Reimagining Science Teaching and Learning: Preparing Secondary Science Teachers as Equity Advocates, Designers, and Social Change Agents

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Abstract. This research explores the learning and development of justice-centered secondary science teachers that are prepared with the tools and skills needed to design equitable and authentic science learning experiences for students from racial, linguistic, and socioeconomic groups historically/currently marginalized in society, school, and science. The goal of this study is to examine the types of course materials and experiences that empower pre-service secondary science teachers as equity advocates, critically conscious designers, and agents of social change. Using pre-service teacher interviews and course artifacts, and instructor reflections and observations, this study seeks to better understand how pre-service teachers' perspectives of science, goals for teaching science, and vision for their students shifted after engaging in a secondary science methods course. By exploring the learning and development of secondary science teachers through a critical, sociocultural, and learning sciences lens, findings demonstrate the types of experiences that have the potential to transform the teaching and learning of science in schools.

Introduction

> *We want to reimagine what this looks like by recreating education spaces in a way that says come as you are and be brilliant as you are, and once we create these spaces for young people they believe it, they hold onto it….These things shape the identity, they shift your confidence, they move something in the depth of your soul, and they help you to reimagine yourself to be in a way you've never seen before.*
> Dr. Christopher Emdin (2018)

The opening statement serves as a call to action for the interdisciplinary community of science education researchers, teacher educators, and learning scientists. Specifically referencing students from racial, linguistic, and socioeconomic groups historically/currently marginalized in society, school, and science, Dr. Emdin highlights the importance of designing inclusive science learning environments that recognize and support students' diverse ways of knowing and sense making practices. In addition, he highlights the importance of a collective reimagining of what transformative science teaching and learning could be, and the powerful relationships between learning, identity construction, and the possibilities students of color imagine for themselves in science. In these ways, this statement captures the theory of change guiding this research: Increasing racial diversity in science and creating equitable opportunities for students of color to learn, do, and become in science, requires a fundamental shift in how secondary science teachers are prepared to "see" and support students of color while engaging them authentically in science. In addition, it requires opportunities for pre-service teachers to reflect on their role and vision for teaching science and to engage in the types of instructional and pedagogical practices that support equity and inclusion.

The underrepresentation of African American, Latinx, and other students of color in advanced high school science courses and later in science fields is widely agreed upon (Darling-Hammond, 2010; Oakes, Ormseth, Bell, & Camp, 1990). To address these disparities, science reform initiatives often aim to bolster students' knowledge and skills, guided by the assumption that exposure to authentic science experiences will increase racial diversity in science. As important as these programmatic efforts are, equitable access to science remains limited by an opportunity gap that leaves youth of color continually at the margins (Ladson-Billings, 2006; Milner, 2012). Furthermore, research shows that science classrooms much like mathematics learning environments are racialized spaces (e.g., Martin, 2009; Nasir, 2012; Parsons, Tran, & Gomillion, 2008; Warren & Rosebery, 2011; Visintainer, 2020). Thus, deficit-oriented narratives about students of color, including societal and institutional perceptions of what racial minorities lack (e.g., ability, motivation, interest in pursuing science) and homogenous narratives about who does/can do science (e.g., white, male) position youth of color outside of who is supported in becoming a scientifically literate citizen in U.S. society. This raises questions about how racialized narratives in science (i.e., storylines with historical pasts, constructed from racist and deficit-oriented ideologies about who does and can do science) are lived, experienced, and shape youth of

colors' science identity, or sense of self in relation to science (Nasir, 2012). However, while research shows that racial discrimination impacts the long-term science trajectories of women of color (Carlone & Johnson, 2007; Johnson, Brown, Carlone, & Cuevas, 2011), and the pathways of African American university science students and faculty (Brown et al., 2016), treatments of race in relation to science, specifically when exploring science identity construction for youth of color, are limited (Mutegi, 2013; Parsons, 2014). Thus, even though Latinx and African American students express equal or greater interest in pursuing science than their white and Asian peers (U.S. Commission on Civil Rights, 2010), racial disparities in science persist (Darling-Hammond, 2010).

We are at an unprecedented time in history when racial injustice and racialized narratives of belonging (and exclusion) are on the rise; exacerbated by a political climate that has validated and promoted deficit-oriented narratives about students of color that negatively impact their schooling experiences (Costello, 2016). In addition, developing scientific literacy skills is necessary for engaging fully and democratically in a technology and data-rich society, and in an era when science evidence is undermined in order to intentionally blur the lines between facts and fake news. Furthermore, environmental challenges (e.g., climate change) continue to become more pressing at national and global levels, requiring a diversity of voices, knowledge, and perspectives for the derivation of sustainable solutions However, while communities of color disproportionately experience environmental injustice and climate-influenced environmental impacts due to discriminatory land use and ownership practices (e.g., urban heat islands, air quality) the voices of people of color are often missing from social and political discourse involving environmental management and planning.

In addition, states such as California have adopted the latest science education reform, the Next Generation Science Standards (NGSS), as the official state standards. NGSS has potential to support students as critical thinkers and problem solvers and other scientific literacy skills by moving away from formulaic instantiations of the scientific method (e.g., prescribed labs) and better aligning with the way real scientists do their work. Furthermore, NGSS has the potential to support more equitable science teaching and learning experiences by leveraging non-dominant students' diverse experiences and sense making practices as resources to build on in science classrooms (Bang et al., 2017). These issues highlight opportunities and challenges for the science education community.

Therefore, the preparation of secondary science teachers requires a collective reimagining of what science teaching and learning could be that includes an extends far beyond science content knowledge. Thus, before we can transform science teaching and learning experiences in schools, we need to reimagine secondary science teacher preparation to more holistically support the learning and growth of pre-service teachers. This includes: a foundational understanding of the history of race in U.S. society and how it shapes science education, opportunities to recognize students' diverse cultural and sense making practices, and experience designing equitable and authentic science teaching and learning experiences. Thus, by broadening what teachers are able to see and do, and the identities they make available in science classrooms, we can move towards a liberatory science education that supports and expands beyond the practices and knowledge traditionally valued in school (Bang et al., 2017).

Objective

This study explores how participation in a secondary science methods course shapes pre-service science teachers' learning, growth, and trajectories as equity advocates and change agents. The goal of this study is to better understand the types of course materials, activities, and experiences that promote the preparation of socially responsive secondary science teachers and empower them as designers of inclusive and equitable science learning experiences. Using pre-service teacher interviews, course assignments and artifacts, and instructor reflections and observations, this study examines the dimensions and elements of the course that shaped and promoted shifts in pre-service science teachers understanding of issues of equity, and perspectives of science and students from racially/ethnically, socioeconomically, and linguistically diverse populations. In addition, this study examines how to prepare and empower teacher candidates as designers of learning environments that position students as learners and doers of science, thus generating new possibilities for who they can become in science.

This study builds on an emerging construct of a socially and politically relevant, racially and critically conscious pedagogical vision (Visintainer, 2017). This construct builds from Cole's (1996), conception of prolepsis, a process where a teacher's cultural past shapes their imaginings of what is possible in the future for their students, and captures Gutiérrez's (2008) encouragement of aspiring educators to approach learning with new pedagogical imaginations. It is through the lens of a sociopolitical, critically conscious pedagogical vision that this study explores the following research questions:

- What are pre-service science teacher candidates' ideas about science teaching and learning and students from linguistically, racially, and socioeconomically diverse populations when they enter the course? What shifts following participation in the course?
- What types of course activities, materials, and experiences foster the development of a sociopolitical critically conscious pedagogical vision and empower teacher candidates as designers of equitable and authentic science experiences? What are teacher candidates prepared to *do* after completing the course?
- How does engaging in contemporary science issues (e.g., climate change impacts, environmental justice) support pre-service teachers in designing learning experiences that position students as creators and producers, epistemic agents and change agents, and science and community experts?

Theoretical framework

This study approaches the preparation, learning, and development of science teachers through a critical, sociocultural, and learning sciences lens at the intersection of race, culture, learning, and identity in science education.

Sociocultural perspective of race, identity, and learning

This research draws on sociocultural theories of race, learning, and identity (Wenger, 1998). Race and racial groupings are conceptualized as socially constructed, historically embedded categories of power and privilege (Omi & Winant, 1994) with tangible outcomes for access and opportunities in science. Science teaching and learning are approached from the perspective that learning is a cultural process (Nasir et al., 2006), identities are constructed through interaction between individuals and the social world (Holland et al., 1998) from the social categories made available (Nasir, 2012). Furthermore, learning and identity construction are considered distinct yet highly interrelated processes (Nasir & Camps, 2009).

Engaging students in authentic science practices and experiences

There is a rich body of literature illustrating how authentic science experiences provide opportunities for students to develop deep understanding of content (Lehrer, 2009), construct unique epistemological stances (e.g., Sandoval, 2005), and identify as capable science learners (e.g., Bouillion & Gomez, 2001). In addition, research examining processes of learning and identity construction in science show students of color thrive when their identities as learns and doers of science are supported in science learning environments (e.g., Calabrese Barton, Tan, & Rivet, 2008; Polman & Miller, 2010) and that high school students' ideas about what science is and who can do science shifted together while conducting an air quality research project in their community (Visintainer, 2017). While NGSS aligns with the goals of engaging students authentically in science and presents exciting opportunities, this new reform and way of engaging with science also presents challenges. First, NGSS requires teachers to engage with science and teach in ways that they often have not experienced themselves. Second, designing and implementing equitable approaches to science instruction requires teachers to expand their instructional and pedagogical repertoires, and reflect on how they create or limit learning opportunities for students from diverse backgrounds. More research is needed that explores *how* to support pre-service secondary science teachers in designing and implementing science curricula that engages students meaningfully in contemporary science issues and practices.

Role of teachers: Power, perspectives, and science teaching

As one source of power in science classrooms, teachers play a central role in shaping the identity options available and the futures students imagine for themselves in science. For example, teachers have the opportunity to create, expand, or limit the identity options available to youth of color through the organization of structures, cultural practices, social interactions, and relationships (Nasir, 2004). In addition, teachers have the power to uphold, challenge, and resist inequitable school policies, practices, and sorting mechanisms (e.g., tracking). Furthermore, research in mathematics shows that teachers' perceptions of their students' ability matters; shaping how students view themselves as learners, the identities options available to them, and their future trajectories in mathematics (Cvencek, et al., 2011). However, challenges can arise with the common mismatch between majority white teacher candidate pools and the diverse student populations these candidates are being prepared to teach. For example, in their exploration of beginning white science teachers' beliefs about teaching in multicultural schools, Bryan & Atwater (2002) found that the participating teachers commonly held deficit-oriented views about students of color, racialized views about social influences on learning, and problematic beliefs about how to address diversity (e.g. lowering expectations). Similarly, Bianchini & Solomon (2003)

found that beginning teachers needed adequate resources to grapple with their understanding of social and cultural processes. Thus, providing opportunities for pre-service teachers to dig in, explore, and discuss intersections of race, culture, and learning in science is essential.

Conceptualizing pedagogical vision: Fostering hope and possibility

"Pedagogical vision" is defined as the way that teacher's own backgrounds and experiences shape their goals and purposes for teaching science, what they envision their students doing with science, and the possibilities they imagine for who their students can become in science. This construct builds from Cole's (1996) idea of ideal artifacts and the process of "prolepsis" where ideas, experiences and cultural pasts shape imaginings of what is possible in the future. Through the process of prolepsis, ideal artifacts carry meaning across time and are projected into the future in ways that structure and mediate activities at present (Cole, 1996). Of particular importance is that ideal artifacts align with actions to influence the structuring of the classroom environment and interactions between teachers and students in the present (Nasir, 2004). The ways students are exposed to and negotiate a variety of identities and practices during activities organized by the teacher can over time support "an array of imagined trajectories of becoming" (Nasir & Hand, 2006, p.468). In this way, an instructor's pedagogical vision and the futures they imagine for their students play a central role in the possibilities generated. Thus, teachers need the opportunity to reimagine what is possible when students are positioned as creators, social dreamers, and designers of their futures (Gutiérrez, 2008) in science classrooms. Thus, the type of vision, I explore in this study centers race, is historically embedded, and politically and racially conscious.

Methods

This research utilized qualitative (e.g. interviews) and quantitative (e.g. surveys) data sources with secondary science pre-service teachers as the unit of analysis. Through this approach, this study seeks to better understand the learning and development of justice-centered secondary science teachers. In addition, this study aims to determine the types of course materials and experiences that prepare and support pre-service teachers as designers of authentic and equitable science learning experiences that cultivate positive identity construction in science.

Study context

This study took place at a large public university in the San Francisco Bay Area that serves a racially/ethnically diverse student population. The university is a designated Hispanic Serving Institution, Asian American and Native American Pacific Islander Serving Institution, and first-generation college students comprise 40% of the student population. The College of Education at the university houses teacher credential programs that serve candidates from diverse racial/ethnic and socioeconomic backgrounds. The teacher preparation programs credential a large amount of teachers that serve the local region and beyond. After obtaining their credential, many teachers work in local school districts.

The specific research site for this study was the secondary science methods course, an integral part of the single subject credential program, and a requirement for becoming a credentialed secondary science teacher at the university. The course met once per week, for six hours, over the 16 weeks of the Spring 2019 semester. The methods course was designed to center equity and justice. The course included interdisciplinary resources and the inclusion of expert educators that contributed to the implementation of the course. Through the course, teacher candidates gained practice-based experience in the promotion of inquiry-based, learner-centered classrooms. In addition, candidates practice designing equitable and authentic science learning experiences through lesson and unit plans intended to engage diverse student populations in contemporary science phenomena and NGSS. Signature assignments for the course include: a *Teaching Statement and Philosophy of Equity, Design Principles for Teaching Science for Equity and Inclusion*, and lesson plans and a unit plan focused on the theme of global climate change.

Participants

Teacher Candidates. Eight of the nine teacher candidates that took the course participated in the study. Candidates included one male and seven women who identified racially as Asian (4) and white (4). All teacher candidates were in their first semester of the credential program when they took the course.

Course instructor. I am an assistant professor in science education, a white, middle class woman, and the instructor for the science methods course. I redesigned the course to center equity and justice. I taught the redesigned course once prior to the implementation of the course studied in Spring 2019.

Data sources and analysis

This study utilized three main data sources: 1) Course artifacts and evaluations, 2) Teacher candidate interviews, and 3) Instructor reflections and observations.

Pre-service teacher candidate course artifacts

Throughout the course, teacher candidates completed reflections, on-line weekly reading discussions, and assignments. Artifacts analyzed for this study included: Teaching statements completed at the beginning and end of the course, annotated design principles, lesson plans, and unit plans. At the end of the course, teacher candidates completed an anonymous on-line evaluation administered through the university, which were included.

Course Artifact Analysis. Course artifacts were analyzed and coded for teaching goals, perspectives about students and science, and shifts that occurred during the course. For example, candidates wrote a draft of a *Teaching Statement and Philosophy of Equity* at the beginning of the course and then revised the draft for their final portfolio. Thus, it was possible to examine shifts in their goals, vision, and approaches to teaching science for equity and inclusion from the beginning of the course to the end.

Pre-service teacher candidate interviews

Interviews were conducted with five teacher candidates and took place during the semester after they had completed the course. Interviews focused on their experiences with science, their goals for teaching science, how they envisioned science teaching and learning, shifts that occurred over the semester, and the main things they took away from the course. Interviews were semi-structured, conducted one-on-one with the researcher/me, and audio recorded. The interview protocol were designed from an interpretivist perspective using descriptive and structural questions (Spradley, 1979).

Interview Analysis. Interviews were transcribed, read in full, and coded using an open coding process (Miles & Huberman, 1994). Coding categories included teacher's backgrounds in science, their goals for teaching science, and their ideas about diversity and equity in science education. Coding was done inductively and categories were created through an iterative process (Miles & Huberman, 1994). All coding categories emerged from the data and were not predetermined.

Course instructor reflections and observations

During the course, I recorded reflections and observations of assignments, activities, and experiences with visiting teachers that struck me as important and/or unique. Field notes were recorded after notable classrooms activities, discussions, visiting teacher presentations, and other events.

Reflections and Observation Analysis. Coding of fieldnotes was done inductively and through an iterative process to remain open to novel constructs, interactions, and resources (Miles & Huberman, 1994). Field notes were coded for how class activities and resource were taken up and utilized or resisted by participants and moments of positioning between students and instructors. Because I served as the instructor for the course, my subjectivity in recording field notes, interpreting moments and behaviors, and position of power in the study context factored into the weight placed on this data source during analysis. Thus, the observations served a limited role in findings and were used most commonly to provide additional context for events mentioned by TCs during interviews and/or in assignments.

Findings

Overall, findings show that when provided opportunities to: (1) explore their own biases and beliefs about science and students from racial/ethnic, linguistic, and socioeconomic groups historically and currently marginalized in society school and science, and (2) learn strategies for teaching science for equity and justice, teacher candidates were empowered to design inclusive, authentic lesson plans and units.

Teacher candidate perspectives entering the course

Findings show that the teacher candidates entered the course with limited understanding of issues of equity in education broadly, and science education specifically. In addition, their experiences exploring intersections of race, identity, and learning, and the history of race in U.S. society and how this shapes opportunities to learn and become in science were limited. Teacher candidates described learning science in static ways (e.g., lectures) and expressed limited experiences with authentic science practices. On the first day of the course, I positioned the teacher candidates as future designers of meaningful science experiences and emphasized the powerful role teachers play in supporting identity construction in science classrooms. Throughout the course this positioning stayed at the fore of my course goals and implementation.

Course materials, activities and experiences during the course

Findings show that a combination of course materials, activities, and visiting education expert presentations promoted teacher candidates' growth and development along their pathways of becoming critically engaged science educators. Themes that emerged were the importance of transdisciplinary perspectives on teaching and learning, both in and outside of science education, for shaping a critical pedagogical vision. Of particular importance was the inclusion of readings, theoretical frameworks, and perspectives of learning from a transdisciplinary foundation. For example, teacher candidates expressed that they developed a critical stance and culturally/socially responsive vision through readings and digital resources (e.g., TED Talks) that explored learning theories and transformative philosophies of teaching and learning from interdisciplinary scholars of color (e.g., bell hooks, 1994).

In addition, teacher candidates described the central role of materials that explicitly connected theory and educational research to practice (e.g., Boaler 2006) and linked race, culture, learning, and equity to specific instructional and pedagogical approaches (e.g., Ladson-Billings, 1995). These materials were critical for shaping their vision for teaching science for equity and inclusion and allowed them to understand how they could realize this vision through their instructional design.

Finally, teacher candidates emphasized the importance of engaging in science practices as learners during lessons offered by visiting expert teachers as helpful for their work as designers of authentic and inclusive learning environments. In addition, experiences that challenged their positioning as learners were powerful. For example, during the visit, the candidates briefly experienced what it might feel like to be a second language learner. The visiting teacher taught a ten minute third grade math lesson in Spanish during which candidates struggled to understand the instructions and communicate with each other and the teacher. Many were visibly frustrated, some gave up entirely. Afterward the visiting teacher had the candidates reflect on their experiences and thus, how emerging multilingual students might feel in science classrooms. Candidates expressed feelings of shame, anxiety, discomfort, and anger/frustration. The visiting teacher then expressed that they were a group of highly educated people, yet if an outsider had observed them during the lesson they probably would have concluded that they weren't very intelligent. This point resonated deeply with the class. Candidates then reflected on how the emotions they expressed manifested as behaviors (e.g., disengagement, acting out). The realization that students of color are labeled as not intelligent and with these same negative behaviors, and are perceived through a deficit lens in classrooms everyday had a profound impact on the candidates. After this experience, they learned how to build linguistic supports into their science instruction; something they now understand as essential to learning.

Post course shifts: Empowering designers of transformative futures

Overall, findings show that when provided opportunities to explore their own biases/beliefs about science and students from diverse populations, and learn strategies for teaching science for equity and justice, teacher candidates were empowered to design inclusive, authentic lesson plans and units. For example, during her interview Amanda stated: "I thought teaching science was all about knowing your content, but it's so much more than that." In her course evaluation, she described how course materials shaped her perspective of science and students:

> This course was very different from what I expected, in a good way. I initially thought the class would focus only on NGSS, but instead it changed my perspective of teaching and made me realize how much power I have in young peoples' lives. I feel like all of the readings and assignments helped me grow and expand my mindset.

In addition, as part of their final teaching portfolio, teacher candidates revised their *Teaching Statement and Philosophy of Equity*. In their final statements, candidates expressed a rich understanding of issues of equity in science education and articulated the need to cultivate scientifically literate citizens. For example, Lisa stated:

> I believe every student has the right to reach their full potential and live the richest life possible; education is the essential power that enables people to achieve this. My goals for teaching science are to help students develop understanding towards core scientific principles and practices, critical evaluation of scientific information, and the ability to apply science to make informed decisions and solve practical problems in their lives.

Furthermore, teacher candidates made connections between course readings, their goals for teaching science, and instructional approaches that promoted these goals. For example, Jennifer stated:

> An important strategy to engage students in science learning is to make learning meaningful to students' lives and utilize students' prior knowledge, diverse cultural backgrounds and experiences as assets. I need to notice, support, and engage students' diverse sense- making repertories and design instruction from students' experiences, resources, and interests."

Candidates created a unit plan and lesson plans that integrated equity, inclusion, and engagement in NGSS. The unit plan focused on global climate change from their disciplinary perspective; thus they worked as an interdisciplinary community of learners and built off of others expertise to guide the design. Teacher candidates designed innovative NGSS-aligned units that centered equity and justice.

Conclusions and implications

Findings illustrate that engaging teacher candidates in science practices and issues of equity through a diversity of course materials and experiences empowered them as designers and change agents. This is important because though states such as California have adopted NGSS as their official state science standards, the design of curricular materials are very much in their infancy. Thus, a unique opportunity exists to create equitable science learning experiences for diverse student populations. Findings from this study illustrate aspects of the courses design and elements (e.g., activities, experiences) that supported engagement with issues of equity, the derivation of practice-based solutions, and promoted the development of socially responsive secondary science teachers.

Scholarly significance

Findings from this project have implications for teacher education, policy, and practice. By exploring the preparation, learning, and development of secondary science teachers through a critical, sociocultural, and learning sciences lens, we can better understand pre-service teachers experiences, sense making, challenges, and the resources needed to holistically support their professional growth as equity advocates and change agents. This study is a necessary first step in the development of a sustainable science teacher preparation pathway that reimagines and prepares science teachers to realize the possibilities for transformative science teaching and learning in schools.

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