Mason, A.Z., Harmsen, A.G., & Smith, J.L. (2015). The role of altruistic values in motivating underrepresented minority students for biomedicine. *BioScience*, *65*(2), 183-188. https://doi.org/10.1093/biosci/biu199

Tolbert, S., & Bazzul, J. (2017). Toward the sociopolitical in science education. *Cultural Studies of Science Education*, *12*(2), 321-330. https://doi.org/10.1007/s11422-016-9737-5

Toulmin, S. E. (1958). *The uses of argument*. Cambridge University Press.

Underwood, J. B., & Mensah, F. M. (2018). An investigation of science teacher educators' perceptions of culturally relevant pedagogy. *Journal of Science Teacher Education*, *29*(1), 46-64. https://doi.org/10.1080/1046560X.2017.1423457

United States Census Bureau. (2020, July 9). *Quick facts Gaston County, North Carolina*. https://www.census.gov/quickfacts/fact/table/gastoncountynorthcarolina/PST045219

Upadhyay, B., Atwood, E., & Tharu, B. (2020). Actions for sociopolitical consciousness in a high school science class: A case study of ninth grade class with predominantly indigenous students. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21626

U.S. Department of Education. (2020). Office for Civil Rights (Data collection). Available from http://ocrdata.ed.gov/

Waterland, R. A., & Jirtle, R. L. (2003). Transposable elements: targets for early nutritional effects on epigenetic gene regulation. *Molecular and cellular biology*, *23*(15), 5293-5300. https://doi.org/10.1128/MCB.23.15.5293-5300.2003

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *46*(1), 74-101. https://doi.org/10.1002/tea.20281

CHAPTER IV [ARTICLE 3]: IS IT POSSIBLE TO TEACH JUST SCIENCE? DESIGNING PROFESSIONAL DEVELOPMENT FOR CRITICAL SCIENCE CONSCIOUSNESS

Lenora M. Crabtree

Abstract

As disparate impacts from a global pandemic highlight systemic inequities, science classrooms can become important places for teachers and students to grapple with the intersections between science and systemic oppression. Science teachers, however, are often ill-equipped to discuss and explore racism and other forms of systemic oppression through science teaching and learning. In this article we propose a new construct, critical science consciousness, and an innovative method for teacher education research, Teacher Development-Design Research, to address this challenge. We present a hypothetical learning trajectory and describe its design and enactment in a professional development workshop along with the literature and design heuristics that supported development of an instructional sequence and learning goals. Our findings indicate that science practices and critical pedagogies of place are promising design heuristics. In addition to the design process, we describe a method of retrospective analysis and three paradigmatic cases, instances during one iteration of this research, that illustrate the opportunities and challenges inherent in designing for critical science consciousness.

Is it possible to Teach Just Science?

Designing Professional Development for Critical Science Consciousness

Environment and organism are one (Just, 1933).

As current and ongoing global crises reveal the impact of systemic inequities on the health and survival of communities, a question posed by Brazilian educator Paulo Freire takes on new significance:

> A biology teacher must know biology, but is it possible just to teach biology? …Is it possible to discuss, to study, the phenomenon of life without discussing exploitation, domination, freedom, democracy, and so on? I think that it's impossible, but I am also sure that if I am a teacher of biology, I must teach biology (Horton & Freire, 1990).

To paraphrase Freire, a teacher of science must teach science, but is it possible to do so efficaciously and not address ways that food insecurity, contaminated air, soil, and water contribute to health disparities in marginalized communities? Research has established the potential for critical science education to interrogate and disrupt oppressive systems (Bang & Marin, 2015; Barton, 2003; Johnson, 2011; Lee & Luykx, 2006; Mensah, 2011; Stromholt & Bell, 2018). Studies also reveal, however, a hesitance among science educators to confront systems of power and privilege through curriculum and instruction (Brown & Crippen, 2017; Calabrese & Tan, 2020; Rodriguez, 1998; Sheth, 2019; Suriel & Atwater, 2012). To acknowledge and address the impact of systemic racism in classrooms and communities, science educators and education researchers must move beyond constructs that promote generic appreciation of Otherness and embrace critical theoretical and culturally relevant frameworks (Parsons, 2014; Underwood & Mensah, 2018).

Drawing on decades of research and her own experiences as a student, Ladson Billings (2018) moves beyond questions of what is *possible* to describe culturally relevant science education from a student's perspective:

> There is a science out there in which African American students desperately want to participate. This is a science that explains the epidemic of diabetes or AIDS in a [student's] community …a science that challenges social constructions such as race. …a science that [can mobilize people] to fight social injustice and intellectually empowers people. This is a science that allows students to do something rather than sit passively while something is done to them (p. xvi).

Broadening this vision, she stresses, "If we begin to strengthen science teaching for those who are most vulnerable in our system, we are likely to strengthen it for everyone" (Ladson Billings, 2018, p. xviii – xix). Curricula and instruction that discouraged Ladson Billings's (2018) engagement in science persist for many students of color today (King & Pringle, 2019; Mensah & Jackson, 2018). In addition to emphasizing students' intellectual growth and cultural competence, Ladson Billings's (1995) framework for culturally relevant pedagogy (CRP) necessitates that teachers support students' sociopolitical, or critical, consciousness; if educators lack critical consciousness, enacting CRP is not possible (Ladson Billings, 2011). When teachers emphasize broadly framed environmental issues or employ generic crime lab activities, but avoid topics they consider to be politically volatile, they reinforce students' perception of schools as places unable or unwilling to address issues of immediate relevance to them (Barton & Tan, 2020; Ladson Billings, 2017).

While a growing body of research offers powerful examples of culturally relevant science curriculum and instruction (Brown, 2017; Brown et al., 2020; Lee et al., 2015; Sparks et al.,

2020; Upadhyay, Atwood, & Tharu, 2020), exemplar teachers in this literature are frequently identified as persons of color (e.g. Morales Doyle, 2017; Madkins & de Royston, 2019; Mensah, 2011; for an exception see Laughter & Adams, 2012). According to Freire (1970; 1973), developing critical consciousness is daunting for those who identify with a dominant group; approximately 90% of secondary science teachers in the U.S. identify as white (Banilower et al., 2018). Researchers are beginning to investigate how the critical consciousness of white *students* might be supported (Kokka, 2020; Stephan et al., under review). An emerging body of research also explores how PD might support the development of critical consciousness among *teachers* in diverse disciplines (Kohli et al., 2015; Zion et al., 2015). So far, there has been little discussion about how *practicing science teachers'* critical consciousness might be developed. In addition, limited attention has been paid to educators' understanding of how science is implicated in the creation and maintenance of systemic oppression, a construct we refer to as *critical science consciousness* (CSC) (Crabtree & Stephan, in press; Crabtree & Stephan, in process).

The question of how to develop science teachers' critical consciousness and CSC is both a theoretical and practical problem. Simon (2000) describes a similar problem in teacher education as a Catch-22: "we are unable to foster adequate teacher development because we do not understand the developmental processes sufficiently, and we are unable to understand the developmental processes because we do not have situations to observe where teachers are developing this expertise" (p. 336). The goals of Designed-based Research (DBR) are intertwined and include both the development of educational theory and the improvement of a practical innovation (The Design Based Research Collective, 2003). This broad approach to designing for learning inherently offers opportunities for researchers to attend to political and

systemic inequities inherent in schools and classroom settings (Stromholt & Bell, 2018). In this article, we propose Teacher Development-Design Research (TD-DR), an adaption of DBR, to address intersecting challenges.

TD-DR is a methodology for systematically and cyclically understanding how the design of a Professional Development (PD) workshop might develop teachers' understanding of culturally relevant, anti-racist science education. Context is an essential feature of DBR; accordingly, a TD-DR project to develop teachers' critical consciousness and CSC is carried out in a PD setting. In this article, we describe one macro-cycle of a TD-DR project designed to support secondary science educators' development of CSC. First, we explain the theoretical frameworks that inform and guide this research and provide a general overview of a TD-DR project. Next, we describe in detail one cycle of a TD-DR project and offer an analysis of three areas of tension related to the broader phenomenon of CSC that emerged during the design and implementation of a PD experience. We conclude with implications from this project for teacher educators, researchers, and others seeking to address systemic racism and others forms of oppression through science education.

Theoretical Perspectives

"We carry our history. We act our history." James Baldwin

In design experiments, theoretical frameworks, guided by theoretical perspectives, serve the dual roles of scaffolds to guide development of design heuristics and lenses through which designers understand what happens in an instructional setting (Gravemeijer & Cobb, 2013). Parsons' (2014) seminal review of education research related to race and ethnicity informs our theoretical framework. In the literature reviewed, Parsons (2014) found two distinct flaws: individualism, a focus on individuals as opposed to groups with similar experiences, and

presentism, a focus on current challenges in science education that ignores historical roots; in light of these findings, she recommends that research in this area reflect a critical perspective within the transformative paradigm. Guided by these recommendations, the design research described in this article draws on Transformative Theory of Adult Learning (Mezirow, 1991; 1997) and Critical Race Theory (Bell, 1992; Crenshaw et al., 1995).

Transformative Theory of Adult Learning

As design researchers interested in the development of practicing teachers' critical consciousness, it is important that we acknowledge the uniqueness of adult as learners. As a product of their lived experiences, adults possess a frame of reference that filters new ideas and regulates actions; in essence, they are trapped in their own histories (Mezirow, 1991). Frames of reference, however, may be transformed through discourse and critical reflection (Freire, 1970; Habermas, 1981; Mezirow, 1997). According to Mezirow (1991), "the job of adult educators is to help learners look critically at their beliefs and behaviors, not only as these appear at the moment but in the context of their history and consequences in the learners' lives" (p. 197-198). Transformative, or emancipatory, learning is evidenced by greater awareness of perceptual filters, openness to the perspectives of others, increased participation in reflective discourse, and alterations in established patterns of expectations and behaviors (Mezirow, 1991). As adults "learn what freedom, equality, democracy, and emancipation mean in [a] microcosm … they can act politically to create interpersonal relationships, organizations, and societies in which others can discover the meaning of these values as well" (Mezirow, 1991, p. 208-209). Despite its appellation, Mezirow (1991) situates Transformative Theory of Adult Learning within constructivism. Notably missing from this framework is explicit attention to power and privilege,

an underlying principle of transformative research (Mertens, 2015). Consequently, we also draw on critical race theory (CRT) to foreground the sociopolitical nature of our work.

Critical Race Theory

Critical Race Theory (CRT) emerged within critical legal studies (Crenshaw et al., 1995), but is deeply rooted in the Black intellectual tradition (DuBois, 1903). Employing CRT to interrogate racism in educational settings, Ladson Billings and Tate (1995) contend that race remains the most significant factor determining inequities in American classrooms and schools. Although race is a social construct, the racialized nature of society and its impact on "raced" persons, including students and teachers, must be addressed (Ladson Billings & Tate, 1995, p. 48). Employing a critical race lens, Mutegi (2011) addressed the failure of Science for All proponents to acknowledge those who have not benefitted from science in the past. Research that seeks to support equity and diversity in the teaching and learning of science must also attend explicitly to ways that whiteness impacts teachers and students (Le & Matias, 2019). In their work with pre-service Teachers of Color, Mensah and Jackson (2018) invoke the notion of "Science as White Property" and the practice of counter-storytelling to expose race and power in science education and increase participants' sense of belonging in the teaching and learning of science (p. 8). In our work, we draw on this literature and studies by Sheth (2019) that challenge practicing teachers to grapple with racism in curriculum and instruction. We endeavor to design PD experiences that support the development of critical consciousness and CSC among adult science educators, particularly those whose lived experiences have offered few opportunities to examine racism and other systems of oppression in science education. Framing our work within CRT guided the development of Learning Goals for the instructional sequence designed for a PD workshop and provided theoretical grounding for this TD-DR experiment.

Teacher-Development Design Research: An Overview

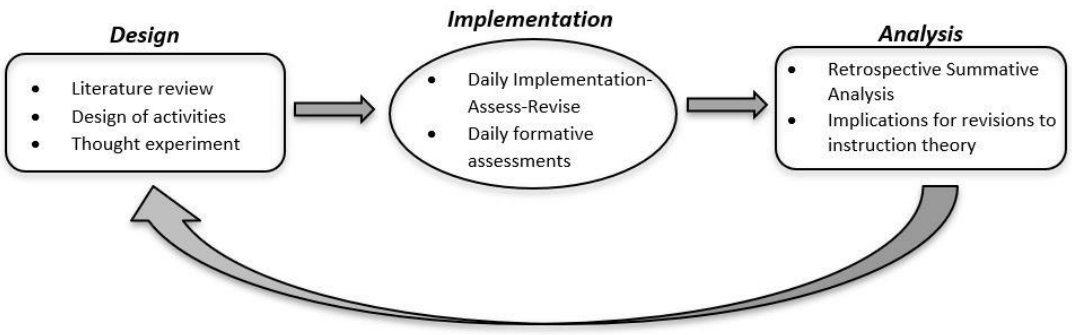
Since white science teachers rarely possess the critical consciousness and CSC we wish to study, design-based research allowed us to create the circumstances in which to develop teachers' consciousnesses while at the same time studying its development. DBR gained prominence in math and science education as a research methodology uniquely positioned to bridge the research to practice gap (Bakker & Van Eerde, 2013). In science education, researchers have employed DBR methodologies for varied purposes including development of new vocabulary instruction tools for English Learners (Barber, 2013) and explorations of community engagement in the creation and implementation of science-learning environments (Bang & Marin, 2015). In addition to its usefulness in classroom and informal education settings, DBR can be carried out to support teacher learning. Simon (2000) adapted the Constructivist Teaching Experiment (Cobb, 1987; Steffe, 1991) within the context of pre-service teacher education as a Teacher Development experiment (TDE). Our adaptation, TD-DR, draws on the methods of design, implementation, and analysis integral to a Constructivist Teaching Experiment and DBR (Gravemeijer & Cobb, 2013) as well as the emphasis on teacher education inherent in TDE to study teacher learning during PD experiences designed to enhance science teachers' enactment of culturally relevant praxis.

DBR is a highly interventionist and iterative process (Cobb et al., 2003). Accordingly, a TD-DR project occurs in multiple macro-cycles involving three phases: Design, Implementation, and Analysis/Revision (Figure 1). During the Design Phase, the designer(s) engages in a thought experiment, hypothesizing how an instructional innovation may be realized with potential participants. In the Implementation Phase, the designer(s) enacts the innovation in an authentic context. During the Analysis/Revision Phase, findings from analysis of data collected during the

Design and Implementation Phases inform revisions to the innovation to be enacted in subsequent iterations. Ideally, multiple macro-cycles occur until a stable instructional innovation is ready for adaptation in other settings. According to Cobb (2003), the aim of a DBR project is not necessarily to determine whether an intervention worked but to analyze *how* the intervention supported learning, information that may be useful to those who want to adapt the intervention in their own unique contexts.

Figure 1

One macro-cycle in design research.



Note. Adapted from Stephan & Cobb (2013).

Design Phase

The starting point of the design phase of TD-DR involves identifying a practical or theoretical problem to explore. For researchers concerned with teacher development, this problem may be one of teacher practice. During the design phase, researchers conduct a literature review to locate research that may guide them in the development of the instructional innovation. Informed by the literature, and possibly a pre-existing instructional theory, the researcher(s) drafts an initial learning trajectory. A hypothetical learning trajectory (HLT) is the product of a thought experiment conducted by the researcher(s) that presupposes how designated learning

goals might be accomplished as participants engage in discourse around instructional activities and materials (Simon, 1995; Simon & Tzur, 2004). To inform the development of the HLT, individuals with expertise in various aspects of the problem may be engaged as a Design Team. For a TD-DR, the district curriculum specialist or instructional coach can play an important role as a member of the design team. Meetings involving Design Team members and the primary researcher(s) should be audio recorded for later analysis; data generated during this phase may also include memos documenting conjectures, dilemmas and decision-making processes (Cobb & Gravemeijer, 2013). During this phase, pre-implementation interviews may also be conducted. Participant interviews in a design research experiment serve multiple purposes. Designers may choose to use pre-intervention interviews to 1) identify a reasonable starting point for an HLT; 2) provide insight into individual teacher's development over the course of the experiment; and 3) provide data for case studies of select participants (Simon, 2000).

Implementation Phase

During the second phase, Implementation, the researcher(s) executes the HLT in the setting for which was designed. During the enactment of the innovation, video cameras should be used to capture the discourse of participants as well as their interaction with the materials and instructor. For TD-DR around sensitive topics (e.g. race, gender identity, sexual orientation, or mental health), researchers may choose to audio record to maximize the degree to which participants are comfortable engaging in the experience. During implementation, the research team conducts mini-cycles on a daily basis by implementing planned activities, informally analyzing what participants learned that day, and possibly revising planned activities for the next day if warranted (Gravemeijer & Cobb, 2013).

Analysis/Revision Phase

In contrast to other forms of education research, the goal of DBR is not necessarily to investigate whether an innovation worked, but *how* the materials and methods supported or constrained participants' learning (Cobb et al., 2003). At the completion of the implementation, data collected throughout the Design and Implementation phases are analyzed formally. An analytic framework guided by the theoretical underpinnings of the study should be employed as a lens through which sense can be made of the data. One analysis of the data should reveal the actualized learning trajectory so that revisions to the HLT can be developed, setting the stage for a subsequent cycle of research. Another form of analysis may explicate facets of the phenomenon under investigation by highlighting paradigmatic incidents (Gravemeijer & Cobb, 2013). The goal of a successive series of design macro cycles is the development of a stable instructional theory. A mature instructional theory may guide others who wish to adapt the sequence within their own contexts or conduct further research. In the next section, we describe in detail one cycle of a TD-DR experiment and articulate how the design heuristics, learning goals and instructional materials were developed and implemented in a PD workshop highlighting critical science consciousness.

Critical Science Consciousness Teacher Development–Design Research

The objective of the research described here was to design, implement, and revise an instructional sequence to support the development of teachers' critical consciousness and CSC. What follows is an account of one macro-cycle of the TD-DR project. The extensive literature review, development of design heuristics and Learning Goals, pre-workshop interviews and a proposed instructional sequence that occurred during the Design Phase are described. While the implementation of the instructional sequence during a PD workshop is briefly addressed, a more detailed account of the case study that anchored the workshop and analysis of collective

participant learning during this phase are described elsewhere (Crabtree & Stephan, in press; Crabtree & Stephan, in progress).The Analysis Phase and actualized HLT are clarified and suggested revisions explained.

Design Phase

Identification of a Practical or Theoretical Need

What appeared to be missing at the time of this research were studies exploring how to *design* for the development of critical consciousness among practicing science teachers. In addition, we were unable to locate research examining how science content might serve as a catalyst to provoke critical consciousness. The idea for the TD-DR project described in this article emerged as findings from a related research project around a 13-week PD seminar revealed that employing a social justice lens to study epigenetics heightened participants' awareness of systemic inequities (Crabtree & Lim, in progress). In addition, we observed that opportunities to question the framing of scientific data, particularly around the subject of race, supported *content-specific* critical consciousness, a phenomenon we identified as *critical science consciousness* (CSC). Initially, we defined this new construct as an awareness of the potential for science to disenfranchise or liberate marginalized groups. As we designed the innovation described in this article, we worked with members of the Design Team to review existing literature, identify design heuristics, and conduct pre-workshop interviews that informed the development of learning goals and the HLT.

Literature Review

CRP, Critical Consciousness, and Teacher Education

We employ CRP as an organizing framework for our research because it foregrounds sociopolitical, or critical, consciousness (Ladson Billings, 1995). Culturally relevant teachers

"help students develop a critical consciousness that allows them to question the veracity of what they read in classrooms and pose powerful questions about… problems of living in a democracy that attempts to serve a diverse populace" (Ladson Billings, 2017, p. 146). A recent study suggests science teacher educators have limited understanding of the critical pedagogies inherent in CRP; these findings underscore the challenge science teacher educators face to adopt frameworks that contest hegemony in it most pernicious form. (Underwood & Mensah, 2018). According to Mahoney (1997), it is difficult for those whose identities align with the dominant group to perceive and disrupt oppressive systems.

"The underlying philosophy of design research is that you have to understand the innovative forms of education that you might want to bring about in order to produce them" (Gravemeijer & Cobb, 2013, p. 45). Adapting DBR to create an innovative PD workshop provided an opportunity to support teachers in becoming critically conscious science educators and develop theory around how to do so. The author, a PhD candidate at the time of this research who identifies as a white female, served as the lead designer and instructor for the workshop. An interdisciplinary design team composed of experts in DBR, epigenetics, math education, engineering education, science curriculum, special education, and classroom instruction joined us in the learning process. As we reviewed the literature around science, race, and racism, we were confronted with our own lack of knowledge regarding how Western science and science education have perpetuated White Supremacy (Gould, 1996; Green, 2014; Kendi, 2016). Members of the design team who identify as Black challenged their colleagues to consider what education for liberation might mean for teachers and teacher educators who identify as white, as well as for students of color.

Race, Science, and Science Education

To guide the design of our learning goals we sought a deeper understanding of the intersections of race and science. Informed by CRT, we acknowledge that race remains one of the most significant factors determining inequities in the U.S. (Ladson Billings & Tate, 1995; Le & Matias, 2019). Through our review of literature, we were reminded that science does not occur in a vacuum; it is influenced by cultural, economic, and political forces, and it, in turn, influences society (Roberts, 2011). During and following the Enlightenment (1715-1789 AD), leading scientists in fields including anthropology, anatomy, taxonomy and others published textbooks and research findings that reified racial categories and White Supremacy (Gould, 1996; Kendi, 2016; Roberts, 2011). Scientists influenced by White Supremacist ideology conducted dehumanizing experiments on persons of color that led to increased medical knowledge and economic windfalls (Kendi, 2016; Skloot, 2010).

At the beginning of the 21st Century, a much-anticipated announcement by the leading scientists in the Human Genome Project confirmed that there is no biological basis for race (Roberts, 2011). Despite these findings, genetics education continues to support biological essentialism at the genome level (Donovan, 2014; Duster, 2015; Sparks, Baldwin, & Darner, 2020). Analyses of high school science textbooks and interviews with university professors indicate that definitions of race as a biological entity influence instruction in universities and secondary schools (Morning, 2011). Observational research suggests that even those science teachers who express a commitment to CRP possess limited capacity to critically analyze representation in textbooks or confront essentialist perspectives (Sheth, 2019). Empirical studies involving middle and high school students underscore the negative impact of racialized genetics instruction on students' willingness to address societal inequities, but also suggest that humane

genetics education has potential to reduce racial bias (Donovan, 2014; 2016; Donovan et al., 2019).

During our pilot study, we learned that the emerging field of epigenetics can offer a new lens through which teachers might think about disparate health and education outcomes. As we continued to examine the literature related to genetics instruction and race, we began to understand how the framing of race in textbooks and instruction leads to false assumptions regarding the root causes of health disparities. Modern geneticists and bio-pharmacologists who fail to consider the socio-cultural history of a group or the impact of the environment on genetic expression may attempt to find explanations for disparate health outcomes in the genomes of marginalized groups when none exist (Duster, 2015). Examples include the search for a genetic explanation for high rates of prostate cancer in the genomes of Black men who have experienced exposure to environmental toxins, and the search for a genetic explanation for the high rates of diabetes in Native American populations that have been subjected to famine and genocide (Duster, 2015). According to Sullivan (2013), "while the connection between racism and the risk of poor health isn't news to most people of color, it is profoundly challenging the way that the life sciences thinks about the etiology of many diseases and grapples with questions of how to measure racial discrimination" (p. 192). As we designed the instructional sequence for this TD-DR project, one design team member noted, "Are we trying to get the teachers to look at something like poor health in the current perspective, for example a lack of access to healthy food - or a historical perspective, as in how did we get here? The latter is more powerful, but probably the harder ask." Guided by this literature review and our theoretical framework, we established two design heuristics to find a launching point for our instructional sequence and inform the development of instructional materials.

Design Heuristics

Design Heuristic 1 – Critical pedagogies of place

> *Presentism preempts critical examination; it inhibits learning from the past and using these lessons to inform what occurs in the present and what is envisioned and engineered for the future (Parsons, 2014, p. 178).*

While our pilot study was conducted with teachers in an urban emergent (Milner, 2012) school district, the opportunity to continue this research in a region that has a distinct social and economic history prompted an extensive re-design of the initial PD. We were particularly intrigued by the decolonizing methodologies and place-based emphasis Chinn (2007) and Glasson et al. (2006) employed in their studies of science educator PD in Hawaii and Malawi, respectively. Across learning contexts, science education literature reflects a heightened focus on critical Place-Based Education (Bang & Marin, 2015; Brown, 2019; Brown et al., 2020; Schindle-Dimick, 2016; Morales-Doyle, 2017; Stromholt and Bell, 2018). According to Ladson Billings (2011), to create these types of experiences, "teachers must… educate themselves about both the local sociopolitical issues of their school community… and the larger sociopolitical issues (e.g. unemployment, health care, housing) that impinge on their students' lives".

According to Gutierrez and Vossoughi (2010), "when intellectual work is situated in the historical particularities of the community, thinking historically can change one's relationship with observed contradictions, including how to re-mediate in ways that foster shifts in perspective" (p. 103). Participants in this TD-DR experiment teach high school science in a county whose communities and schools were shaped by textile manufacturing and the raw materials on which it depended. In the 1990's, the impacts of globalization led to the closure of the region's manufacturing facilities. Today, disparate rates of obesity, diabetes, and heart disease reflect longstanding patterns of socioeconomic inequality between the descendants of

those who labored in the fields and mills, and those who owned them. Adopting critical pedagogies of place as a design heuristic supported our commitment to engage teachers in learning more about the place they live and teach (Bell, 2019), and to trouble the notion of education as a way out.

Design Heuristic 2 – Scientific Inquiry

Critical consciousness development is supported by "problem posing," a pedagogy through which students become "critical co-investigators in dialogue with the teacher" (Freire, 1970, p. 81). Like problem posing, scientific inquiry is "both a pedagogy and a learning outcome" (Brown, 2017, p. 1145). As we reviewed the design of our pilot study, we noted that tasks that involved analyzing graphs or debating varied interpretations of data supported teacher learning to a greater extent. A commitment to engaging the participants themselves in scientific inquiry as a design heuristic created impetus to find materials and methods that would support teachers' critical awareness through science practices.

While inquiry can be defined many ways, the science practices outlined in *The NGSS Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NGSS Lead States, 2013) support a form of inquiry learning closely aligned with the work of practicing scientists (Furtak & Penuel, 2019). Although the Framework has been criticized as lacking explicit attention to equity and diversity (Rodriguez, 2015), Brown's (2017) meta-synthesis identified multiple instances of complementarity between inquiry-based practices and culturally relevant/responsive teaching involving *student* sociopolitical consciousness. Examples of critical inquiry in *teacher* education, however, are limited (e.g. Chinn, 2007; Grimberg & Gummer, 2013). We identified four science practices as most suitable for the purposes of this workshop: Asking Questions and Defining Problems; Analyzing and Interpreting Data;

Constructing Explanations; Obtaining, Evaluating, and Communicating Information. These practices were incorporated into the tools and tasks designed to support problem posing and encourage critical discourse during this professional development experience.

Participant Pre-Interviews

To construct the learning goals that form the basis of the *hypothetical learning trajectory*, the author conducted pre-workshop interviews with six of the seven participants in the two weeks preceding the workshop. The seventh participant was not available for pre- or post-workshop interviews but did attend and participate fully in workshop sessions. All participants in the interviews and workshop identify as white. Four of the participants identify as female, and three as male. Five of the seven participants are employed at traditional public schools; two teach in an Early College setting. Two teachers who attended the workshop teach at schools in which a majority of students identify as Black (40-42%) or Hispanic (15-18%); other schools represented by this group of teachers have a student population in which the majority (63-78%) identify as white (Department of Education, 2016). The group included a novice teacher who had been teaching for one year, three with 5 – 10 years of teaching experience, two teachers with 10-20 years of experience, and one with more than 25 years of experience. Subjects taught included Biology, Chemistry, Physics, Earth and Environmental Science, and Anatomy and Physiology.

Informed by our literature review, we constructed an interview protocol (Table 1). To begin the process, we reviewed questions published by Underwood and Mensah (2018) and conducted an internet search that generated ideas for Questions 5, 11 and 12. We designed four questions (3, 6, 8 and 10) to probe teachers' understanding of social justice and equity and constructed Questions 4 and 7 to their familiarity with the concept of critical consciousness. In Question 11, we requested teachers respond to the statement, "Science and race have always

gone hand in hand," (adapted from Marks, 2017) to uncover any awareness of ways science contributed to the notion of race as a biological construct. We designed question 12 to explore how teachers might translate ideas about social justice to contexts other than race and socioeconomic status. The intent of question 14 was to uncover teachers' perspectives regarding their role in the broader context of schooling and education.

Participants' responses to Question 7 confirmed our expectation that teachers would come to the workshop with varying levels of critical awareness. When asked how they support students' critical consciousness, some participants described incorporating topics such as industrial pollution and farming. One teacher emphasized the importance of helping students from diverse background learn to work together while another admitted to having no knowledge of what the term "critical consciousness" might mean. Question 12 generated the most surprising answers. Most of the interviewees rejected the idea of genetic testing to determine gender quickly, making a distinction between gender ("how you identify) and sex ("genetic") without hesitation. Two teachers indicated they are currently teaching students going through transition while another stated he has adapted student surveys and registration forms to allow students to self-identify. It should be noted that the state in which the teachers are employed has received national attention for legislative action related to transgender issues and local parents of transgender children have been active in raising awareness.

Table 1

Interview protocol

Questions
1. Tell me about your current teaching responsibilities. What subjects do you teach? Which subjects are your favorite to teach? How long? In what capacities?
2. How do you describe your ethnicity or race?
3. What experiences have you had that shaped your understanding of social justice and equity?
4. How did you decide to enroll in this specific Professional development workshop? What do you expect to learn during the workshop?
5. Science is a value-free zone. To what extent do you agree with that statement?
6. In what ways do you explore topics of equity and social justice in your classroom?
7. How do you facilitate critical consciousness development in your science classroom?
8. Do you discuss equity and social justice in connection with any specific science topics/content/curriculum?
9. In a science methods course I teach, several students insist they treat all of their students the same. Several others said that they do not treat all of their students the same. What do you think?
10. How are social justice and equity addressed in the NC Essential Standards for the subjects you teach?
11. A UNCC Anthropologist, Jonathan Marks, has been quoted as saying that, "Race and science have always gone hand in hand." What do you think Marks meant by that?
12. According to a draft memo leaked to The New York Times, the US Department of Health and Human Services (HHS) proposes to establish a legal definition of whether someone is male or female based solely and immutably on the genitals they are born with. Genetic testing, it says, could be used to resolve any ambiguity about external appearance. What questions arise for you upon reading this? If Brittney Johnson from Channel 9 News asked for your comments as a science scholar, what might you say?
13. Some have said that science can be liberating. Do you agree with that statement? What does liberation mean to you?
14. Is teaching political?

We had hoped to uncover participants' views on "colorblind teaching" (Underwood & Mensah, 2018, p. 59) through answers to Question 9 but found that teachers primarily focused on the need to address learning differences when answering this question. Although participants did

not address how students' racial identity might impact their school experiences, one teacher did elaborate on the importance of differentiating lessons for English Learners. Responses to Question 11 focused on the scientific enterprise as opposed to the construct of race. A participant stated that the quote, "science and race have always gone hand in hand," might relate to the idea that science is a "Western thing" that grew out of Greek culture "with lots of Arabic influence" while several participants described science as a "white man's club." In reference to race, teachers acknowledged a reluctance to address "things that have happened that we are not proud of." According to one respondent, "you don't want to get that angry parent phone call for saying something inappropriate."

The responses we received to Questions 3, 6, 8 and 10, were the most helpful for developing the learning trajectory and instructional materials. Although the interviewer employed the terms "social justice and equity" in four different questions, few teachers referenced racial, ethnic, or economic disparities. In response to Question 3, teachers used generic terms to describe students ("we're all people!") and discussed the need to differentiate instruction for students with learning differences. Only two teachers described personal experiences that involved race; both indicated that the racism they had witnessed in their own families had taught them "what not to be like." When asked how they address equity and social justice in the classroom (Question 6), teachers admitted that they "shy away from difficult conversations," explaining "it's hard to facilitate that discussion." Questions 8 and 10 addressed potential connections between science content and issues of social justice and equity. Some participants struggled with these questions, but four teachers mentioned food access as a social justice issue. Their expressed interest in food equity supported our choice of this topic as a launch point for the instructional sequence.

While most of the participants did not discuss socioeconomic status in response to Question 3, one teacher noted that he had lived "a pretty good life," but could now see evidence of what he had learned through "classes on poverty and education" in the performance of his students: "People in the lower socio-economic groups are going to have a harder time, they are going to do a lot worse." When the interviewer asked for clarification, the teacher stated that stress, health, limited time with parents, and not being read to as a child "affect the development of the brain." According to the teacher, students in advanced classes tend to be the "higher socioeconomic kids who …did not have that stress and those kinds of things that make them feel like they can't try harder." The practice of academic tracking often sorts students by socioeconomic class as opposed to academic potential (Darling-Hammond, 2010). Attributing students' placement in academically tracked courses to immutable characteristics suggests a troubling deficit framework; this response prompted us to consider how we might support participants' awareness of oppressive systems without reinforcing biological determinism.

Learning Goals

While the concept of CSC emerged from the findings of the pilot study, our literature review led us to expand our definition of this multi-faceted construct to include ways that systems of oppression impact the scientific enterprise and are reinforced by it (Gould, 1996; Kendi, 2016; Marks, 2017). Data from pre-workshop interviews also prompted further clarification of the Learning Goals (Table 2).

Table 2

Learning Goals

Learning Goal 1: *Participants develop awareness of ways that inequities in society impact the scientific enterprise and science education.*
• Social, economic, and political systems shape the questions scientists ask and how they seek to answer those questions (Duster, 2015; Gould, 1996; Marks, 2017). • Aspects of identity and experience influence whose contributions are recognized, and whose knowledge is considered scientific. (Bang & Marin, 2015; Glasson et al., 2010)
Learning Goal 2: *Participants become more aware of ways that the scientific enterprise and science education contribute to systemic inequities in broader society.*
• Western science perpetuated the fallacy that racial categories have a biological basis, a misconception that continues to influence science education in the 21st century (Gould, 1996; Kendi, 2016; Morning, 2011). • Genetics instruction in secondary science classrooms reinforces erroneous notions about race (Donovan, 2014; 2016). • False conjectures about human categories and biological determinism prompt researchers to seek answers to health disparities in gene sequences, while ignoring the social and cultural history of groups with varied experiences (Duster, 2015; Lorusso, 2011).
Learning Goal 3: *Participants recognize the potential for critically conscious science education to contribute to the liberation of individuals, groups, and society.*
• In the early 20th century, high incidences of disease among persons experiencing poverty were heralded as examples of genetic inferiority; as nutritional causes for diseases were uncovered, cures were developed (Etheridge, 1972; Gould, 1996). • Researchers in the field of epigenetics have uncovered mechanisms through which varied environmental conditions impact health outcomes (Rothstein et al., 2017; Waterland & Jirtle, 2003). • An understanding of epigenetics can equip future scientists and policy makers to address inequities at their root cause. (Duster, 2015; Sullivan, 2013)

Context of Teacher Development – Design Research Project

Our commitment to critical, place-based pedagogies prompted us to engage in a more extensive study of the place we planned to conduct this TD-DR experiment. The county in which the workshop participants teach has a dark history of violence including the internationally publicized murder of a white, pregnant textile worker involved in efforts to organize African American mill employees (Horton, 2015). In addition to Ella May, the police chief was killed in a separate incident during a strike at the largest textile mill in the Southeast. The historically

significant strike and the violence that ended it are rarely discussed by area residents. We suspected that this event and the oppression it highlights might serve as the context for our CSC workshop, but we lacked materials to support a science-related inquiry of this topic.

Through further research, we learned that two of the murdered textile worker's children had died of pellagra, a disease with which we were unfamiliar (Horton, 2017). Further research led us to discover that during the first half of the 20th century, outbreaks of pellagra resulted in mental illness and death for thousands of mill workers, tenant farmers, and their children. Over a time span of 35 years, scientists established niacin deficiency to be the immediate cause of pellagra; public health surveys of mill villages also revealed the socio-political nature of the epidemic (Goldberger, 1916; Goldberger, Waring, & Willets, 1915; Goldberger & Wheeler, 1920; Goldberger, Wheeler, & Sydenstricker, 1920a; 1920b). Recent research reveals disparate rates of death from pellagra among Black individuals compared with those who were white (Marks, 2003). When a search of the literature uncovered original research conducted by the Public Health Service, the concept of an interrupted case study to investigate systems of oppression came into focus (Crabtree & Stephan, in press). The case study would set the stage for teachers to explore related topics including food inequities, epigenetics, the environmental justice movement, and race. The life and death of a pregnant union organizer emerged as a powerful launching point for our learning trajectory.

Implementation Phase

Informed by our literature review and participant interviews, and guided by our heuristics and learning goals, we designed a hypothetical learning trajectory (Table 3) which we implemented along with accompanying materials during a four-day PD workshop with seven practicing high school science teachers. Data collected during this phase include audio

recordings of large and small group discussions along with recordings of conversations between the instructor and a design team member present at the workshop. Due to the sensitive nature of the topics being discussed, we chose not to video record the sessions. Other data collected include teachers' reflective writings, field notes, and artifacts including teachers' identity work.

Identity work

In addition to the instructional activities described in the HLT (Table 2), participants engaged in reflective writing and a group discussion to launch each day's session. As an introductory exercise, teachers created an "I'm from" poem using "Where I'm from" (Lyon, 1999) as a mentor text. Each participant completed sentence stems on stickie notes that were then combined to form a collective "We're from" poem. On Day 2, participants wrote a reflective journal entry completing the sentence stem "I am from [this place]," "I am of [this place]," *or "*I am at [this place]" that best reflects their relationship to the district/county in which they teach. On the third day, in an adaptation of the "Draw a Scientist" activity (Chambers, 1983), teachers responded to the prompt: *Who inspired your love of science and science education? Draw and label that person*. These activities, and the discussions they prompted, provided opportunities for teachers to reflect on their unique identities as individuals, members of a community, and science educators (Bryce, Wilmes, & Bellino, 2016).

Establishing Norms

Educators who seek to engage adults in transformative learning experiences should be prepared to interrupt intrusions that might hinder full participation in critical discourse (Mezirow, 1991). One way to do this is to set and enforce norms for participation. On the first day of the PD workshop, we introduced four norms to the group: 1) Be open; 2) Lean into discomfort; 3) Be aware of intent v. impact; and 4) Focus on what is in our locus of control. On

the second day, an additional norm was added: 5) Avoid the use of derogatory terms for individuals or groups. This norm was added in response to a request from participants who were uncomfortable with terms that a colleague used to describe mental illness on the previous day of the workshop. At the beginning of each morning session norms were reviewed. During several sessions, participants referred to the norms in a manner that conveyed the group's sense of shared responsibility to promote productive, respectful discourse.

Analysis/Redesign Phase

Retrospective analyses of design experiments should include a formal analysis of participants' collective and individual emerging understandings and an examination of how those were supported or constrained. In addition, designers might choose to examine paradigm cases, instances within the context of the experiment that inform broader phenomena (Gravemeijer & Cobb, 2013). To document emerging critical consciousness and CSC among this group of teachers, we drew on theories of social constructivism (Cobb & Yackel, 1996; von Glasersfeld, 1995) and employed an adaptation of Toulmin's (1958) argumentation scheme (Stephan & Rasmussen, 2002). Our findings and a detailed explanation of our method of analysis are reported elsewhere (Crabtree & Stephan, in progress). Here we describe a retrospective analysis of the design of the workshop framed by three paradigmatic cases that place the experiment within the broader context of critical consciousness and CSC in science teacher education. Specifically, the research questions we sought to answer through a broader analysis of this macro-cycle are:

1) In what ways did the design of the professional development experience enable and constrain the high school teachers' development of critical consciousness and CSC?

2) What revisions to the instructional sequence are indicated by an analysis of the design and implementation of the professional development experience?

First, we provide a brief description of the data that informed our analysis and the method we used to assess that data. Then we identify and explicate three paradigmatic cases that reveal challenges and opportunities for TD-DR around critical consciousness and anti-racism education. We conclude with a summary of our findings and implications for future work.

Data and Method of Analysis

The process by which a research team develops a deeper understanding of the phenomenon being explored is a distinctive feature of design experiments; thus, detailed documentation of the entire process is essential (Cobb et al., 2003). To begin a retrospective analysis and identify paradigmatic cases, we gathered data including transcripts of design team meetings, pre- and post-workshop interviews, workshop sessions, and informal conversations between design team members. In addition, we collected memos, literature review notes, field notes, and artifacts from the workshop including participants' written responses to activities, reflective writing, and identity work. The documentation of claims, challenges, and warrants created during our formal analysis of teacher learning that we call an argumentation log (Crabtree & Stephan, in process) also served as data for this broader analysis. Once assembled, we reviewed the data and constructed a comprehensive account of the design process to better understand decisions that led to the instructional sequence, materials, and methods employed in this experiment. Through this process, we identified competing conjectures during the design process and workshop sessions. We reviewed transcripts of design team meetings and workshop sessions to develop a deeper understanding of the context in which these tensions emerged. In Crabtree & Stephan (in progress), we documented the CC and CSC that developed among

participants as they engaged in the PD workshop. Due to space constraints, we illustrate how retrospective analysis of participants' emerging consciousness informs revisions to the HLT with three examples rather than present the revision process in its entirety. In this way, we let the three instances serve as paradigmatic of the rationale for and process of revising particular parts of the HLT. We organize these paradigmatic cases around three ongoing tensions during this design experiment. The first case illustrates opportunities to address problematic frameworks that may emerge during critically framed professional development in the moment, on a daily basis. When such decisions occur, they should be documented so that their rationale can be recalled as the revised trajectory is created at the end of the cycle. The second case highlights the importance of attending to hesitation or resistance around race and racism during design and implementation of an instructional sequence. The final case illustrates the potential for TD-DR to support teachers as powerful agents of change. For each case, we summarize a portion of the HLT and describe how specific instructional tasks and tools were expected to support teacher learning. Next, we situate the tensions that emerged within this experiment and in the broader phenomenon of CSC. Finally, we provide an analysis of these examples and describe actualized (Case 1) and proposed (Cases 2 and 3) revisions to the HLT (Table 4).

Case 1: Challenging Deficit Frameworks

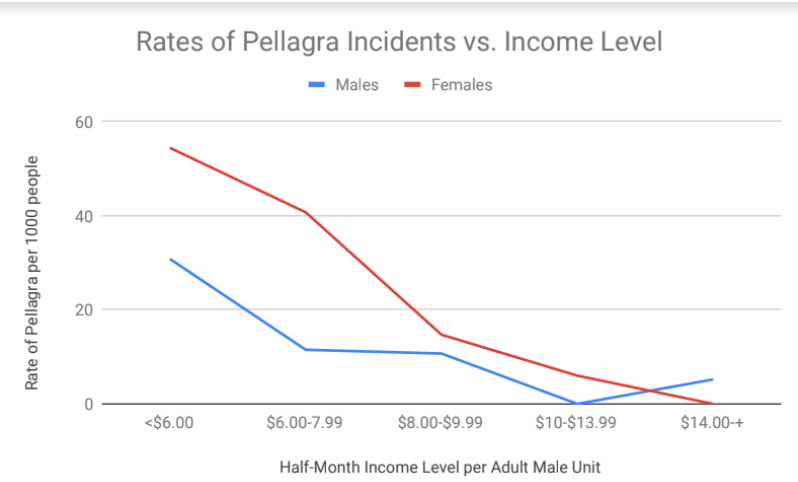
Hypothetical Learning Trajectory

Informed by critical pedagogies of place, a possible learning route for critical consciousness and CSC begins with a local historical event rooted in systemic inequities. We anticipated that framing an investigation of pellagra within the biography of Ella May, the white union organizer murdered during a textile workers' strike, might support interest and engagement. We designed an initial activity for participants to create a timeline of Ella May's

life and hypothesized that during this activity they might ask, “Why were her children dying?” and “What is pellagra?” To explore the pellagra epidemic, we created an interrupted case study (Crabtree & Stephan, in press). As part of the case study, we designed a task for participants to create graphs using original Public Health survey data (Goldberger, Wheeler & Sydenstricker, 1920). We hypothesized that teachers would discern the inverse relationship between pellagra incidence and income and question whether higher wages might have prevented pellagra (Figure 2). We also anticipated that teachers would notice the exclusion of Black persons from the survey data. A more recent analysis of deaths from pellagra revealed that Black women had the highest rates, followed by Black men, white women, and white men (Marks, 2003). We expected that engaging in science practices to explore these issues would increase teachers’ awareness of intersections between scientific research and inequities in society (Learning Goals 1 & 2).

Figure 2

Relationship between pellagra and income level of males and females



Pellagra and diabetes share geographical and socioeconomic distributions. After completing the case study, we planned for participants to compare maps showing the high incidence of both diseases across the Southeastern U.S. We designed this activity to prompt

teachers to interrogate the historical, political, and economic systems in which pellagra and diabetes are rooted. We also planned to have participants use a mapping application to explore access to full-service grocery stores and transportation in the communities in which their students live. Following this activity, teachers might discuss how they would engage students in a similar exercise. We hoped this activity would increase participants' awareness and willingness to support student advocacy around the challenge of food equity (Learning Goal 3).

Competing Conjectures

Discussions around food access, poverty, and disparate rates of disease during the workshop underscore a tension we experienced throughout the TD-DR project. Pre-workshop interview responses revealed a lack of awareness on the part of at least one participant that tracking sorts students by race and socioeconomic class as opposed to academic potential (Darling-Hammond, 2010). A similar narrative arose during the case study. As participants created and analyzed graphs that show an inverse relationship between income and incidence of pellagra (Figure 2), some concluded "people could think poor people cause it." Surprised by this interpretation, we asked, "Is it possible that *poverty* causes pellagra?" The group agreed that it *was* possible, "It just depends on how you interpret the graph, and who's saying it." Later in the case study, as participants grappled with a question regarding the cause of pellagra, one group of participants concluded that the epidemic occurred due to "the economy and ignorance [on the part of] poor people [who] didn't know what pellagra was." Tensions between individualist and systemic perspectives continued as the discussion shifted to the relationship between poverty and food access today. Some participants asserted that limited access to healthy food among families experiencing poverty leads to higher rates of obesity, diabetes, and related diseases while others

attributed health disparities to what is valued or considered important by individuals and families.

An in-the-moment Revision to the HLT

Based on interview data and participant discussions around poverty, food access, and individual choice, we wondered if the community mapping task might reinforce deficit perspectives and bolster determinist views. Aware of the overwhelming presence of Whiteness in science education (Le & Matias, 2019), we also questioned modeling an activity with white teachers that if enacted in classrooms might result in students labeling their own communities as food deserts. After reviewing additional literature on food equity, we omitted the community mapping exercise. Employing data from a critical ethnography of a food distribution program (Kolavalli, 2019), we created a Gallery Crawl activity that emphasized the knowledge and agency of food aid recipients. By incorporating the actual words of clients at a food distribution center we hoped to create a space for counter-storytelling (Ladson Billings & Tate, 1995) within this overwhelmingly white space.

We printed and mounted published dialogue between food aid recipients and food distribution volunteers on large posters around the room. In the published study, the food aid seekers are identified as being Black and Black/Latinx, while the volunteer instructors of nutrition classes at the food distribution center are identified as white. Teachers rotated silently from poster to poster, reading and writing their responses. In one dialogue included in this activity, food aid seekers attending a mandatory nutrition class assert that they do not have access to fresh fruit. In response, the white instructor asks, “Don’t you know you live in a food desert?” Workshop participants critiqued the instructor’s condescending tone and manner during the activity and in the discussion that followed. Written responses on Gallery posters included:

"They know they live in a food desert without having to name it." "[The volunteer instructors] are treating the symptoms and not the disease – lack of access!"; "It isn't as simple as [the volunteer instructor] makes it sound." "[Food aid recipients] know what to do, but that is not the reality of their situation."

Analysis and Further Revisions

Our data indicate that the redesigned instructional sequence and addition of actual words between oppressed/oppressors allowed participants to encounter persons experiencing food insecurity as agentic, informed community members. In their written responses and in the discussion that followed, participants aligned themselves with food seekers. During the remaining workshop sessions and post-workshop interviews, participants cited this activity as one that altered their frame of reference around food inequity and health disparities (Mezirow, 1991). The mid-course revision supported teacher learning and disrupted a harmful narrative that places blame for oppression on the oppressed. Post-workshop analysis underscores the vital role that this "in the moment" revision played in the overall trajectory of the PD experience.

Case 2: Grappling with Whiteness

Hypothetical Learning Trajectory

To launch the discussion about epigenetics, we designed an activity to introduce a review of the structure and function of DNA. During this activity, we planned for participants to conduct an internet search using the search string, "Ernest E. Just," or "James Watson". We hypothesized that teachers would not be familiar with the contributions Ernest Just, a Black biologist, made to science (Learning Goal 1). We also anticipated they would be unaware of derogatory statements attributed to James Watson and might wonder how they should address these comments by a celebrated scientist with their students (Learning Goal 2).

The final part of the instructional sequence was designed to probe and challenge teachers' ideas around the nature of race (Learning Goal 2). We anticipated that these conversations might involve dismantling the false notion that racial categories have a biological basis. We drew on Donovan's (2014; 2016; 2019) research with middle school students that suggests racialized instruction regarding sickle cell anemia (SCA) reinforces biological essentialism. Donovan (2016) recommends using reading materials (textbooks, handouts) that make no reference to race or geography during genetics instruction. Unlike middle school students, adults possess prior knowledge regarding SCA. We hypothesized that using maps to explore the extent of SCA in Southern Asia, along with the distribution of haplotypes across Southern Asia that differ from those in Africa, might prompt teachers to interrogate previous assumptions. We expected that this new knowledge might lead some teachers to question perceptions of SCA as a "Black" disease and to interrogate their frames of reference around race.

In a critical qualitative inquiry, Sheth (2019) describes an encounter in which a student asks his Biology teacher, "Why are we not all of the same race?" (p. 37). We incorporated this vignette into a task in which teachers would discuss with a colleague how they might answer the student's question. We predicted some teachers would express frustration at their lack of knowledge around this topic while others might cling to notions of biological essentialism. At this point, the instructor planned to discuss ways in which the construction of racial categories was used to justify the Trans-Atlantic Slave Trade and colonization of Africa by European powers. (Learning Goal 2) We anticipated teachers might ask how they can teach about SCA and other "raced" disorders without reinforcing race as a biological construct. We also hypothesized that at this point in the workshop they might be prepared to interrogate ways systemic oppression is reinforced in science classrooms (Learning Goal 3).

Competing Conjectures

Discussions around race and racism created tension throughout the design and implementation phases. From our literature review, previous experience, and pre-workshop interviews, we knew that white teachers might avoid discussing race. To develop CSC, however, it is essential that teachers interrogate false notions about racial categories (Learning Goal 2). Early in the design phase, several design team members who identify as White expressed concern that if race was emphasized too early in the workshop some participants might not return for later sessions. After an extended discussion, a team member who identifies as Black questioned why race had to be "massaged in" to the HLT. Agreeing with her colleague, another Black team member noted that if a White instructor brought up race in a PD workshop, her response would be "yeah, let's talk about it!" In contrast, a White team member explained, "I'm coming from the other side where people will cry." Ultimately, the decision was made to discuss the construction of race on the fourth day of a four-day PD workshop.

Data related to enactment of the activity comparing Ernest Just and James Watson reveal an additional tension: reluctance on the part of the instructor and other design team members to interrogate racism. After using the internet to find information about Dr. Ernest Just, a group of workshop participants described his contributions to the field of biology, noting that Just conducted most of his research in Europe "where he was still discriminated against, but always by Americans." A second group had no difficulty finding racist, misogynist, and ableist statements made by James Watson. When asked to share their findings, the group noted that Watson held "some rather controversial views about how skin color is related to intelligence;" those along with other "discriminatory and inappropriate comments," resulted in his resignation from his final academic position. While we prompted teachers to think about who is celebrated in

science, we did not acknowledge how the celebration of James Watson and lack of attention to Ernest E. Just are indicative of racism. Instead, we encouraged teachers to add Ernest Just and others including Imhotep, Charles Drew, and Katherine Johnson to their curriculum to "show [students] that people of color, people in other countries, and women have been doing science for hundreds of thousands of years."

The instructional sequence unfolded on day four as designed. The discourse around the geographical distribution of SCA occurred as anticipated. Responses generated by participants to the question, "why we are not all of the same race," primarily focused on race as a social construction created when people noticed commonalities and differences among groups while others discussed ways that race and culture intersect. Two participants shared an internet-based resource that explicates the evolution of skin color. We acknowledged the value of this resource, but also noted that it answered the question of why humans have different skin colors, not "why are we not all of the same race." To encourage participants to think critically about the period in which racialized categories arose, we displayed images representing the Trans-Atlantic Slave Trade and the colonization of Africa. We did not, however, discuss the role that Western science played in the creation and perpetuation of White Supremacy.

Analysis and Revisions

According to Le & Matias (2019), the emotions of white teachers often become "strategic tool[s] to silence racial dialogue and progress" (p. 21). The HLT that emerged from the design process reveals that the team decision to avoid discussions of race at the beginning of the workshop was probably in error. While the design of the HLT places race at the end of the instructional sequence, data reveal that the subject of race was raised by participants themselves on the first day of the workshop when someone uncovered disparate outcomes among Black and

white women being treated for pellagra. To engage in anti-racist science education, teachers and teacher educators must be prepared to reject any suggestion that disparate health outcomes among racialized groups are rooted in genetic differences. Conversations around race continued throughout the case study and Gallery Crawl activity. Even though the topic surfaced naturally multiple times, we postponed a full discussion of the construction of racial categories until the final session. By doing so, we may have allowed false ideas about race to persist without being challenged.

In order to disrupt notions of Science as White Property (Mensah & Jackson, 2018), teacher educators and designers of PD must move beyond "Hidden Figures" approaches that fail to challenge why so few persons of color are included in the canon of science (Butler, 2014; Sheth, 2019). While contributions of scientists of color were heralded during the workshop, we failed to interrogate the racism exemplified by textbooks and curriculum guides that celebrate James Watson although his racist statements have been widely publicized (Marks, 2017). It is interesting to note that the teachers in this workshop were very aware of Watson and Crick's failure to give credit to Rosalind Franklin for her role in the development of the double helix model. According to Parsons (2014), advancements that have been "around gender in science education are informative for race- and ethnicity- focused efforts" (p. 181).

Our analysis also reveals that instructional materials did not acknowledge the role *science and scientists* played in the creation of racism through classification schemes, craniometry, intelligence testing, and other forms of science and pseudo-science (Gould, 1996). When addressing the question, "Why are we not all one race?" we displayed a slide with pictures of the enslavers and colonizers, placing the blame for the notion of White Supremacy solely in the realm of the *social* sciences. By doing so, we failed to acknowledge the role *science* played in

constructing notions of a biological racial hierarchy (Kendi, 2016). We also limited our discussion of racism to a Black/White dialetic and failed to interrogate our presence as settler colonists on indigenous land.

According to Le and Matias (2019), “whiteness operates in subtle, and yet, at times, not so subtle, ways to maintain White supremacy” (p. 21). This case serves as an example of the importance of attending to issues that provoke resistance and discomfort among designers as well as participants, especially around issues of race and racism. Our analysis requires several revisions to the instructional sequence. First, discussion of the construction of racial categories should occur much earlier in the sequence. In our revised HLT, we have placed the discussion immediately after participants explore food equity, however, we recommend that instructors be prepared to address this topic whenever it arises in the workshop. This initial discussion of race will address the fact that race is the child of racism, not the parent (Coates, 2014). In addition, we will design tools to help participants understand the role that scientific racism has played in the creation and perpetuation of White Supremacy.

To disrupt conceptions of Science as White Property (Mensah & Jackson, 2018), we recommend changes to the task comparing Ernest Just and James Watson. Our revised design maintains the open inquiry approach but incorporates prompts to promote additional discourse among participants. After participants share findings, we will challenge teachers to consider ways in which access to resources and education affects opportunities for persons from marginalized groups (Sheth, 2019). The reality that celebrated scientists contributed to notions of White Supremacy and patriarchy will be interrogated, and teachers will have opportunities to discuss how they might address racism in science through their curriculum and instruction.

Finally, we will encourage participants to reflect on ways that White Supremacy devalues indigenous knowledge and influences our perspective on who can engage in science.

Case 3: Supporting Teacher as Agents of Change

Hypothetical Learning Trajectory

To further support teachers' implementation of justice-oriented curricula, we planned to introduce teachers to the Environmental Justice movement through the story of its origins (McGurty, 2007). Following this presentation and discussion, we designed an activity for participants to create and present a lesson plan around an Environmental Justice issue in their primary subject area (Biology, Chemistry, or Earth and Environmental Science). We anticipated that participants would find numerous intersections between environmental justice and state curriculum standards. More importantly, we hypothesized that they would transfer what they had learned about systemic inequities to issues of environmental justice and interrogate how corporations and government authorities are complicit in environmental racism (Learning Goal 3). We situated these activities in the HLT after discussing epigenetics and prior to unpacking the construction of race. We also anticipated that after discussing race and racism, participants might question how schooling reinforces racial inequities (Learning Goal 2) and be ready to consider ways they can engage in science education for liberation (Learning Goal 3).

Competing Conjectures

Analysis of participants' Environmental Justice lesson plans reveal limited attention by this group of teachers to ways that power structures maintain systemic oppression. According to one group's plan, students would read stories about the impact of pesticide exposure on agricultural workers and their children and then research non-chemical methods farmers might use to control harmful insects; the ongoing struggle by agricultural workers for fair wages and a

safe work environment was not addressed. Two presentations highlighted the problem of hog waste disposal, a significant concern in the state in which these teachers live. One group planned to study how soil and water are affected by excessive hog wastes and then engage students in a Town Hall activity during which students would be assigned to different stakeholder groups. Through this activity teachers hoped to support students' abilities to engage in scientific argumentation and consider varying points of view. When participants were asked how they planned to address disparities in access to power, they acknowledged they had not considered this factor. While one teacher mentioned that many persons employed in the hog industry are Hispanic, neither group addressed the fact that the majority of homes next to "spray fields" in this area are primarily owned by Black families who are descendants of those enslaved prior to 1865.

Power also emerged as a point of tension during the final session of the workshop. As participants discussed how racial categories came into being, several acknowledged that their understanding of racism is limited compared to that of their students. Teachers acknowledged they had not learned the history of marginalized groups and were curious about who controls what is taught in classrooms. Several participants wondered aloud if it is possible to "change the system." It takes "power and money" to change systems, one participant asserted, and "[teachers] don't have money or power." As the conversation continued, the group agreed that as teachers they do have the power to discuss race and racism within their own classrooms. When a participant suggested, however, that teachers should "also try to influence… our peers to think this way as well," her colleagues hesitated, admitting they were not comfortable addressing racial inequities with other adults. Post-workshop interviews revealed similar tensions. One teacher described his own high school experience characterized by memorization of facts as

opposed to critical thinking and learning, but also acknowledged that praise for high test scores is a strong motivating factor. While some participants described plans to discuss systemic inequities with students, others expressed concern that doing so might bring unwanted attention from administrators and parents.

Analysis and Revisions

Tensions around power that emerged during the final sessions of the workshop are not surprising given the participants' struggle described earlier to recognize the role that systems play in the creation of disparate outcomes. Analysis of data reveals a lack of awareness regarding ways that wealth and influence can be used to silence those with limited resources. It is intriguing, however, that this same group of teachers were quick to point out their own positionality as the oppressed (lacking power and money) within an oppressive educational system. According to Mahoney (1997), the transparency of privilege makes it possible for those in the dominant culture to only perceive those areas in which one is not powerful; to the marginalized, however, the bubble of privilege is not transparent at all. We acknowledge, however, that these educators work in a system in which they have limited control over the curriculum they teach or ways in which their students are assessed.

Our analysis reveals the need for several revisions as outlined in Table 4. First, instead of trying to address multiple topics in one workshop, we recommend that the instructional sequence center *either* food equity *or* environmental justice. By narrowing the focus, participants can engage in a case study, interrogate racism and race in relationship to the central topic, and hear the stories of those affected by oppressive systems prior to working with their colleagues to develop a lesson plan. In addition, we plan to scaffold the activity with a set of questions for teachers to address in their presentation: Who are the stakeholders? How is power distributed

among these stakeholders? In what ways are persons in your local community impacted by this or similar issues? Is there activism occurring around this issue currently? Who is engaged in that activism?

Our analysis also suggests revisions to the HLT that reflect our commitment to inquiry and a critical place-based approach through an activity designed to support teachers in the process of decolonizing schools and classrooms. According to the data, during the final session of the workshop and in post-workshop interviews, participants questioned how they might become active in creating systemic change. We have added an activity to the instructional sequence through which teachers will examine policies and practices in the places they inhabit each day. Using data available on the Department of Education Office of Civil Rights website (2016), participants can evaluate whether their school and school district provide equitable access to advanced learning opportunities in science for students of color and students experiencing poverty. If disparities are uncovered, teachers will be able to discuss with their colleagues how they might work together to disrupt inequitable systems.

Conclusion

As institutions grapple with systemic racism, innovative frameworks are needed to support culturally relevant, critically oriented science teacher education. In this article, we introduced a construct, Critical Science Consciousness (CSC), and method, TD-DR, to address this pressing need. Our findings underscore the importance of intentional design and critical analysis in the development and implementation of innovative professional development. Our analysis also indicates that employing science practices to investigate systemic inequities in the places teachers live and teach has great potential. While the CSC workshop described in this manuscript was enacted in a specific context, we have described the design, implementation,

analysis, and suggested revisions, to inform others who might want to adapt this innovation in their own unique settings.

The research reported here has several implications. According to Horton and Freire (1990), a biology teacher must *know* biology. Likewise, a science teacher educator must *know* science education. Does a teacher educator know their discipline if they have not interrogated its history? To challenge the historical legacy of racism in science and science education, Sheth (2019) calls for critically-framed tools, resources and practices to support teachers as they "grapple with racism" (p. 56). The activities and tools created for this innovation supported white science teachers' awareness of systemic inequities, an important step in recognizing the harm done to groups marginalized by race. Our experience also suggests that designing an innovation to support practicing teachers' CSC is a transformative process for designers and instructors as well as for those with whom they have an opportunity to learn.

As cell phone videos expose ubiquitous violence against persons of color, it is imperative that science teachers and teacher educators address the role science continues to play in the framing of Black and White as biologically distinct categories. The workshop reported here was conducted in 2019, however the analysis and writing of this manuscript occurred during the initial months of 2020. Consequently, these issues have taken on a more urgent tone with each news cycle. The combined realities of Covid-19 and a long-overdue reckoning with racism should not be ignored by science educators or education researchers. As new data unveils increasingly disparate outcomes for individuals and communities under the weight of systemic oppression, it is imperative that those who provide on-going teacher education understand the inequities that created our current reality and become conscious of the power we possess to engage in emancipatory science education.

Table 3

A Hypothetical Learning Trajectory

Topic	Learning Goals	Tools	Activities/ Science Practices (NGSS, XXXX)	Possible Topics of Discourse
Investigating Pellagra	1 2 3	Historical case study: • Ella May biography (2-page handout) • Narratives: History of pellagra • Original scientific publications • Diagrams of cellular respiration • Map: Pellagra in the United States • Graph: Pellagra deaths from 1915 – 1930	Constructing a timeline; reading historical summaries; analyzing graphs and maps; forming hypotheses; analyzing experiments and surveys; creating graphs; presenting findings Asking questions; analyzing and interpreting data; using mathematics and computational thinking; developing and using models; constructing explanations; evaluating and communicating information	•The impact of non-sustainable agriculture •The silence around Ella May's murder and the 1929 textile workers' strike •What is pellagra? •Possible causes of pellagra •Bias in scientific investigations •The ethics of conducting experiments in prisons •Connections between pellagra and poverty •Implications of the high rates of pellagra among females and specifically Black females
Pellagra, Diabetes and Obesity	1	Maps: Pellagra (Marks, 2003) and Diabetes Type II (Center for Disease Control website)	Evaluating maps Analyzing and interpreting data; constructing explanations	•Similarities between the pellagra and diabetes/ obesity epidemic •Factors that contribute to high incidence of diabetes
Mapping food insecurity	1	Mapping applications	Identifying food deserts	• Access to fresh food and produce • Transportation as an important factor in food access

Who do we celebrate as a scientist?	2	Websites containing biographical information re: Ernest Just and James Watson	Internet search, discussion and presentations Obtaining, evaluating and communicating information	• Contributions of Ernest Just • Recent statements by James Watson • Race and science identity
Linking the Past and the Present: Epigenetics	1 3 4	Diagrams of epigenetic mechanisms Video: Epigenetics Images, data and maps: A new perspective on Diabetes and the Pima	Evaluating and discussing historical events and recent scientific findings Using models, analyzing and interpreting data, constructing explanations	• Epigenetics is a confusing concept • Connections between famine in previous generations the current diabetes epidemic
Environmenta l Justice	1	Narrative and visual images: the birth of the environmental justice movement in Warren County, NC Essential Standards for science courses	Analyzing State Standards; cooperative lesson planning; presenting participant-designed units Obtaining, evaluating and communicating information	• Lack of knowledge about the environmental justice movement • Intersections between the concept of environmental justice and State curriculum • The challenges of time and standardized testing
Sickle cell anemia (SCA) as a model of a "raced" disease	2 3	• Maps: Global distribution of SCA • Visual: current education research on genetics instruction	Analyzing maps, re-evaluating previous conceptions re: SCA; Discussing current research Using models; analyzing and interpreting data; engaging in argument	• SCA as a disease with African origins • Human migration and sickle cell genes • New knowledge of multiple haplotypes alters conceptualization of SCA as "raced" disease

			from evidence	• Framing genetics instruction in non-raced ways • Curriculum standards and testing
Defining race	2 3 4	• Diagrams: the evolution of skin color	Pair and share conversations; large group discussion Engaging in argument from evidence; obtaining, evaluating, and communicating information	• What is race? • Does discussing race in a science classroom reinforce race as a biological construct? • White supremacy in society today

Table 4
A Revised Hypothetical Learning Trajectory

Topic	Learning Goals	Tools	Activities/ Science Practices (NGSS, XXXX)	Possible Topics of Discourse
Investigating Pellagra	1 2 3	Historical case study: • Ella May biography (2-page handout) • Narratives: History of pellagra • Original scientific publications • Diagrams of cellular respiration • Map: Pellagra in the United States • Graph: Pellagra deaths from 1915 – 1930	Constructing a timeline; reading historical summaries; analyzing graphs and maps; forming hypotheses; analyzing experiments and surveys; creating graphs; presenting findings Asking questions; analyzing and interpreting data; using mathematics and computational thinking; developing and using models; constructing explanations; evaluating and communicating information	•The impact of non-sustainable agriculture •The silence around Ella May's murder and the 1929 textile workers' strike •What is pellagra? •Possible causes of pellagra •Bias in scientific investigations •The ethics of conducting experiments in prisons •Connections between pellagra and poverty •Implications of the high rates of pellagra among females and specifically Black females
Pellagra, Diabetes and Obesity	1	Maps: Pellagra (Marks, 2003) and Diabetes Type II (Center for Disease Control website)	Evaluating maps Analyzing and interpreting data; constructing explanations	•Similarities between the pellagra and diabetes/ obesity epidemic •Factors that contribute to high incidence of diabetes

Addressing Food Inequity Today		Data from ethnographic study of a food distribution center (Kolavalli, 2019)	Gallery Crawl and discussion Evaluating and communicating information	• Perceptions that food distribution volunteers have of food aid recipients • Underlying causes of food insecurity
Sickle cell anemia (SCA) as a model of a "raced" disease	2 3	Maps: Global distribution of SCA Visual: current education research on genetics instruction	Analyzing maps, re-evaluating previous conceptions re: SCA; Discussing current research Using models; analyzing and interpreting data; engaging in argument from evidence	• SCA as a disease with African origins • Human migration and sickle cell genes • New knowledge of multiple haplotypes alters conceptualization of SCA as "raced" disease • Framing genetics instruction in non-raced ways • Curriculum standards and testing
Defining race	2 3 4	Diagrams: the evolution of skin color; 18th and 19th century; craniometry classification systems Images: Enslavement and Colonization	Pair and share conversations; large group discussion Engaging in argument from evidence; obtaining, evaluating, and communicating information	• What is race? • Does discussing race in a science classroom reinforce race as a biological construct? White supremacy in society today
Engaging Students in Justice Issues	3	Guiding questions	Analyzing NGSS or state Standards; cooperative lesson planning; presenting participant-designed units	• Connections between NGSS or state standards and science-oriented justice issues • Topics that engage students and acknowledge/support them as agents of change

Linking the Past and the Present: Epigenetics	1 3 4	Diagrams of epigenetic mechanisms Video: Epigenetics Images, data and maps: A new perspective on Diabetes and the Pima	Evaluating and discussing historical events and recent scientific findings Using models, analyzing and interpreting data, constructing explanations	• Epigenetics is a confusing concept • Connections between famine in previous generations the current diabetes epidemic
Investigating Inequitable Access to Advanced Courses	2 3	Department of Education Office of Civil Rights website	Finding and analyzing equity data for individual schools and districts; presenting findings; brainstorming solutions Analyzing and interpreting data; constructing explanations	• Racial inequities in access to advanced science and math coursework • Potential ways to raise awareness and increase opportunities for marginalized students • Other areas of inequity (discipline disproportionality)

References

Bakker, A., & Van Eerde, D. (2013). An introduction to design-based research with an example from statistics education. In A. BiknerAhsbahs, C. Knipping, & N. Presmeg (Eds.), *Doing qualitative research: methodology and methods in mathematics education* (pp. 2-56). Springer. https://doi.org/10.1007/978-94-017-9181-6_16

Baldwin, J. (1984). On being white... and other lies. *Essence*, *14*(12), 90-92.

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530-544. https://doi.org/10.1002/tea.21204

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. Horizon Research, Inc.

Barber, A. (2013). Fostering science comprehension, vocabulary and motivation in English language learners: A design research study. In T. Plomp & N. Nieveen (Eds.), *Educational design research* (pp. 141-158). SLO.

Barton, A. C. (2003). *Teaching science for social justice*. Teachers College Press.

Barton, A. C., & Tan, E. (2020). Beyond Equity as Inclusion: A Framework of "Rightful Presence" for Guiding Justice-Oriented Studies in Teaching and Learning. *Educational Researcher*, https://doi.org/0013189X20927363.

Bell, D. (1992). *Faces at the bottom of the well: The permanence of racism*. Basic Books.

Bell, P. (2019) Infrastructuring teacher learning about equitable science instruction. *Journal of Science Teacher Education*, 30(7), 681-690. https://DOI:10.1080/1046560X.2019.1668218

Brown, B. A. (2019). *Science in the city: Culturally relevant STEM education*. Harvard Education Press.

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *Journal of Research in Science Teaching, 54*(9), 1143-1173. https://doi.org/10.1002/tea.21401

Brown, J. C., & Crippen, K. J. (2017). The knowledge and practices of high school science teachers in pursuit of cultural responsiveness. *Science Education, 101*(1), 99-133. https://doi.org/10.1002/sce.21250

Brown, B. A., Ribay, K., Pérez, G., Boda, P. A., & Wilsey, M. (2020). A virtual bridge to cultural access: Culturally relevant virtual reality and its impact on science students. *International Journal of Technology in Education and Science, 4*(2), 86-97. https://doi.org/10.46328/ijtes.v4i2.45

Bryce, N., Wilmes, S. E., & Bellino, M. (2016). Inquiry identity and science teacher professional development. *Cultural Studies of Science Education, 11*(2), 235-251. https://doi.org/10.1007/s11422-015-9725-1

Butler, M. (2014). Second-class citizens, first-class scientists: Using sociocultural perspectives ot highlight the successes and challenges of African American scientists during the Jim Crow era. In M. Butler, M. Atwater, & M. Russell (Eds.) Multicultural science education: Preparing teachers for equity and social justice (pp. 29-39). Springer. https://doi.org/10.1007/978-94-007-7651-7_3

Chambers, D. W. (1983). Stereotypic images of the scientist: The Draw-a-Scientist Test. *Science education, 67*(2), 255-265. https://doi.org/10.1002/sce.3730670213

Chinn, P. W. U. (2007). Decolonizing methodologies and indigenous knowledge: The role of culture, place, and personal experience in professional development. *Journal of Research in Science Teaching, 44*(9), 1247-1248. https://doi.org/10.1002/tea.20192

Coates, T. N. (2014). *Between the world and me*. Text Publishing.

Cobb, P. (1987). An investigation of young children's academic arithmetic contexts. Educational Studies in Mathematics, 18, 109-124. https://doi.org/10.1007/BF00314722

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Crabtree, L. & Lim, J. H. (in progress). Learning and teaching science through critical pedagogies: A multiple case study.

Crabtree, L. & Stephan, M. (in press). Using critical case studies to cultivate in-service teachers' critical science consciousness. *Innovations in Science Teacher Education*.

Crabtree, L. & Stephan, M. (in process). But that happens today: An analysis of teacher learning around critical science consciousness.

Crenshaw, K., Gotanda, N., Peller, G., & Thomas, K. (1995). Critical race theory. *The Key Writings that formed the Movement.* The New Press.

Darling-Hammond, L. (2010). *The flat world and education: How America's commitment to equity will determine our future*. Teachers College Press.

Donovan, B. M. (2014). Playing with fire? The impact of the hidden curriculum in school genetics on essentialist conceptions of race. *Journal of Research in Science Teaching*, *51*(4), 462-496. https://doi.org/10.1002/tea.21138

Donovan, B. M. (2016). Framing the genetics curriculum for social justice: An experimental exploration of how the biology curriculum influences beliefs about racial difference. Science Education, 100(3), 586–616. https://doi.org/10.1002/sce.21221

Donovan, B. M., Semmens, R., Keck, P., Brimhall, E., Busch, K. C., Weindling, M., Duncan, A., Stuhlsatz, M., Bracey, Z., Bloom, M., Kowalski, S. & Salazar, B. (2019). Toward a more humane genetics education: learning about the social and quantitative complexities of human genetic variation research could reduce racial bias in adolescent and adult populations. *Science Education*, *103*(3), 529-560. https://doi.org/10.1002/sce.21506

DuBois, W.E.B. (1903). *The souls of black folk*. Millenium Publications.

Duster, T. (2015). A post-genomic surprise. The molecular reinscription of race in science, law and medicine. *The British Journal of Sociology*, *66*(1), 1-27. https://doi.org/10.1111/1468-4446.12118

Etheridge, E. (1972). *The butterfly caste: A social history of pellagra in the South*. Greenwood Publishing.

Freire, P. (1970). *Pedagogy of the oppressed*. Bloomsbury Publishing.

Freire, P. (1973). *Education for critical consciousness*. Bloomsbury Publishing.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*(1), 167-186. https://doi.org/10.1002/sce.21488

Glasson, G. E., Frykholm, J. A., Mhango, N. A., & Phiri, A. D. (2006). Understanding the earth systems of Malawi: Ecological sustainability, culture, and place-based education. *Science Education*, *90*(4), 660-680. https://doi.org/10.1002/sce.20148

Glasson, G. E., Mhango, N., Phiri, A., & Lanier, M. (2010). Sustainability science education in Africa: Negotiating indigenous ways of living with nature in the third space. *International Journal of Science Education, 32*(1), 125-141. https://doi.org/10.1080/09500690902981269

Goldberger, J. (1916). The transmissibility of pellagra: Experimental attempts at transmission to the human subjects. *Public Health Reports, 31*(46) 3159-3173. https://doi.org/10.2307/4574262

Goldberger, J., Waring, C. H., & Willets, D. G. (1915). The prevention of pellagra: a test of diet among institutional inmates. *Public Health Reports (1896-1970)*, 3117-3131. https://doi.org/10.2307/4572932

Goldberger, J., & Wheeler, G. A. (1920). The experimental production of pellagra in human subjects by means of diet. In J. Goldberger (Ed.), *Goldberger on pellagra*. (pp. 54-94). Baton Rouge, LA: Louisiana State University Press.

Goldberger, J., Wheeler, G., & Sydenstricker, E. (1920). A study of the relation of diet to pellagra incidence in seven textile-mill communities of South Carolina in 1916. *Public Health Reports, 35*(12), 648-713. https://doi.org/10.2307/4575517

Goldberger, J., Wheeler, G., & Sydenstricker, E. (1920). A study of the relation of family income and other economic factors to pellagra incidence in seven cotton-mill villages of South Carolina in 1916. *Public Health Reports, 35*(46), 2673-2714. https://doi.org/10.2307/4575780

Gould, S. J. (1996*). The mismeasure of man.* Norton.

Gravemeijer, K. & Cobb, P. (2013). Design research from a learning perspective. In T. Plomp (Ed.) *Educational design research* (pp. 45-85). SLO.

Green, A. (2014). The systematic misuse of science. In M. Butler, M. Atwater, & M. Russell (Eds.) Multicultural science education: Preparing teachers for equity and social justice (pp. 11-28). Springer. https://doi.org/10.1007/978-94-007-7651-7_2

Grimberg, B. I., & Gummer, E. (2013). Teaching science from cultural points of intersection. *Journal of Research in Science Teaching*, *50*(1), 12-32. https://doi.org/10.1002/tea.21066

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational researcher*, *32*(4), 3-12. https://doi.org/10.3102/0013189X032004003

Gutiérrez, K. D., & Vossoughi, S. (2010). Lifting off the ground to return anew: Mediated praxis, transformative learning, and social design experiments. *Journal of Teacher Education*, *61*(1-2), 100-117. https://doi.org/10.1177/0022487109347877

Habermas, J. (1981). *The Theory of Communicative Action*. Beacon Press.

Horton, K. (2015). *Martyr of Loray Mill: Ella May and the 1929 textile workers strike in Gastonia, North Carolina.* McFarland and Company, Inc.

Horton, M. & Freire, P. (1990). *We make the road by walking.* Temple Press.

Johnson, C. C. (2011). The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *Journal of Research in Science Teaching*, *48*(2), 170-198. https://doi.10.1002/tea.20405

Just, E. E. (1933). Cortical cytoplasm and evolution. *American Naturalist*, *67*(108) 23. https://doi.org/10.1086/280466

Kendi, I. X. (2016). *Stamped from the beginning: The definitive history of racist ideas in America*. Random House.

King, N. S., & Pringle, R. M. (2019). Black girls speak STEM: Counterstories of informal and formal learning experiences. *Journal of Research in Science Teaching*, *56*(5), 539-569. https://doi.org/10.1002/tea.21513

Kohli, R., Picower, B., Martinez, A. N., & Ortiz, N. (2015). Critical professional development: Centering the social justice needs of teachers. *The International Journal of Critical Pedagogy*, *6*(2).

Kokka, K. (2020). Social justice pedagogy for whom? Developing privileged students' critical mathematics consciousness. The Urban Review. https://doi.org/10.1007/s11256-020-00578-8.

Kolavalli, C. (2019). Whiteness and Food Charity: Experiences of Food Insecure African-American Kansas City Residents Navigating Nutrition Education Programs. *Human Organization*, *78*(2), 99-109.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (2018). Foreward. In J. Settlage, S. Southerland, L. Smetana, & P. Lottero-Perdue (Eds.) *Teaching science to every child* (pp. xi-xvii). [Foreward]. Routledge.

Ladson-Billings, G. (2011). Yes, but how do we do it? Practicing culturally relevant pedagogy. In J. Landsman & C. Lewis (Eds.), *White teachers/diverse classrooms: Creating inclusive schools, building on students' diversity and providing true educational equity.* (pp. 33-46). Stylus.

Ladson-Billings, G. (2017). The (r)evolution will not be standardized: Teacher education, hip hop pedagogy, and culturally relevant pedagogy 2.0. In D. Paris and H. S. Alim (Eds.),

Culturally Sustaining Pedagogies: Teaching and Learning for Justice in a Changing World. (pp. 141-156). Teachers College Press.

Ladson-Billings, G. & Tate, W. F. (1995). Toward a critical race theory of education. *Teachers College Record*, *97*(1) 47-68.

Laughter, J. C., & Adams, A. D. (2012). Culturally relevant science teaching in middle school. *Urban Education*, *47*(6), 1106-1134. https://doi.org/10.1177/0042085912454443

Le, P. T., & Matias, C. E. (2019). Towards a truer multicultural science education: how whiteness impacts science education. *Cultural Studies of Science Education*, *14*(1), 15-31. https://doi.org/10.1007/s11422-017-9854-9

Lee, O., & Luykx, A. (2006). *Science education and student diversity: Synthesis and research agenda*. Cambridge University Press.

Lorusso, L. (2011). The justification of race in biological explanation. *Journal of Medical Ethics, 37*, 535-539. http://dx.doi.org/10.1136/jme.2011.043752

Lyon, G. E. (1999). *Where I'm from: Where poems are from*. Absey & Co.

Madkins, T. C., & McKinney de Royston, M. (2019). Illuminating political clarity in culturally relevant science instruction. *Science Education*, *103*(6), 1319-1346. https://doi.org/10.1002/sce.21542

Marks, H. (2003). Epidemiologists explain pellagra: gender, race, and political economy in the work of Edgar Sydenstricker. *Journal of the History of Medicine and Allied Sciences, 58*(1), 34-55. https://www.muse.jhu.edu/article/39699.

Marks, J. (2017). *Is science racist?* Polity.

McGurty, E. (2007). Transforming environmentalism: Warren County, PCBs, and the origins of environmental justice. Rutgers University Press.

Mensah, F. M. (2011). A case for culturally relevant teaching in science education and lessons learned for teacher education. *The Journal of Negro Education*, 296-309. https://www.jstor.org/stable/41341135

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science teacher education. *Teachers College Record*, *120*(1), 1-38.

Mertens, D. (2015). *Research and evaluation in education and psychology*. Sage Publications.

Mezirow, J. (1991). *Transformative dimensions of adult learning*. Jossey-Bass.

Mezirow, J. (1997). Transformative learning: Theory to practice. *New Directions for Adult and Continuing Education*, (74), 5-12.

Milner, R. (2012). But what is urban education? *Urban education, 47*(3) 556-561. https://doi.org/10.1177/0042085912447516

Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education*, *101*(6), 1034-1060. https://doi.org/10.1002/sce.21305

Morning, A. (2011). *The nature of race: How scientists think and teach about human difference*. Los Angeles, CA: Univ of California Press.

Mutegi, J.W. (2011). The inadequacies of "Science for All" and the necessity and nature of a socially transformative curriculum approach for African American science education. *Journal of Research in Science Teaching*, 48(3), 301-316. https://doi.org/10.1002/tea.20410

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press.

Parsons, E. C. (2014). Unpacking and critically synthesizing the literature on race and ethnicity in science education. *Handbook of research in science education*, 167-183.

Roberts, D. (2011). *Fatal invention: How science, politics, and big business re-create race in the twenty-first century*. New Press/ORIM.

Rodriguez, A. J. (1998). Strategies for counterresistance: Toward sociotransformative constructivism and learning to teach science for diversity and for understanding. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *35*(6), 589-622. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6<589::AID-TEA2>3.0.CO;2-I

Rodriguez, A. J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. *Journal of Research in Science Teaching*, *52*(7), 1031-1051. https://doi.org/10.1002/tea.21232

Rothstein, M. A., Harrell, H. L., & Marchant, G. E. (2017). Transgenerational epigenetics and environmental justice. *Environmental epigenetics*, *3*(3). https://doi.org/10.1093/eep/dvx011

Sheth, M. J. (2019). Grappling with racism as foundational practice of science teaching. *Science Education*, *103*(1), 37-60. https://doi.org/10.1002/sce.21450

Skloot, R. (2010). *The immortal life of Henrietta Lacks*. Broadway Paperbacks.

Simon, M. A. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for research in mathematics education*, 114-145. https://doi.org/10.2307/749205

Simon, M. (2000). Research on mathematics teacher development: The teacher development experiment. In A. Kelly & R. Lesh (Eds.), *Handbook of research design in mathematics and science education* (pp. 335-359). Lawrence Erlbaum Associates Publishers.

Simon, M. & Tzur, R. (2004) Explicating the Role of Mathematical Tasks in Conceptual Learning: An Elaboration of the Hypothetical Learning Trajectory, *Mathematical Thinking and Learning, 6*(2) 91-104. https://doi.org/10.1207/s15327833mtl0602_2

Sparks, R. A., Baldwin, K. E., & Darner, R. (2020). Using Culturally Relevant Pedagogy to Reconsider the Genetics Canon. *Journal of Microbiology & Biology Education*, *21*(1). https://doi.org/10.1128/jmbe.v21i1.1901

Stephan, M. & Cobb, P. (2013). Teachers engaging in integer design research. In T. Plomp & N. Nieveen (Eds.), *Educational design research: Introduction and illustrative cases* (pp. 277-298)**.** SLO (Netherlands institute for curriculum development)

Stephan, M., & Rasmussen, C. (2002). Classroom mathematical practices in differential equations. *Journal of Mathematical Behavior, 21,* 459–490. https://doi.org/10.1016/S0732-3123(02)00145-1

Steffe, L. P. (1991). The constructivist teaching experiment: Illustrations and implications. In E. von Glasersfeld (Ed.), *Radical constructivism in mathematics education* (pp. 177-194). Kluwer Academic. https://doi.org/10.1007/0-306-47201-5_9

Stromholt, S., & Bell, P. (2018). Designing for expansive science learning and identification across settings. *Cultural Studies of Science Education*, *13*(4), 1015-1047. https://doi.org/10.1007/s11422-017-9813-5

Sullivan, S. (2013). Inheriting racist disparities in health: Epigenetics and the transgenerational effects of white racism. *Critical Philosophy of Race*, *1*(2), 190-218. https://doi.org/10.5325/critphilrace.1.2.0190

Suriel, R. L., & Atwater, M. M. (2012). From the contribution to the action approach: White teachers' experiences influencing the development of multicultural science curricula. *Journal of Research in Science Teaching*, *49*(10), 1271-1295. https://doi.org/10.1002/tea.21057

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 32(1), 5–8. https://doi.org/10.3102/0013189X032001005

Toulmin, S. E. (1958). *The uses of argument*. Cambridge University Press.

Underwood, J. & Mensah, F.M. (2018). An investigation of science teacher educators' perceptions of culturally relevant pedagogy." *Journal of Science Teacher Education, 29*(1), 46-64. https://doi.org/10.1080/1046560X.2017.1423457

Upadhyay, B., Atwood, E., & Tharu, B. (2020). Actions for sociopolitical consciousness in a high school science class: A case study of ninth grade class with predominantly indigenous students. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21626

U.S. Department of Education. (2016). *Office for Civil Rights* (Data Collection). Retrieved from http://ocrdata.ed.gov/

von Glasersfeld, E. (1995). *Radical constructivism: A way of knowing and learning*. The Falmer Press.

Waterland, R. A., & Jirtle, R. L. (2003). Transposable elements: targets for early nutritional effects on epigenetic gene regulation. *Molecular and cellular biology*, *23*(15), 5293-5300. https://doi.org/10.1128/MCB.23.15.5293-5300.2003

Zion, S., Allen, C. D., & Jean, C. (2015). Enacting a critical pedagogy, influencing teachers' sociopolitical development. *The Urban Review*, *47*(5), 914-933. https://doi.org/10.1007/s11256-015-0340-y

CHAPTER V [ARTICLE 4] USING CRITICAL CASE STUDIES TO CULTIVATE IN-SERVICE TEACHERS' CRITICAL SCIENCE CONSCIOUSNESS

Lenora M. Crabtree and Michelle Stephan

In press at *Innovations in Science Teacher Education*.

Abstract

Culturally relevant and responsive science instruction includes support of students' socio-political, or critical, consciousness. A lack of experience with marginalization, and limited attention to critical perspectives in science content and methods courses, however, may leave educators ill-equipped to address intersections of diversity, equity, and science instruction. Curriculum is needed that supports critical consciousness development among science teachers and their students. We describe an innovation, a critical inquiry case study, designed to address this essential facet of culturally relevant pedagogy. Design research methodology guided our development of an interrupted, historical case study employed as part of a four-day professional development workshop for secondary science teachers. In addition to provoking critical awareness and agency, the case study was designed to highlight ways that science itself may create or perpetuate inequities, or serve as a tool for liberation, a content-specific construct we call *critical science consciousness*. Implementation of the critical case study and participating teachers' interactions with case materials are described. In addition, we highlight learning goals developed to support critical science consciousness and provide insights into ways teachers exhibited growth in each area. Teachers report heightened understanding of the role science

plays in perpetuating inequities, transformations in ways they think about systemic inequities that impact students and families, and growing awareness of the possibilities inherent in teaching science for liberation.

Using Critical Case Studies to Cultivate In-service Teachers' Critical Science Consciousness

> Are there other examples besides Pellagra? …What else happened because people didn't have the resources or power to heal or fix whatever was happening to them? …What else happened that they never taught us?
>
> (Teacher participant, Critical Science Consciousness workshop)

Equipping teachers to engage all students in equitable and meaningful science education is a persistent challenge for science teacher educators (Atwater et al., 2010; Underwood & Mensah, 2018). Research indicates that when instruction and mentoring emphasize issues relevant to marginalized communities, student engagement and persistence increase (Campbell et al., 2015; Garibay, 2015; Thoman et al., 2015). These findings underscore an essential component of culturally relevant instruction; culturally relevant practitioners actively support students' development of socio-political, or critical, consciousness (Ladson-Billings, 1995). However, studies of science teachers learning to be culturally relevant practitioners reveal limited attention to critical perspectives (Brown et al., 2019; Johnson, 2011; Suriel & Atwater, 2012).

A lack of attention to facets of culturally relevant teaching that align with a critical approach (Freire, 2000; Giroux, 2011) is not unique to science teacher education. According to Ladson-Billings (2011), while educators understand the importance of high expectations for all learners and make attempts to foster cultural competence, they are often unable to support student critical consciousness because they "have not developed a socio-political consciousness of their own" (p. 41). Teacher candidates, the majority of whom are White, may only be prompted to consider topics of "diversity" and "equity" in a specific course reserved for this purpose during their pre-service teacher education (Ladson-Billings, 2011, p. 42). According to Madkins and de

Royston (2019), "teachers' consciousness must be robust enough to weave [culturally relevant teaching] into the daily fabric of their teaching; it must constitute their pedagogical approach rather than being an add-on" (p. 8). Limited attention in science content and content-specific teacher preparation courses to ways that science, discrimination, and injustice intersect, combined with a lack of personal experience of marginalization, leaves future educators ill-equipped to incorporate critical aspects of culturally relevant instruction in science classrooms (Underwood & Mensah, 2018). Innovations in science teacher education that support critical consciousness and content-specific critical consciousness development are needed.

In this article, we describe an instructional resource, a critical case study, designed as part of a larger 4-day professional development for in-service secondary science educators. The main purpose of the professional development was to engage teachers in experiences that had the potential to promote critical consciousness. In the next section, we define critical consciousness and introduce critical *science* consciousness (CSC), a discipline-specific form of socio-political consciousness, that heavily informed our work. We then discuss the research methodology that guided the design, implementation, and analysis of the professional development sessions (Design-based Research). Guided by our methodology, we designed a critical case study as one of the experiences that led to increased CSC. Thus, we describe literature supporting the use of case studies in teacher education and science education and present the specific case study used in this research. We conclude by summarizing findings related to teachers' critical consciousness and CSC development, and discuss the implications of those findings. We contend that critical case studies provide a research-based, yet novel, lens through which teachers can explore how science, race, and poverty intersect and, as a result, be equipped to recognize and address systemic inequities in classrooms, schools, and communities.

Critical Science Consciousness

To be critically consciousness is to possess an awareness of one's situated reality, to acknowledge systemic inequities, yet maintain a belief that oppression can be overcome; critical consciousness is hopeful, not fatalistic (Friere, 2000). Teachers who support critical consciousness development encourage students to use their knowledge "both to critique the world in which they live and, when necessary, to intervene in socially responsible ways in order to change it" (Giroux, 2011, p. 14). In an earlier study (Crabtree & Lim, under review), we found that teacher participants were able to combine critical consciousness and new scientific knowledge to consider ways that science has created and perpetuated inequities. According to Erduran and Dagher (2014), the degree to which science is a social institution is an under-emphasized aspect of Nature of Science instruction. Acknowledging the political nature of science enables students to "develop a critical sense of scientific literacy without undermining the importance, value, or benefits of scientific knowledge and rationality" (Erduran & Dagher, 2014, p. 148).

We define *critical science consciousness* (CSC) as an understanding of the role that science has played in marginalizing groups, as well as an awareness of the potential for science to liberate. In designing a PD experience to support in-service science teachers' CSC, the following learning goals were created:

LG1. Teachers will understand that science has been practiced in ways that are inequitable and unjust, e.g. who is acknowledged as a scientist, what questions scientists ask, and how investigations to answer those questions are conducted (Sheth, 2019).

LG2. Teachers will develop an awareness that science has contributed to individual and systemic inequities in society, e.g. race as a biological construct (Donovan, 2014; 2016; Kendi, 2016; Morning, 2009;); focusing on individuals as opposed to systems and structures that oppress (Parsons, 2014; Tolbert & Bazzul, 2017).

LG3. Teachers will recognize the potential for science to contribute to the liberation of individuals, groups, and society.

Teacher Development Design Research

Designing for increased CSC begs the creation of new professional development materials that build critical consciousness through the lens of scientific inquiry. As such, Design-based Research was used to guide the development of the professional development experience. Design Research has gained prominence in mathematics and science education and varies in its purposes and settings (Cobb et al., 2003; Stephan & Cobb, 2013). Although Design Research can be conducted at a range of levels, the process we describe here is Teacher Development Design Research (TD-DBR) (Simon, 2000) in which a PD experience is designed, implemented, analyzed, and revised by a lead instructor who is a member of a research team. The main activity of researchers in this approach (TD-DBR) is highly interventionist in that the instructor/researcher is proactively altering the PD experience in real time based upon how participants engage in the PD with the learning goals as the backdrop.

The TD-DBR project described in this article was conducted to test and revise a PD experience designed to cultivate in-service science teachers' critical consciousness in general, and CSC in particular. The design team included the first author, a former high school science teacher and doctoral candidate at the time of the study who served as the PD instructor, and the second author, a university mathematics educator, as well as two high school teachers (science and Special Education), one district science leader, two design research experts, and a university faculty member/research biologist. The research question that guided the project was: *In what ways does the PD experience support and constrain the growth of in-service high school science teachers' a) critical consciousness and b) critical science consciousness?*

Case Studies and Science Teacher Education

One set of instructional materials that we designed to ground the initial work of the participants was a critical case study. The case method has been adapted for science education and science teacher preparation as a pedagogical strategy to engage students and pre-service teachers in active, collaborative, inquiry-based learning (DeCoito & Fazio, 2017; Herreid et al., 2012). Case methodology offers a profound opportunity to increase theoretical understanding and promote a form of knowledge that moves beyond "how" to explicate "what and why" (Shulman, 1986, p. 13). Historical incidents, socio-scientific issues, and current controversies related to science can be investigated through well-designed cases (Allchin, 2000; DeCoito & Fazio, 2017). Case studies offer opportunities for students to explore the tentative, creative, and culturally situated aspects of the nature of science that are difficult for students and teachers to conceptualize; the interrupted case method is especially well suited for science education as its structure encourages students to wrestle with an authentic research problem in ways that mirror how scientists actually work (Herreid et al., 2012).

Cases should not merely report an event, they should be a "case of something… that can be explicated, interpreted, argued, dissected, and reassembled" (Shulman, 1986, p. 12). Although criticality is not an essential element of case pedagogy, we have found that the method's narrative form invites the use of critical perspectives to explore issues of power and agency. When developed using a critical lens, the story embedded in a case becomes a vehicle to illuminate persons or events excluded from dominant narratives. The use of storytelling as a counter-narrative, a tenet of critical race theory (Ladson-Billings & Tate, 1995), offers opportunities for voices that have been silenced by more powerful forces to be heard.

We draw from these emphases to create a new model for science teacher education, the Critical Case Study. Critical Case Studies incorporate historical or current incidents in science to support learning and provoke critical consciousness and CSC. Topics investigated using this approach have the potential to increase participants' awareness of ways in which power, opportunity, and resources are unequally distributed. Critical case studies highlight narratives of those who have been marginalized in and through science. As this example described reveals, critical case studies also provide opportunities for science teacher educators to model the incorporation of Next Generation Science Standards (NGSS) science practices, cross-cutting concepts, and disciplinary core ideas (NGSS Lead States, 2013) in creative ways (see Table 1).

In addition to case methodology, the case described below incorporates a critical pedagogy of place (Gruenewald, 2003). The educators who attended the PD live and teach in a region of the Southeastern United States dominated by the textile industry throughout the 20th Century. Although most of the mills are now idle, their specter looms large over classrooms, schools, and communities. Incorporating elements of historical, interrupted case studies and critical, place-based pedagogy, "Mill Mothers' Lament: The Scourge of the South" explores the history of an epidemic that has disappeared from science textbooks, revealing the impact of poverty and race in the pre-World War II "New" South (Etheridge, 1972, p. 152).

Table 1

Alignment of Case Study with NGSS Three-Dimensional Learning

Case Study Elements	Science Practices	Cross-Cutting Concepts	Disciplinary Core Ideas
Introduction	Asking questions	Cause and Effect	ESS3.C: Human impacts on earth's systems
Part 1	Asking questions	Patterns	LS1.B Growth and development of organisms
Part 2	Asking questions	Patterns	LS1.C: Organization for matter and energy flow in organisms
Part 3	Constructing explanations	Cause and Effect	PS3.D: Energy in chemical processes and everyday life
Part 4	Obtaining, evaluating, and communicating information	Cause and Effect	LS1.B: Growth and development of organisms
Part 5	Using Mathematics Analyzing data	Cause and Effect	ETS2: Links among engineering, technology, science, and society
Part 6	Asking questions Evidence-based argumentation	Systems and system models Stability and change	LS2.C: Ecosystem dynamics, functioning and resilience
Part 7	Developing and using models	Energy and matter: Flows, cycles and conservation	LS1C: Organization for matter and energy flow in organisms
Part 8	Using mathematics Analyzing and interpreting data	Patterns Cause and effect	ETS2.A: Interdependence of science, engineering and technology

Overview of the Workshop

A critical case study was incorporated within a PD workshop attended by seven high school science teachers who consented to be part of the TD-DBR study. Teacher participants were recruited through an email sent by the district curriculum specialist to all secondary science educators. This method of random sampling resulted in a group of participants who exhibited diversity in their length of teaching experience, science content expertise, instructional level of courses taught, school size, and school demographics, however, all participants identified as White. Workshop sessions were conducted by the first author on four consecutive days in July 2019. Data collected during the TD-DBR study included pre- and post-workshop interviews with six of the participants, audio-recordings of workshop sessions, field notes, small-group responses to critical case study questions, and reflective writings by teacher participants. Participants engaged in activities related to the critical case study during the first two days of the workshop. During the preceding week, the teachers had participated in a district-sponsored PD in the same setting. Accordingly, they exhibited a level of comfort with each other and in the setting. Prior to introducing the case, the instructor guided the group to establish norms and engage in a reflective team building exercise.

To launch the critical case study (available at http://bit.ly/millmotherslament), and in keeping with the place-based focus of the workshop, participants read a brief biographical sketch of a local White woman, Ella May, a mother, textile worker, songwriter, and leader in attempts to unionize Southern textile mills (Horton, 2015). Participants worked in small groups to construct a timeline of Ella May's life, tracing her family's movements from subsistence farming to logging, sharecropping, and eventually, textile work. Ella May's murder, carried out by a White mob as she was riding in a truck transporting Black potential strikers to a rally, made

international headlines. Only one teacher, however, was familiar with the event. As they learned that four of Ms. Mays' nine children died before the age of two, participants cited a desire to earn a *living* wage as a powerful motivator for the young mother's involvement in the strike. Records revealed that Ella May's children died of whooping cough and pellagra (Horton, 2015). One teacher stated, "My students would relate to her story. Many of them are working to help their family." Unlike whooping cough, participants had never heard of pellagra which provoked a desire to investigate further.

Mill Mothers' Lament: The Scourge of the South

The critical case study described below was created using Google Forms and is available at http://bit.ly/millmotherslament. As an interrupted case study, participants were provided with access to each of the eight parts in sequence. Working in small groups of three or four, participants read, discussed insights, and engaged in science practices to answer questions embedded in the case study. For example, in Part 5, teachers transferred data from historical public health surveys into electronic spreadsheets for analysis. As participants engaged in the activities, PD leaders moved from group to group to listen for their thinking, observations which allowed the instructor to conduct a large group debrief session around the teachers' ideas. For each part of the case, following 15-20 minutes of collaboration, the instructor encouraged teachers to discuss their findings with the larger group before having access to the next part of the case study. To maintain a sense of mystery and allow participants to experience ways in which science knowledge evolves (Herreid et al., 2012), they were asked not to access the internet during the case study.

Part 1: A Sudden Epidemic

Part One introduced pellagra, a deadly disease first reported in the United States in the early 1900's characterized by a severe rash and symptoms including dementia (Etheridge, 1972). The fact that the disease most often occurred in low-income households offered opportunities for teachers to think about systemic inequities that impact groups, as opposed to individuals (Learning Goal 2). During small group discussions, teachers expressed surprise that they had never heard of pellagra. A prompt within the case materials asked participants to record what intrigued them about the disease; participants indicated they were intrigued that the disease had a greater impact on "the poor more than the wealthy." An additional question in the case study prompted participants to think about lines of inquiry they would pursue if they were in the position of Dr. Goldberger, a Public Health scientist dispatched to investigate the epidemic.

Part 2: A Long Train Ride

Riding along with Dr. Goldberger from Baltimore to Augusta, GA, participants read varied hypotheses regarding the cause of pellagra promoted in 1914. Common in Southern Europe among agricultural workers, peasants, and beggars, explanations for pellagra ranged from spoiled corn to bacterial infection (Rajakumar, 2000). Privately-funded groups surveying mill villages reported inconclusive evidence regarding possible links among diet, sanitary conditions, and pellagra (Bollett, 1992). The Public Health Service conducted experiments on animal models which were inconclusive. A question in the case study materials prompted teachers to consider why researchers investigating the same disease might reach different conclusions. Participants' responses that "different backgrounds and specialties" as well as "money and race biases" might impact conclusions indicated an awareness that scientific investigations can be influenced by the identity of those conducting research (Learning Goal 1). Drawing a parallel between pellagra and

the HIV/AIDS epidemic one teacher stated, “It’s just like HIV—who it affects, impacts who cares. Money equals power” (Learning Goal 2).

Part 3: Hypotheses and Investigations

As Dr. Goldberger traveled throughout the Southern United States, he observed the living conditions and noted that persons experiencing poverty consumed a diet of cornbread, molasses, and fatback. Questions embedded in the case study materials prompted participants to discuss inferences Dr. Goldberger might have made from his observations and ways lack of knowledge of Southern culture might have allowed him to see what others did not see. These questions prompted the teachers to consider again how bias might impact scientific investigations (Learning Goal 1). One small group concluded that while familiarity may be beneficial, it can also blind investigators to the “big picture.”

Part Four: Orphanages, Sanitarium, Prison Farms, and Filth Parties

Dr. Goldberger and a team of investigators conducted experiments to determine the cause of pellagra in orphanages, sanitariums, prisons, and laboratories. Using primary sources (Goldberger, 1916; Goldberger et al., 1915; Goldberger & Wheeler, 1920), teachers worked in small groups to determine the hypotheses, methods, materials, variables, results, and conclusions reached in their assigned experiment. The investigations included studies in which the variety of food provided to children in an orphanage and residents of a sanitarium was increased; in a separate study, however, the diet of prison inmates was restricted. These contrasting situations were included in the case study to provoke discussions among participants about ways scientific investigations may cause harm to vulnerable populations (Learning Goal 1).

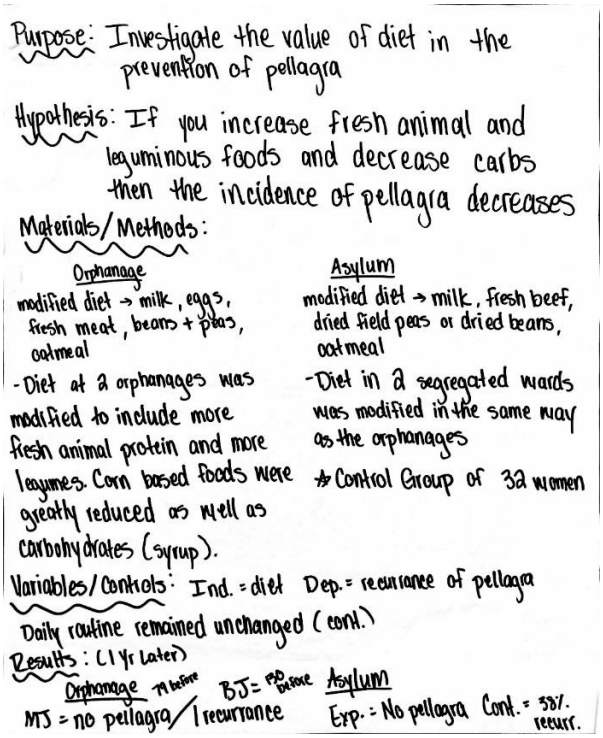
As the small groups worked, an older teacher who, as a child, lived near the town in which his assigned experiment was conducted exclaimed,

> They are treating the [Black] women differently! Even in the experimental group the Black women are not doing as well. It's right there in the data! [The sanitarium] is segregated and they're treating them differently. I know this area and I guarantee this place was segregated and the Black women were not getting the same treatment.

After analyzing the experiments, participants displayed their findings on posters and presented them at an "Annual Conference on Pellagra" [Figure 1]. During a discussion of the group's collective findings, several teachers challenged the ethics of the experiment in which food was withheld from incarcerated persons. "Is that right to do, even if you have been found guilty of a crime?" one teacher asked. "Would they be allowed to do that today?"

Figure 1

Poster Created by Teacher Participants

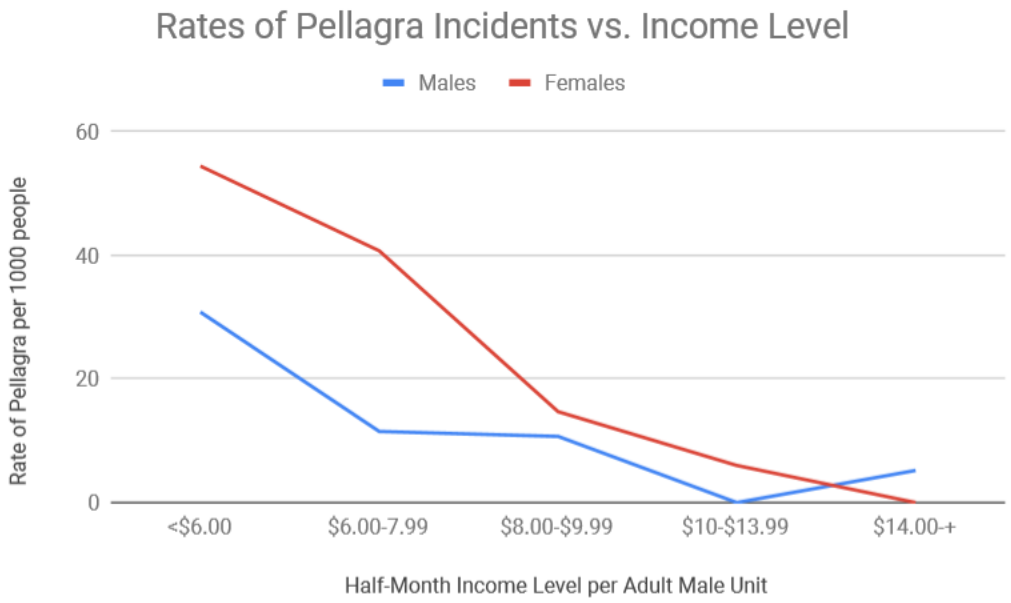


Part Five: Pellagra and the Economy

In addition to conducting empirical investigations, Dr. Goldberger and a team of epidemiologists surveyed mill villages in South Carolina to explore correlations between the salary of the mill workers, food consumption, and pellagra (Goldberger et al., 1920a; 1920b). This portion of the case study incorporated technology as participants transferred original data into spreadsheets and created graphs that exposed the extent to which the incidence of pellagra correlated with gender and income levels [Figure 2]. This exercise was designed to reveal the power of data generated by scientific investigations to illuminate systemic inequities and potentially provoke change (Learning Goal 3). Graphs created by the participants emerged as important images informing small and large group discussions about gendered roles, income inequities, and food insecurity in the present as well as the past.

Figure 2

Graph Created by Teacher Participants



Although surveys conducted in mill villages provided evidence of a relationship between pellagra and family income, careful reading revealed a glaring omission. “With the exception of

a few negro families which were not considered, all were white, and with hardly a single exception, of Anglo-Saxon stock, born in this country of American-born parents" (Goldberger et al., 1920b, p. 2678). This sampling methodology illustrates how questions and methods in science investigations may reflect bias (Learning Goal 1) and perpetuate systemic inequities (Learning Goal 2). As teachers read this excerpt emphasized in the case materials, they expressed surprise; during small group discussions several participants drew parallels between the exclusion of Black families in these surveys and gender exclusion in pharmaceutical research.

Part Six: A Premature Celebration

Fewer cases of pellagra occurred as cotton prices rose in 1920. In 1921, however, a steep decline in cotton prices led to a significant number of new cases. In a graphic example of the potential for science to contribute to the liberation of marginalized groups (Learning Goal 3), Dr. Goldberger's documentation of this new phase of the epidemic sounded an alarm that reached the White House. President Harding's appeals to Congress and the Red Cross to provide relief, however, were met with loud denials by Southern leaders (Bollett, 1992).

Questions embedded in the case study prompted participants to examine the impact of monoculture on the region and to discuss whether pellagra was a disease of ignorance, economy, or both. Some teachers focused on a lack of knowledge and poor dietary practices among persons who experienced pellagra, stating "if they knew what it was though... I am sure they could've re-evaluated their thinking." Others challenged their colleagues to consider what this case revealed about financial barriers to healthy eating, "What do you do? There's no other food." Participants also connected inequities that created the pellagra epidemic to food insecurity today:

> Yeah, that [situation still] exists today. ...When I go home I [can] cook a meal for my family. But if I'm poor, I may go to a second job because I need more money.... So, I

> can't make food even though I know I need to feed my children healthy things. ...There's still a barrier even though you know that it's bad for you. There are still economic barriers that keep people feeling like they [can] never do the right thing.

Part Seven: The Pellagra Preventing Factor

Combining a breakthrough announced in 1937 with current models of cellular respiration, teachers evaluated how a lack of niacin, a critical component of NAD, produced the symptoms of pellagra in this section of the case. Bolstered by the need for a healthy workforce during World War II, government regulators mandated the fortification of wheat flour with niacin in the early 1940s (Etheridge, 1972). Outbreaks of pellagra subsided, revealing once again the liberatory potential of scientific advancements coupled with new technologies (Learning Goal 3). Lingering questions remained, however, regarding why knowledge of this epidemic has disappeared from classrooms and textbooks.

Part Eight: New Questions About an "Old" Disease

In Part 8, teachers analyzed new findings that revealed extensive racial and gender disproportionality in deaths from pellagra (Chacko, 2005; Marks 2003); at the height of the epidemic, more Black women died from pellagra than any other group. While analyzing this data, one participant concluded, "Basically, the Black females were members of two groups that are discriminated or treated [as] lesser," revealing that critical scientific inquiry might support teachers' understanding of concepts including intersectionality (Crenshaw, 1990). During this section of the case study, teachers were prompted to return to the sampling methodology described in Part 5 (Goldberger et al.,1920b) and consider ways that "research practices determine what is seen and not seen, analyzed, or considered" (Marks, 2003, p. 55). One group

of teachers summarized their discussion with the following statement: “What is studied is what is worth studying in the eyes of those doing or paying for the research.”

Emerging Critical Science Consciousness

Case study materials employed during the PD experience provoked teachers to consider ways that science relates to issues of social justice and equity. Participants also made multiple connections between their curriculum and topics addressed in the case study. One teacher planned to use the case study to help students understand that “deforestation led to the decrease in subsistence farming, which made them all move to the mill cities and started the whole thing…so they can see why it's so important to have a sustainable model and what can happen when you don’t.”

In addition to discussions that occurred during the implementation of the case study, further evidence of teacher growth emerged in post-workshop interviews. Three learning goals relative to critical science consciousness development guided the design of the instructional materials and analysis of the interview data. Learning Goal 1 addressed teachers’ awareness that science can be practiced in ways that are inequitable. Evidence of learning included increased awareness by teachers of the potential for bias to influence scientists’ methods and conclusions. In addition, participants described the lack of concern regarding the impact of pellagra on persons of color as evidence of their limited value to those investigating the epidemic. The potential for science to contribute to broader societal inequities was the focus of Learning Goal 2. Connections made by participants between ways discrimination in science may reinforce health disparities revealed growth in this area.

Learning Goal 3 addressed the importance of teachers recognizing that science can be a tool for liberation. An interesting expansion of this objective emerged during post-workshop

interviews as participants described the important role inquiry played in their learning during the workshop. One participant stated, “I just enjoyed working with the data and ...trying to find an explanation for this trend.” Another said, “Anytime we get to look at data and discuss it with our groups and try to draw conclusions… it’s really very engaging, very memorable. You’re practicing the skills, honing the skills, using science.” In a similar fashion, he described a classroom in which he would be motivated to stay in the teaching profession as one in which, “students are coming up with solutions ...coming up with new conceptions about the world and then using those in their lives.” As these statements revealed, the opportunity to engage in inquiry can be liberating for teachers as well as students. Using critical inquiry in professional development provides a model of teaching science for liberation for practicing teachers.

Analysis revealed that studying a historical epidemic both supported and constrained teachers’ development of critical consciousness related to racial discrimination. In a post-workshop interview, one participant described the treatment of persons of color as having been “glossed over” when he was younger, acknowledging that “the people in charge did not want the truth out because then they would have to admit there is a discriminatory factor, there is a racial factor. There [are] truths that they did not want known.” Another teacher stated, “I definitely reached the conclusion that a long time ago there were a lot of injustices relating to things like race and skin color.” When asked if these issues still exist today, the participant stated, “Um, it’s possible. Certainly not to the degree it did back then.” This response revealed a challenge presented by addressing issues of race and class discrimination using *historical* case studies. While the instructional materials prompted one teacher to re-evaluate what had been ignored in the past, the historical nature of the case study allowed the other teacher to persist in his belief that inequities do not occur to a significant degree in the present.

Conclusions and Implications

For teacher educators seeking to incorporate a critical framework in teacher preparation and professional development, the "dilemma lies in how to get teachers—who have been educated and inducted into patterns of tradition and hierarchy that reproduce inequality—to teach in critical, emancipatory ways" (Ladson-Billings, 2000, p. 151). Based on our experiences with practicing teachers, we suggest the use of critical case studies to support the development of teacher socio-political consciousness. Other topics that science teacher educators may consider exploring include incidents of environmental injustice, distribution of "free" cigarettes that led to nicotine addiction among members of the military, and the role of pharmaceutical companies in the opioid epidemic. The case study summarized in this article prompted participants to reconsider deficit-based conceptualizations of communities experiencing poverty and the compounding impact of racial discrimination. We also find that critical case studies can be designed to support the development of CSC, a deeper understanding of ways that science has contributed to inequities yet can also be a tool for liberation. By incorporating critical inquiry, science teacher educators can support teachers and promote a more socially just and culturally relevant science education.

References

Allchin, D. (2000). How not to teach historical cases in science. *Journal of College Science Teaching*, *30*(1), 33.

Atwater, M. M., Freeman, T. B., Butler, M. B., & Draper-Morris, J. (2010). A case study of science teacher candidates' understandings and actions related to the culturally responsive teaching of science. *International Journal of Environmental and Science Education*, *5*(3), 287-318.

Bollett, A. (1992). Politics and pellagra: The epidemic of pellagra in the U.S. in the early twentieth century. *The Yale Journal of Biology and Medicine, 65*, 211-221.

Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2019). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. *Urban Education. 54*(6), 775-803. https://doi.org/10.1177/0042085918794802

Campbell, A., Skvirsky, R., Wortis, H., Thomas, S., Kawachi, I., & Hohmann, C. (2014). NEST 2014: Views from the trainees - Talking about what matters in efforts to diversify the STEM workforce. *CBE-Life Sciences Education*, *13*(4), 587-592. https://doi.org/10.1187/cbe.14-04-0068

Chacko, E. (2005). Understanding the geography of pellagra in the United States: The role of social and place-based identities. *Gender, Place & Culture*, *12*(2), 197-212. https://doi.org/10.1080/09663690500094849

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13. https://doi.org/10.3102/0013189X032001009

Crenshaw, K. W. (1990). Mapping the margins: Intersectionality, identity politics, and violence against women of color. *Stanford Law Review*, *43*, 1241.

DeCoito, I., & Fazio, X. (2017). Developing case studies in teacher education: Spotlighting socio-scientific issues. *Innovations in Science Teacher Education, 2*(1).

Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the Nature of Science for Science Education*. Springer.

Etheridge, E. (1972). *The butterfly caste: A social history of pellagra in the South*. Greenwood Publishing.

Friere, P. (2000). *Pedagogy of the oppressed*. Bloomsbury Academic.

Garibay, J. (2015). STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students*? Journal of Research in Science Teaching*, *52*(5), 610-632. https://doi.org/10.1002/tea.21203

Giroux, H. (2011). *On critical pedagogy.* Bloomsbury.

Goldberger, J. (1916). The transmissibility of pellagra: Experimental attempts at transmission to the human subjects. *Public Health Reports, 31*(46) 3159-3173. https://doi.org/10.2307/4574262

Goldberger, J., Waring, C. H., & Willets, D. G. (1915). The prevention of pellagra: a test of diet among institutional inmates. *Public Health Reports (1896-1970)*, 3117-3131. https://doi.org/10.2307/4572932

Goldberger, J., & Wheeler, G. A. (1920). The experimental production of pellagra in human subjects by means of diet. In J. Goldberger (Ed.), *Goldberger on pellagra*. (pp. 54-94). Louisiana State University Press.

Goldberger, J., Wheeler, G., & Sydenstricker, E. (1920). A study of the relation of diet to pellagra incidence in seven textile-mill communities of South Carolina in 1916. *Public Health Reports, 35*(12), 648-713. https://doi.org/10.2307/4575517

Goldberger, J., Wheeler, G., & Sydenstricker, E. (1920). A study of the relation of family income and other economic factors to pellagra incidence in seven cotton-mill villages of South Carolina in 1916. *Public Health Reports, 35*(46), 2673-2714. https://doi.org/10.2307/4575780

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational researcher, 32*(4), 3-12. https://doi.org/10.3102/0013189X032004003

Herreid, C., Schiller, N., & Herreid, K. (2012). *Science stories: Using case studies to teach critical thinking*. NSTA Press.

Horton, K. (2015). *Martyr of Loray Mill: Ella May and the 1929 textile workers strike in Gastonia, North Carolina.* McFarland and Company, Inc.

Johnson, C. C. (2011). The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *Journal of Research in Science Teaching, 48*(2), 170-198. https://doi.org/10.1002/tea.20405

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (2000). Put up or shut up: The challenge of moving from critical theory to critical pedagogy (A formative assessment). In D. Hursh & E. W. Ross (Eds.), *Democratic social education: Social studies for social change*.(pp. 149-164). Routledge.

Ladson-Billings, G. (2011). Yes, but how do we do it? Practicing culturally relevant pedagogy. In J. Landsman & C. Lewis (Eds.), *White teachers/diverse classrooms: Creating inclusive schools, building on students' diversity and providing true educational equity* (pp. 33-46). Stylus.

Ladson-Billings, G. & Tate IV, W. (1995). Toward a critical race theory of education. *Teacher's College Record*, *97*(1), 47-68.

Marks, H. (2003). Epidemiologists explain pellagra: gender, race, and political economy in the work of Edgar Sydenstricker. *Journal of the History of Medicine and Allied Sciences*, *58*(1), 34-55. https://doi.org/10.1093/jhmas/58.1.34

Madkins, T., & de Royston, M. (2019). Illuminating political clarity in culturally relevant science instruction. *Science Education, 103*(6), 1319-1346. https://doi.org/10.1002/sce.21542

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.

Rajakumar, K. (2000). Pellagra in the United States: a historical perspective. *Southern Medical Journal, 93*(3). 272-277.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://doi.org/10.3102/0013189X015002004

Simon, M. (2000). Research on mathematics teacher development: The teacher development experiment. In A. E. Kelly & A. Lesh (Eds.), *Handbook of research design in mathematics and science education* (pp. 335-359). Lawrence Erlbaum Associates Publishers.

Stephan, M., & Cobb, P. (2013). Teachers engaging in mathematics design research. In T. Plomp, & N. Nieveen (Eds.), *Educational design research – Part B: Illustrative cases* (pp. 277-298). SLO.

Suriel, R. L., & Atwater, M. M. (2012). From the contribution to the action approach: White teachers' experiences influencing the development of multicultural science curricula. *Journal of Research in Science Teaching*, *49*(10), 1271-1295. https://doi.org/10.1002/tea.21057

Thoman, D.B., Brown, E.R., Mason, A.Z., Harmsen, A.G., & Smith, J.L. (2015). The role of altruistic values in motivating underrepresented minority students for biomedicine. *BioScience*, *65*(2), 183-188. https://doi.org/10.1093/biosci/biu199

Underwood, J. B., & Mensah, F. M. (2018). An investigation of science teacher educators' perceptions of culturally relevant pedagogy. *Journal of Science Teacher Education*, *29*(1), 46-64. https://doi.org/10.1080/1046560X.2017.1423457

CHAPTER VI: CONCLUSION

Annie's voice could be heard long before she reached the doorway to her Biology classroom. Once inside, her tendency to socialize did not inhibit her quick grasp of course content. While absences sometimes affected her grades, Annie's teacher could not ignore the ease with which she learned science concepts or her ability to help others whose intuitive knowledge did not match her own.

Annie's brilliance and personality took center stage one morning when the teacher failed in her attempts to explain a challenging concept. An animated video illustrating how species evolve was engaging, but students still looked confused. As the teacher struggled to help the class make connections between the images and concept, Annie leapt to her feet. "Play it again, Miss!" Fictitious animals appeared on the screen as Annie began an impromptu stream of consciousness verse to explain the process of speciation. As the video ended, everyone snapped appreciation for their classmate-turned-teacher.

As the end of the year approached, Annie's teacher implored her to enroll in an advanced biology course. "I have finished science," she objected. "The office said so." Undeterred, the teacher assured Annie she would do well in the class and that it would prepare her for college. "I know I'm smart, but I need to be where I can be myself," Annie explained. "Ms. Crabtree, don't worry about me. I am happy right where I am. Those White classes aren't for me."

Across the United States thousands of students of color experience science, and the classrooms in which it is taught, as White property (Jackson & Mensah, 2017). While some are discouraged from taking science courses beyond what is required for graduation by counselors, teachers, and administrators who operate from deficit frameworks, others exclude themselves as an act of resistance (Howard, 2018). Annie was a junior during my final semester as a high school science teacher. While her brilliance in science was obvious, previous experiences had

convinced Annie that science teaching and learning occur in White spaces in which she could not be herself. Her story is not an isolated one.

The research described in the articles that comprise this dissertation originated with Annie and other students I encountered who struggled to find their place in science. The lack of access to meaningful science education constitutes a significant social justice issue, yet many White educators continue to teach in ways that ignore or reject the needs of students of color (Johnson & Atwater, 2013). Research conducted over a twenty-year period suggests that students from marginalized backgrounds are eager to engage in science coursework and research that addresses issues of concern to their communities (Campbell et al., 2015; Garibay, 2015; Thoman et al., 2014). These findings echo the asset-pedagogies described by Ladson Billings (1995). A central tenet of culturally relevant teaching involves supporting students' socio-political consciousness; teachers who lack socio-political, or critical, consciousness are unable to enact CRP (Ladson-Billings, 2011; 2017).

In this dissertation we introduced a new construct, *critical science consciousness* (CSC), along with the findings of a Teacher Development-Design Research (TD-DR) experiment conducted by the author. The aim of this research was to develop theory around practicing science teachers' development of critical consciousness and CSC. As design-based research, the investigation was situated in the context of a PD workshop. Each of the three articles that comprise this dissertation explored the process of CSC development through a different lens. Here we present findings, offer implications, and suggest opportunities for future research. In addition, we envision how transformed science classrooms, laboratories, and teacher education programs could be spaces in which Annie might see herself not only as a student but as a scientist and science teacher.

Findings and Implications

> Our greatest intellectual adventures often occur within us – not in the restless search for new facts and new objects on the earth or in the stars, but from a need to expunge old prejudices and build new conceptual structures. No hunt can have a sweeter reward, a more admirable goal, than the excitement of thoroughly revised understanding – the inward journey that thrills real scholars and scares the bejesus out of the rest of us (Gould, 1996, p. 399-400).

Findings that emerge from this TD-DR experiment indicate that science content and practices can be leveraged to increase practicing teachers' critical consciousness and critical science consciousness. Teacher participants in the TD-DR project described the opportunity to examine historical and current public health issues through authentic inquiry as engaging and memorable. Our analysis also suggests materials to support the use of science practices to investigate systemic inequities can be found in the sociopolitical history of a region when one is attuned to the impact of systemic oppression. A desire to situate this research in the place our participants live and teach prompted us to examine the labor struggles characteristic of the textile industry in the southeastern United States. As we researched the intolerable conditions that led women and men to organize and strike, we stumbled upon the pellagra epidemic. Primary source materials detailing research around this event became essential tools in the PD workshop. Like the primary researcher, Dr. Joseph Goldberger, we initially centered our study of pellagra on the White textile workers we assumed were its primary victims. Late in the research process we uncovered studies conducted seventy years after the epidemic revealing disparate outcomes for Black communities that mirror the impact of a pandemic raging at the time of this writing. What lessons are there for us in the history of our places that might help us confront seemingly

insurmountable challenges today? These are the questions a critically conscious teacher can explore with her students. Annie and her peers must discover the answers.

Implications from this project suggest that supporting teachers' CSC demands intentional, reflexive praxis. Jackson and Mensah (2018) employed "science as White Property" to explore the experiences of pre-service teachers of color in science teacher education (p. 9). In our study, we found this construct to be a useful lens to examine ways Whiteness as Property (Ladson Billings & Tate, 1995) operated in the design and implementation of the PD workshop. As a practicing teacher and Biologist, the author, a White female, has experienced "science as White Property" in diverse settings over four decades. Critically examining a cherished discipline in which one has felt welcome, and guiding others to do the same, is a necessary endeavor that should not be left to our colleagues in the arts and social sciences. It is imperative that White science teacher educators and education researchers expose and address White Supremacy in the history and current practices of our discipline. How might doing so alter our praxis and create a more welcoming space for those who demonstrate the gift of teaching like Annie?

At the end of the 20th century the scientists at the helm of the Human Genome Project announced there is no genetic basis for race; 21st century scientists, educated in classrooms in which a biological basis for race was never interrogated continue to receive millions of dollars in grant funding to search for genetic explanations to explain diseases rooted in disparate environmental conditions (Roberts, 2011). Their research and its pharmaceutical products fuel false notions about race while creating profits for stockholders (Duster, 2015). What solutions might we discover if those funds were used to address inequities in cities, towns, and rural areas without clean air, safe drinking water, and access to nutritious foods? How might research and

funding practices be transformed by Annie's presence at scientific conferences and in policy discussions?

As an adaptation of DBR, TD-DR allows researchers to develop theory while enacting innovations in education. Future iterations of this TD-DR project may lead to a stable instructional theory around how to support teachers' CSC. Other possibilities for future research using TD-DR are myriad. Morales-Doyle (2017) has proposed a social justice scientific issues (SJSI) framework that incorporates elements of CRP with a socio-scientific approach. Sadler (2004) defines socio-scientific issues as "complex, open-ended, often contentious dilemmas, with no definitive answers" (p. 514). Our findings support the use of TD-DR to investigate best practices to equip pre-service and in-service science educators to enact SJSI frameworks. It is worth noting that while a myriad of solutions may exist to a dilemma with social justice implications (e.g. where to place a hazardous waste disposal site), resolutions that disenfranchise some while privileging others should not be positioned as equivalent to those that protect vulnerable populations.

We offer TD-DR as a tool for teacher educators seeking to engage in transformative science education research. Scientists value diversity in living things; Western science, however, is often practiced in ways that devalue diverse ontologies and epistemologies (Bang & Marin, 2015). As a collaborative process, TD-DR offers opportunities for science teacher educators to engage in transformative *interdisciplinary* research. The creation of a multi-disciplinary design team for this research brought together individuals with varied interests and expertise who engaged in rich discussions around intersections of science, history, and sociology. One member of the team encouraged us to examine how CSC might liberate White teachers and teacher educators, a challenge that prompted us to consider the impact of epigenetics in new ways.

During the seminar around which the pilot study was conducted, we had discussed the transgenerational impact of the transatlantic slave trade and 400 years of enslavement and oppression on the epigenome of Black students. How might the legacy and cognitive dissonance of enslaving other humans be etched on the epigenome of White students and teachers?

Teacher participants in this project consistently described the use of critical pedagogies as liberating. Science teachers enter the profession to engage students in a discipline they love yet often find themselves "teaching to a test." One participant admitted that if test scores continue to drive his practice, he is not willing to continue teaching. If, however, he can teach in an environment in which "students are coming up with solutions ...coming up with new conceptions about the world and then using those in their lives" he is willing and eager to stay. In a post-workshop interview, a veteran teacher acknowledged, "We are always talking about the human impact on the environment, but we never encourage students to think about the human impact on the humans." As Black, Hispanic, and Native American communities experience disparate rates of hospitalizations and death during a global pandemic while individuals are subjected to police brutality, protest signs carried by students across the globe declare "I can't breathe." In the midst of these crises, students want to discuss the realities of the world they are going to lead. When teachers and teacher educators become learners alongside their students, classrooms become places of liberation. Engaging in research and practice that supports the use of inquiry-based practices to investigate these challenges can provide teachers with the tools and knowledge they need to transform science classrooms into spaces that declare Annie's life matters.

References

Agre, P., & Leshner, A. I. (February 19, 2010). Editorial: Bridging science and society. *Science, 327*, 5968. https://doi.org/10.1126/science.1188231

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. Journal of Research in Science Teaching, 52(4), 530-544. https://doi.org/10.1002/tea.21204

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. Horizon Research, Inc.

Bell, D. (1992). *Faces at the bottom of the well: The permanence of racism*. Basic Books.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347-370. https://doi.org/10.1002/sce.20186

Campbell, A., Skvirsky, R., Wortis, H., Thomas, S., Kawachi, I., & Hohmann, C. (2014). NEST 2014: Views from the trainees - Talking about what matters in efforts to diversify the STEM workforce. *CBE-Life Sciences Education*, *13*(4), 587-592. https://doi.org/10.1187/cbe.14-04-0068

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Corcoran, T. B., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: An evidence-based approach to reform.* CPRE Research Reports. https://doi.org/10.12698/cpre.2009.rr63

Daro, P., Mosher, F. A., & Corcoran, T. B. (2011). *Learning trajectories in mathematics: A foundation for standards, curriculum, assessment, and instruction*. CPRE Research Reports. https://doi.org/10.12698/cpre.2011.rr68

deMarrais, K. & LeCompte, M. (1999*). The way schools work: A sociological analysis of education*. Longman.

DuBois, W.E.B. (1903). *The souls of black folk*. Millenium Publications.

Duster, T. (2015). A post-genomic surprise. The molecular reinscription of race in science, law and medicine. *The British Journal of Sociology*, *66*(1), 1-27. https://doi.org/10.1111/1468-4446.12118

Friere, P. (1970). *Pedagogy of the oppressed*. Bloomsbury Academic.

Friere, P. (2013). *Education for critical consciousness*. Bloomsbury Academic.

Garibay, J. (2015). STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students? *Journal of Research in Science Teaching, 52*(5) 610-632. https://doi.org/10.1002/tea.21203

Gould, S. J. (1996). *The mismeasure of man*. W.W. Norton.

Gramsci, A. (2017). Intellectuals and hegemony. In C. Lemert (Ed.), *Social theory: The multicultural, global, and classic readings* (pp. 209-210). Westview Press.

Howard, J. (2018). The white kid can do whatever he wants: The racial socialization of a gifted education program. *Educational Studies*, *54*(5), 553-568. https://doi.org/10.1080/00131946.2018.1453512

Johnson, N. H., & Atwater, M. M. (2013). The impact of beliefs and actions on the infusion of culturally relevant pedagogy in science teacher education. In M. Atwater, M. Russell, &

M. Butler (Eds.), *Multicultural science education*. (pp. 81-102). Netherlands: Springer. https://doi.org/10.1007/978-94-007-7651-7_6

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. American Educational Research Journal, 32(3), 465-491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (1999). *The Dreamkeepers*: *Successful teachers of African American children*, 2nd ed. Jossey-Bass.

Ladson-Billings, G. (2011). Yes, but how do we do it? Practicing culturally relevant pedagogy. In J. Landsman & C. Lewis (Eds.), White teachers/diverse classrooms: Creating inclusive schools, building on students' diversity and providing true educational equity. (pp. 33-46). Stylus.

Ladson-Billings, G. (2017). The (r)evolution will not be standardized: Teacher education, hip hop pedagogy, and culturally relevant pedagogy 2.0. In D. Paris and H. S. Alim (Eds.), Culturally Sustaining Pedagogies: Teaching and Learning for Justice in a Changing World. (pp. 141-156). Teachers College Press.

Ladson-Billings, G. & Tate IV, W. (1995). Toward a critical race theory of education. *Teacher's College Record*, *97*(1), 47-68.

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science teacher education. Teachers College Record, 120(1), 1-38.

Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. Science Education, 101(6), 1034-1060. https://doi.org/10.1002/sce.21305

Roberts, D. (2011). *Fatal invention: How science, politics, and big business re-create race in the twenty-first century*. New Press/ORIM.

Mutegi, J.W. (2011). The inadequacies of "Science for All" and the necessity and nature of a socially transformative curriculum approach for African American science education. *Journal of Research in Science Teaching*, 48(3), 301-316. https://doi.org/10.1002/tea.20410

National Academy of Sciences, National Academy of Engineering, Institute of Medicine. (2011) *Expanding underrepresented minority participation: America's science and technology talent at the crossroads.* National Academies Press. https://doi.org/10.17226/12984

Parsons, E. C. (2014). Unpacking and critically synthesizing the literature on race and ethnicity in science education. *Handbook of Research in Science Education*, 167-183.

Ravitch, S. & Carl, N. (2016). Qualitative research: Bridging the Conceptual, Theoretical, and Methodological. Sage.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 41(5), 513-536. https://doi.org/10.1002/tea.20009

Sadovnik, A. R. (Ed.). (2007). *Sociology of education: A critical reader*. Routledge.

Saw, G., Chang, C. & Chan, H. (2018). Cross-sectional and longitudinal disparities in STEM career aspirations at the intersection of gender, race/ethnicity and socioeconomic status. *Educational Researcher*, *47*(8) 525-529. https://doi.org/10.3102/0013189X18787818

Sheth, M. J. (2019). Grappling with racism as foundational practice of science teaching. *Science Education*, *103*(1), 37-60. https://doi.org/10.1002/sce.21450

Thoman, D.B., Brown, E.R., Mason, A.Z., Harmsen, A.G., & Smith, J.L. (2015). The role of altruistic values in motivating underrepresented minority students for biomedicine. *BioScience*, *65*(2), 183-188. https://doi.org/10.1093/biosci/biu199

Tolbert, S., & Bazzul, J. (2017). Toward the sociopolitical in science education. *Cultural Studies of Science Education*, *12*(2), 321-330. https://doi.org/10.1007/s11422-016-9737-5

Underwood, J. B., & Mensah, F. M. (2018). An investigation of Science Teacher Educators' perceptions of Culturally Relevant Pedagogy. *Journal of Science Teacher Education*, *29*(1), 46-64. https://doi.org/10.1080/1046560X.2017.1423457

Varner, J. (2014). Scientific outreach: Toward effective public engagement with biological science. *BioScience, 64*(4), 333-340. https://doi.org/10.1093/biosci/biu021

Watts, S.,George M., & Levey, D. (2015). Achieving broader impacts in the National Science Foundation, Division of Environmental Biology. *BioScience, 65*(4), 397-407. https://doi.org/10.1093/biosci/biv006

Woodson, C. G. (1933). *The miseducation of the Negro*. Washington, D.C.: Association Press.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socio-scientific issues education. *Science Education, 89*(3), 357-377. https://doi.org/10.1002/sce.20048