
STEM EDUCATION AND SOCIAL JUSTICE

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The Science, Technology, Engineering, and Mathematics (STEM) field is greatly promoted as a career path for students in recent years, and the demand for individuals specializing in STEM disciplines is expected to rise. Often, when considering STEM, one thinks of careers related to medicine, laboratory settings, or the pure sciences. However, in examining only these aspects of STEM, we may errantly overlook the impacts that P-20 education may have in using STEM as a means for improving student lives. One unique aspect of STEM is its role in helping to improve our well being as individuals and society as a whole, not only through improvements in fields such as technology and medicine, but also as a stimulus for promoting improvements in the community and beyond. There are opportunities for STEM education to aid in social justice through examining local community issues, including environmental quality and access to health and nutritional services, among other topics. As noted by Webb and Barrera in this edition of *Catalyst* (2017), "The primary focus of education is to improve students' lives by providing means to overcome the inequities of school and society, and it is the responsibility of teachers to see that this happens for every learner." This issue of *Catalyst* aims to present a collection of works that examines the role of STEM education in aiding in these opportunities not only for the PK-12 classroom, but also in the college classroom and through pre-service educator training.

In recent months, Parker, Pillai, and Roschelle (2016) released a report entitled *Next Generation STEM Learning for All: Envisioning Advances Based on NSF Supported Research*. The report not only highlights the need to encourage STEM engagement and participation for traditionally marginalized students, but it also notes that *access* to STEM itself is an issue of social justice. By enabling opportunities for all learners to engage in STEM with a social justice lens, Parker et al. (2016) noted that "assuring access to STEM learning for learners traditionally underrepresented in STEM fields can provide opportunities for individual success as well as broader changes that contribute to social justice. Additionally, using a social justice lens to actively engage learners in STEM content provides motivation and engagement not found in decontextualized academic knowledge" (p. 5).

However, the opportunities to engage students in STEM and social justice can be fraught with challenges. The STEM fields, including those focused on STEM education, are in uncharted territory in the era of a new administration. In 2011, former President Barack Obama called for recruiting, training, and retaining 100,000 more STEM teachers within the decade (Obama, 2011). Now, at the time of publication, proposed budget cuts to organizations including the National Institutes of Health, the Environmental Protection Agency, the National Science Foundation, and other federal agencies, along with proposed decreases in funding to educational programs including block grants and 21st Century Community Learning Centers, threaten both scientists' and educators' opportunities to further their research in STEM and social justice (Fountain & Schwartz, 2017; Kamenetz, 2017).

Despite the challenges, there is still hope. Teachers and university programs alike are considering the manner in which STEM can be used to prepare future teachers and empower students within the community. Rather than view STEM as an "ivory tower" career, many individuals are instead embracing it as a tool to instill change and to serve those in the public sector. This issue of *Catalyst* examines how the respective contributors understand "social justice" in STEM Education and how it relates to their work with pre-service teachers, in-service teachers, and students. In this collection of works, we begin with Pitts Bannister, Davis, Mutegi, and Thompson's examinations of how mathematics curriculum could focus on improving the social conditions of African American and Africans worldwide, through changes in curriculum and pedagogy. This is followed by Webb and Barrera's study of simulated language learner experiences in teacher education, emphasizing the need for preservice educators to

consider the ways in which STEM is made accessible to all students in the classroom. Finally, we examine two different perspectives on how to address social justice and STEM education at the high school and college levels. This is done first with Madden, Wong, Vera Cruz, Olle, and Barnett's curricular framework for using social justice-driven STEM in a college-access program for high school students, and followed by Sondel, Koch, Carrier, and Walkowiak's examination of using STEM in teacher education programs to develop future teachers enact opportunities for social justice with their students and community. Together, this edition sends a message of hope for STEM as a driving force for modeling innovative approaches to social justice in a growing field.

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“RETURNING TO THE ROOT” OF THE PROBLEM: IMPROVING THE SOCIAL CONDITION OF AFRICAN AMERICANS THROUGH MATHEMATICS EDUCATION

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Abstract

The underachievement and underrepresentation of African Americans in STEM (Science, Technology, Engineering and Mathematics) disciplines have been well documented. Efforts to improve the STEM education of African Americans continue to focus on relationships between teaching and learning and factors such as culture, race, power, class, learning preferences, cultural styles and language. Although this body of literature is deemed valuable, it fails to help STEM teacher educators and teachers critically assess other important factors such as pedagogy and curriculum. In this article, the authors argue that both pedagogy and curriculum should be centered on the social condition of African Americans – thus promoting mathematics learning and teaching that aim to improve African communities worldwide.

Accentuating Social Transformation: A Mathematics Curricular Approach Driving Purpose behind African-American STEM¹ Education

Historically, scholarship on the STEM (science, technology, engineering and mathematics) education of African Americans has focused largely on the achievement disparity between African Americans and their non-African-American peers. (Cohen, Garcia, Purdie-Vaughns, Apfel, & Brzustoski, 2009; Lewis & Collins, 2001; Lewis, Pitts, & Collins, 2002; Lubienski, 2002; Maple & Stage, 1991). Some researchers have criticized this approach as a one-dimensional treatment that pathologizes African-American youth and emphasizes their perceived failure. (Martin, 2009; Norman, Ault, Bentz, & Meskimen, 2001). Even the growing body of research examining success and high achievement among African-American learners (Berry III, 2008; McGee & Martin, 2011; Thompson & Davis, 2013; Thompson & Lewis, 2005) is, to some degree, a response to this prevailing discourse of African-American pathology. With disparity firmly established as “the problem” of African-American STEM education, much of the scholarship in this area has been aimed at leveling the disparity.

As researchers, we have focused so intently on leveling disparity by focusing on relationships between teaching and learning and factors such as culture, race, power, class (Martin, 2006; Weissglass, 2002; DiME, 2007), learning preferences (Hilliard, 1989; Malloy, 1997), cultural styles (Malloy, 1997; Moody, 1998) and language (Orr, 1987). While such efforts certainly have value, they fail to question whether “leveling disparity” is beneficial for African-American STEM learners. We have tacitly accepted the idea that the purpose of STEM education as articulated by STEM education reform efforts (e.g. National Council of Teachers of Mathematics, 2000; National Governors Association Center for Best Practices, 2010; National Research Council, 1996) is in the best interest of African-American STEM learners. Thompson, Mutegi, and Davis (in review) challenge the assumed benefit of leveling disparity by

- (a) identifying a set of assumptions about disparity that drives the work of some STEM education researchers, and (b) arguing for nation building as a driving purpose for the STEM education of African² people.

The study by Thompson, Mutegi, and Davis (in review) began when Thompson questioned the purpose behind STEM education disparity scholarship. She asked, “Why is it important that we have more African Americans in mathematics? Blacks are overrepresented among NBA players and underrepresented among NHL players. What makes this a problem? Can’t society function well if different groups of people gravitate to different professions or occupations?” To answer this question, she interviewed three, highly regarded mathematics

¹According to the H.R. 1020 (114th): STEM Education Act of 2015, STEM education means education in the subjects of science, technology, engineering, and mathematics, including computer science. Activities related to STEM education may incorporate one or more of the STEM disciplines. For this reason, we refer to mathematics education and/or science education as STEM education.

² We operate from a Pan Africanist perspective. As such, we regard the social, historical, and cultural challenges facing African Americans to be localized manifestations of social, historical and cultural challenges that face people of African descent throughout the diaspora. In this spirit, we invoke the term “African” to characterize people of African descent regardless of where they happen to be on the planet. When we invoke more specific terms, such as “African American,” it is to reflect the characterization used by other authors or to distinguish a particular group of African people from the global African family. This treatment is consistent with our other work in this area (Mutegi, 2011, 2013).

education researchers. The experts she interviewed were well-published authors whose work evinced a long-term commitment to increasing the representation of African Americans in STEM. Two open-ended questions guided her interviews. The first question was, “In your opinion, why should educators be concerned about the underrepresentation of African Americans in mathematics?” The second question was, “What are some benefits of having African Americans pursue mathematics careers?”

The mathematics education researchers interviewed gave three reasons for the necessity of increasing the representation of African Americans in mathematics. These were (a) to establish an African-American presence in STEM fields that will dispel myths surrounding the intellectual capabilities of African Americans; (b) to increase the level of African-American contribution to the technological advancements of this country; and (c) to create a level of critical thinking among African Americans as a means towards social change. These reasons serve to lay bare implicitly held assumptions about the purpose of African-American STEM education scholarship. They reveal a perceived need for people of African descent to gain social acceptance and to make national contributions through their STEM work.

In response, Thompson et al. (in review), suggest that STEM education could also (and perhaps more effectively) be driven by a “liberatory agenda” with the goal of building and improving “the status of Black people globally.” Drawing from the work of Kwame Akoto (1992), they characterize this effort as “Nationbuilding.” We have found that the work of Thompson et al. as well as that of Akoto resonates strongly with STEM education research on social justice. Our objective in this paper is to draw from the spirit of scholars like Thompson et al. and Akoto, to describe how social justice-oriented STEM education might look in practice, specifically in the area of mathematics education. To accomplish this objective, we will first provide an overview of social justice mathematics scholarship. We will then detail one of the curricular approaches drawn from this body of work. The curricular approach detailed (Mutegi, 2011) provides guidance for modifying traditional STEM content (specifically in the area of science) to meet the purpose of educators committed to nationbuilding and social justice. We conclude by demonstrating the application of that model to the mathematical study of combinatorics.

Historical and Contemporary Perspectives of Social Justice in Mathematics Education

In mathematics education, scholars have a long history of trying to achieve social justice. A review of this history reveals that varied perspectives have been used to discuss social justice approaches in mathematics education. The major focus of social justice approaches is to illustrate the social and political dimensions of mathematics and mathematics education and to challenge the perceived neutrality, objectivity and cultural neutrality of mathematics (Vithal & Skovsmose, 1997). Historically, the main terminology used by scholars to discuss social justice approaches in mathematics education were “critical mathematics” (Frankenstein, 1987) and “teaching mathematics for social justice” (Gutstein, 2003). Marilyn Frankenstein and Eric Gutstein are considered leading scholars in the development of social justice perspectives in mathematics education. These scholars have drawn on Paolo Freire’s theory to advance social justice approaches in mathematics education. In particular, Frankenstein (1983) asserts:

Applying Freire's theory to mathematics education directs our attention to how most current uses of mathematics support hegemonic ideologies, how mathematics education

also reinforces hegemonic ideologies, and how critical mathematics education can develop critical understanding and lead to critical action. (p. 327)

Aligned with this perspective, Powell and Frankenstein (1994) challenged the Eurocentric perspective that pervades mathematics to advance the concept of ethnomathematics to achieve social justice. Even though Frankenstein and Powell contributed intellectually to ethnomathematics, d'Ambrosio (1985) is often considered the “father of ethnomathematics.” Ethnomathematics seeks to connect culture and mathematics (d'Ambrosio, 2001). Vithal and Skovsmose (1997) suggest that ethnomathematics primarily involves cultural and social issues. There are four strands of ethnomathematics (a) challenging the traditional history of mathematics, (b) examining traditional cultures of mathematics for colonized people, (c) exploring groups' everyday use of mathematics, and (d) examining the relationship between ethnomathematics and mathematics education.

Gutstein (2007) indicates “the goal of teaching (mathematics) for social justice [is] that students become agents of social change and join in, and eventually lead, the struggles to remake our world for peace and justice” (p. 116). According to Gutstein (2007), teaching (mathematics) for social justice is accomplished through interplay of the three C's – community knowledge, critical knowledge and classical knowledge. Community knowledge is defined as the compilation of knowledge that is brought to a central location such as school. In particular, it “involves several different but related components of knowledge and culture [and] refers to what people already know and bring to school with them” (p. 110). Critical knowledge is comprehension concerning the sociopolitical environment of an individual's current and extensive reality. More specifically, it entails “knowledge about the sociopolitical conditions of one's immediate and broader existence” (p. 110). Classical knowledge is the acquisition of the systematic rituals of classroom, abstract learning.

In more recent times, the language Frankenstein and Gutstein use to discuss critical mathematics and teaching mathematics for social justice has evolved. Critical mathematics is now referred to as “criticalmathematical literacy” (Frankenstein, 2012) and teaching mathematics for social justice is often referred to as “teaching and learning mathematics for social justice” (Gutstein, 2003, 2006, 2012). Frankenstein's and Gutstein's social justice frameworks provide a lens to re-examine African-American STEM education. In particular, what is the nature of STEM education that positions African Americans to use their knowledge of their community in conjunction with critical knowledge of sociopolitical issues to learn classical knowledge of mathematics to effect social change? It is our contention that the mathematics education for Africans must be grounded in their community knowledge and developed in response to the current social conditions of Africans throughout the Diaspora.

“Returning to the Root” of African Tradition

One of Gutstein's collaborators, Tate (2005) framed his social justice scholarship on African-American students. While Gutstein has created social justice mathematical tasks focused on African-American issues (e.g., racial profiling, home buying while Black, etc.), his work has not exclusively focused on African-American students. It also focuses on Latino/a students. Tate is one of the first mathematics education scholars to amass a body of scholarship focused on race, racism, Afrocentricity, social justice and the lived realities of African-American students in mathematics education (Tate, 1993, 1995, 2013). From a research, theoretical and

conceptual perspective, Tate connected and centered Afrocentricity and social justice pedagogical approaches in African-American students' mathematics education. He reported information about their cultural and community knowledge and experiences learning mathematics. Tate's use of Afrocentricity represents the "power of returning to the root of African tradition" (1995, p. 172).

Operating in a similar paradigm, Anderson's (2005) contribution to social justice focused on the Africans contribution to mathematics. In doing so, he challenged the dominant European perspective of mathematics (Anderson, 1990; 2005). Anderson advocates for students to learn about African peoples' contribution to mathematics and help students to understand that white men were not the only people to make contributions to mathematics. In fact, he contends that students should know that Europeans studied in Africa to learn mathematics from Black people.

Building on Tate (2005) and Anderson's (2005) Afrocentric perspectives of mathematics, Martin and McGee (2009) advanced a liberatory perspective of mathematics education for African-American students rooted in Afrocentricity. While their use of liberation is not unique in mathematics, as Powell and Frankenstein (1994) also advanced notions of liberatory mathematics, Martin and McGee's perspective is unique in that they identify African-centered thought and practice as key tools for achieving liberation for African Americans. The use of the term liberation is a reframing of social justice rooted in the history and traditions of African Americans' fight for freedom.

Introducing critical race theory into the mathematics education social justice discourse, Terry (2010, 2011) focuses on the most underserved and underrepresented population: African-American males. He engaged African-American males in social justice oriented mathematics using socially, culturally, and contextually relevant topics, data and pedagogical approaches. Using critical race theory's notion of counter storytelling, Terry developed and called for the use of mathematical counterstories as a social justice pedagogical approach to engage Black males. He argues that African-American males are looking for opportunities to critically examine issues, data and mathematics that directly relate to their lives.

Continuing in the tradition of using critical race theory, Larnell, Bullock, & Jett (2016) seek to broaden the possibilities of social justice scholarship in mathematics education. More specifically, these scholars use a critical race perspective to shed light on the role and operations of race, racism and racial injustice within the teaching and learning mathematics for social justice discourse. Larnell and colleagues use select tenets of critical race theory to offer new perspectives and conceptualizations of teaching and learning mathematics for social justice. Racial realism, interest convergence, critique of liberalism, intersectionality, and counter-storytelling are the tenets of critical race theory that Larnell and associates use to expose "blank and blind spots' with respect to race, racism, and racialization" (p. 27). Furthermore, Larnell et al suggest that incorporating critical race theory into the teaching and learning of mathematics for social justice discourse illuminates the necessity to address intersectionality and complexity of multiple forms oppression and injustice impacting groups.

Summary

Based on the available literature, it can be argued that social justice approaches in mathematics education started with ethnomathematics and critical mathematics. The literature also reveals that the history of social justice approaches in mathematics has not exclusively focused on African Americans. This scholarly area has focused on diverse cultural groups. The

exclusive focus on African Americans has mainly come from the scholarship of African-American scholars (Martin & McGee, 2009; Terry, 2010, 2011).

We continue to advance social justice perspectives and approaches to mathematics by building on this history. We contribute to this existing body of literature by illustrating the application of socially transformative science curriculum as described by Mutegi (2011) to mathematics education. We use this model for several reasons. First, this model focuses explicitly on addressing problems plaguing African people all over the world. Second, it seeks to position learners of African descent as agents of change in their community. It also seeks to inform African learners about the system of racism (white supremacy), help them to recognize how it impacts their academic and social development, and prepare them to struggle for power against this system. This model of socially transformative curriculum argues that we should engage students of African descent in critical discourse about their social conditions and their use of scientific knowledge to change those conditions.

Understanding Socially Transformative STEM Curriculum

The model of socially transformative science curriculum described by Mutegi (2011) draws heavily from (and reflects the commitments of) critical pedagogists (e.g. Allen, 2004; Freire, 1970; Macedo, 1993). The overriding purpose of this approach is to position learners of African descent to (a) become aware of systemic racism, (b) understand how it is established and maintained, and (c) work to change it. According to Mutegi (2011), this purpose can be accomplished when teachers plan curricula that help learners of African descent to attain mastery in each of five areas. These are: content, currency, context, critique, and conduct. Mastery of *content* positions students to better understand the content. It empowers students to answer what- when- where- and how-type questions about the topic. The second area of mastery is *currency*. Mastery of currency positions students to better understand how the topic is related to human beings. The third area of mastery is *context*. Mastery of context positions students to better understand how the topic is related to people of African descent. The fourth area of mastery is *critique*. Mastery of critique positions students to better understand how the topic is related to systemic racism. The final area of mastery is *conduct*. Mastery of conduct positions students to use their emerging knowledge to effect social change. These areas of mastery and the questions they inspire are tools that teachers can use to create or modify curriculum with the intention of teaching for social justice.

Accentuating Social Transformation: A Curricular Approach

Throughout the K-12 pipeline, the National Council of Teachers of Mathematics (NCTM) and the Mathematical Association of America (MAA) advocate for combinatorics to be in sync with the mathematics curricula being used in schools (National Council of Teachers of Mathematics, 1989, 2000). However, the mathematics curriculum in schools serving large populations of African-American students rarely or most times never expose them to combinatorics or any other advanced mathematics content (Ladson-Billings & Tate, 1995; Lubienski, 2001, 2002; Oakes, 1990; Strutchens & Silver, 2000; Tate, 1997) that can be used to improve the conditions of African communities locally and globally. Nkwanta, Hill, Swamy and Peters (2011) provided high school teachers in Baltimore city public schools with a week-long professional development workshop focused on connecting

mathematics and biology and to help them integrate computations into biology courses. More specifically, Nkwanta and associates used the workshop to:

use lattice walks and RNA secondary structures as a way of introducing teachers to enumerative combinatorics integrated with molecular biology... By demonstrating and explaining the importance of integrating mathematics and biology, an objective was to give teachers a sense of how mathematical concepts could be applied to certain adverse health conditions. For example, considering adverse health conditions such as asthma, cancer, diabetes, HIV, and AIDS, it was demonstrated in the workshop that enumerative combinatorics could be used as a tool to help predict RNA structures for the development of more favorable health conditions (p.82).

The health conditions Nkwanta and associates identify significantly impact African communities all over the world. In this article, we use the model of socially transformative STEM curriculum to describe how combinatorics can be used to address the HIV/AIDS epidemic impacting African communities locally and globally.

In their articulation of mathematics literacy as a civil rights issue, Moses and Cobb (2001) point out that,

the importance of algebra [in the U.S.] has emerged with the new technology. It didn't have to be algebra... In France, geometry is the driving force of the math and technology education. So, there's nothing that says it has to be algebra. There's nothing that says it has to be geometry. (p.14)

Similarly, in K-12 schools across the country, there is nothing that says combinatorics cannot be taught to African-American students to help them improve conditions impacting their community locally and globally. An alternative approach is needed to teach African-American students to use their knowledge of combinatorics and other mathematical topics to improve the conditions of African communities worldwide.

Social Transformation through Combinatorics

Mutegi (2011) drew from the work of critical curriculum theorists to develop a model for science curriculum that positions students of African descent to improve their social condition. Here we will illustrate the applicability of Mutegi's approach to mathematics education by providing an example of a curriculum unit on combinatorics. As mentioned, the first area of mastery is *content*. Mastery of content empowers students to answer questions such as, "What is combinatorics? How does combinatorics work? Where is combinatorics used?" The mathematical content presented to students of African descent about combinatorics must get them to see that the study of combinatorics includes permutations, enumeration, combinations, arrangements, and formulas. It must equip them to see that combinatorics is one of the oldest branches of discrete mathematics that is deemed an essential concept for solving problems using computer methods and is regarded as the mathematics of systematic counting (National Council of Teachers of Mathematics, 1989, 2000; Sriraman & English, 2004).

The second area of mastery is *currency*. Mastery of currency empowers students to answer questions such as, “How and where is combinatorics used by humans? How does the application of combinatorics impact mankind in daily life?” Instructional dialogue on combinatorics could equip African-American students to explore (a) the global importance of computers nationwide, (b) the importance of computers for international warfare (c) computer scientist use of combinatorics to advance modern technology, (d) medical professional use of combinatorics to match symptoms with proper medicine, (e) scientist’s use of combinatorics to find a cure for diseases (e.g. HIV/AIDS, cancer, etc.), and (f) industrial use of combinatorics for modernizing manufacturing distribution.

The third area of mastery is *context*. Mastery of context empowers students to answer questions such as, “In what ways is combinatorics important to people of African descent? How has it been used by African people historically or in modern times? In its application, how does it impact the daily lives of African people?” The context of instructional dialogue on combinatorics could prepare African students to understand how combinatorics could be used in service of African people. For example, it could be used as STEM professionals of African descent work to (a) find a cure for HIV/AIDS, malaria, asthma, cancer, and other health problems experienced by African people, (b) develop businesses for African people to capitalize on their inventions (e.g. traffic lights, blood preservation, and polymers), and (c) create housing and buildings for businesses in African communities in order to develop an economic base.

The fourth area of mastery is *critique*. Mastery of critique empowers students to answer questions such as, “How can my understanding of combinatorics help me to better understand the mechanisms by which systemic racism is established and maintained?” The instructional discourse surrounding these questions would engage African students to use their knowledge of combinatorics to investigate systemic racism as a result of (a) denying African students access to courses and knowledge of combinatorics and other higher level mathematics topics that can be used to improve the conditions (e.g. housing, health, etc.) of their community and develop an economic foundation for African people, (b) high rates of health problems (e.g., heart disease, cancer, HIV/AIDS, etc.) affecting African people and the lack of medical care to remedy their health problems or find a cure for the global HIV/AIDS epidemic, and (c) the lack of economic stability in African communities globally.

The fifth area of mastery is *conduct*. Mastery of conduct empowers students to answer questions such as, “How can I use my understanding of combinatorics to improve the social condition of African people? Instructional dialogue about African-American students conduct should equip them to use their knowledge base to (a) work with scientists (e.g. biologists, etc.) to locate better or more stable SL12 and SL3 components of HIV-RNA sequence to aid African people in their efforts to find a cure for the global HIV/AIDS epidemic, (b) develop businesses to distribute African peoples inventions (e.g. traffic signal, peanut products, etc.) to become self-sufficient, and (c) work with computer scientists, engineers, and architects to create housing and buildings for businesses in African communities in order to develop an economic base.

Concluding Comments

The five areas of mastery (i.e., content, context, currency, critique and conduct) are drawn from Mutegei’s (2011) description of socially transformative science curriculum. In this

article, we juxtaposed this work against similar work in mathematics education to develop an alternative curricular approach to prepare African people to address the social realities of their community. This curricular approach builds on the work of several scholars who accentuate “what to teach” and “why we teach” (Anderson, 1990; Martin, 2007; Tate, 1995). In particular, the proposed curricular approach meets the purpose of educators committed to nationbuilding and social justice in that the approaches are viewed and contextualized in ways aimed at changing the lives and mathematics education experiences of people of African descent. To ignore the potential of the proposed curricular approach to inform efforts to meet the needs of African-American STEM learners “is to be like the man who was looking for a lost coin two blocks away from where it was lost because the light was better at the new spot. If he were to continue in that way, the problem would never be solved” (Hilliard, 1974, p. 44).

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PROVIDING EQUAL OPPORTUNITY TO LEARN SCIENCE FOR ENGLISH LANGUAGE LEARNERS: THE ROLE OF SIMULATED LANGUAGE LEARNER EXPERIENCES IN TEACHER PREPARATION

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Abstract

English language learners (ELLs) are the fastest growing student population in our nation's public school systems; yet, preservice and inservice teachers are commonly underprepared to teach science effectively to this group of students. Though obviously inequitable, providing ELLs with poor or subpar science instruction denies them their civil right to equal opportunity to learn science. In this paper, we discuss simulation as a promising way to prepare preservice elementary teachers to plan and deliver quality science instruction and robust opportunities to learn to ELLs.

Responsive and Equitable Education

The primary focus of education is to improve students' lives by providing means to overcome the inequities of school and society, and it is the responsibility of teachers to see that this happens for every learner (Adams, Bell, & Griffin, 1997; Cochran-Smith et al., 2009; Darling-Hammond, French, & Garcia-Lopez, 2002; Michelli & Keiser, 2005). However, this is often not the case in many of the schools across America. Instead, schools tend to have a mainstream agenda founded on European-American cultural norms with little allowance for differences or diversity (Gay, 2002; Heward & Cavanaugh, 2001). And although this is challenging for the numerous minority groups of students being underserved, this unresponsive climate is especially difficult for those immigrant students who do not speak English or those children/students of immigrants with limited English-speaking ability.

In addition to the educational system not supporting the linguistic needs of English language learners (ELLs), their cultural identities tend to go unacknowledged. This divisive approach usually occurs through programmatic assimilation and alienation. Valenzuela (1999) spoke specifically about this in her research and warned that

marginality evolves when children are socialized away from their communities and families of origin.... While youth indeed enter school with these divisions among them, schooling exacerbates and legitimates these differences through the structure of the academic program. (p. 264)

These objectifications of minority students, and in particular ELLs, create serious academic barriers and obstacles to authentic learning and academic success, thus limiting opportunities. In fact, "The educational needs of our minority students have always required much attention, yet they often receive the least and this is certainly the case when it comes to teaching students whose first language is not English" (Barrera, 2016); yet, the learning needs of this group of students cannot be ignored.

According to current demographic statistics reported by the National Center for Education Statistics, there are an estimated 4.5 million ELLs in the nation's public school systems (NCES, 2016a). This rapidly growing student group is primarily concentrated in the urban school setting where they represent approximately 14% of the student population found in large to midsize cities (NCES, 2016a). With respect to enrollment among grade levels, ELLs can be found across elementary, middle, and secondary levels, although 67% of the nation's ELLs are concentrated in the elementary grades (K-5; NCES, 2016b). "As ELLs are the fastest growing student population in the nation, their academic success in both content and language is critical for their participation in college, careers, and citizenship in U.S. society and the global community" (Llosa et al., 2016, p. 420), making their education in general, and science education specifically, a civil right (Tate, 2001). Given this, it is imperative to not only prepare teachers to teach science in rigorous and socially just ways that provide quality opportunities for all students, but to also prepare them to be responsive to cultural and linguistic diversity of ELLs.

When considering science education, it is *opportunity to learn* that is a civil right, overshadowing the chance to share the same learning spaces with non-marginalized peers as a social justice construct (emphasis added, Tate, 2001, p. 1018). Focused on quality science education for all, *opportunity to learn* encompasses three related constructs: time on task (i.e., engaged time, time allocated to science instruction), quality of instruction (relative to concepts assessed), and technology (including science equipment). For instance, if we consider elementary science, the level at which a majority of ELLs are concentrated (NCES, 2016b), we see (a) limited time engaged in science, as science instruction is commonly preempted for mathematics and English language arts or test preparation, (b) curricular or ability tracking that limits exposure to quality science instruction, and (c) little opportunity for students to interact with the tools and technologies of science via hands-on investigations and inquiries (Tate, 2001). Taken together, it should be no surprise that the "science achievement gaps between ELLs and non-ELLs have remained largely consistent and wide based on recent NCES statistics (Llosa et al, 2016, p. 396).

Given these challenges, current research is now recommending a stronger partnering of science and language learning that transforms hands-on activities and second language acquisition techniques into engaging *opportunities to learn* in science (Lee & Buxton, 2013; Lee, Quinn, & Valdés, 2013). This approach not only calls for the integration of best practices from both fields, but also draws upon ELLs' funds of knowledge (González, Moll, & Amanti, 2005) and culturally-rich linguistic experiences as the catalyst for engagement. Yet lists of current best practices for teaching science effectively to ELLs found in the literature often include "many unexplained and unexplored meanings" for which preservice teachers are under-prepared to unpack so early in their careers (Buck, Mast, Ehlers, & Franklin, 2005, p. 1028). Therefore, simply presenting this information to preservice teachers during their preparation program is insufficient to affect their practice. To this end, although a majority of the nation's elementary teachers (82%) feel well prepared to teach science (Banilower et al., 2013), relatively few (17%) feel well prepared to teach science to ELLs (Banilower, Trygstad, & Smith, 2015).

We must also consider that preservice elementary teachers may have limited personal knowledge of being language learners themselves or lack personal or professional experience engaging with non-native English speakers and as a result might feel anxious and unprepared to teach science to ELLs. How, then, can we as teacher educators foster in our preservice elementary teachers an understanding of the learning experiences of ELLs—who must learn content and develop English language proficiency concurrently (Lee et al., 2013)—while instructing them on appropriate teaching practices for ELLs in science (Lee & Buxton, 2013)? This guiding question drove the development of a simulated language learner experience and our subsequent research.

The Simulated Language Learner Experience

Angela (first author), a science teacher educator, collaborated with a foreign language educator to develop a simulated language learner experience for preservice elementary teachers enrolled in the science methods course. Borrowed from medical education, simulation is "a technique that enables the learning and training of individuals and teams through the re-creation of some aspect of the real clinical situation" (Bradley, 2006, p. 261). Given this, our simulated language learner experience put preservice elementary teachers in the role of language learners while providing them with a safe learning context; specific experiences, and attainment of particular knowledge and skills through those experiences related to teaching science to ELLs; and opportunities for reflection to encourage application of knowledge and skills for teaching ELLs to their planning and instruction (Bradley, 2006; Hill, Davidson, McAllister, Wright, & Theodoros, 2014).

The two lessons described below comprised the simulated language learner experience. Both taught in French, these lessons were developed in response to preservice elementary teachers' limited understanding and application of strategies for teaching science to ELLs. Although the preservice elementary teachers could recall and list instruction and assessment strategies for teaching ELLs in science, there was little evidence of these practices in their fieldwork. Through this simulation, we endeavored to not only demonstrate and facilitate discussion of specific supports for language learners in science, but also to foster an understanding and appreciation of the unique learning experiences of ELLs in science. To accomplish this, the preservice teachers were put—unbeknownst to them at the onset—into the role of language learners during two brief, back-to-back science lessons on series and parallel circuits. The foreign language educator with whom we collaborated to develop the lessons served as the teacher during the simulation, and to date over 200 preservice elementary teachers have participated as students.

As mentioned previously, both lessons in the simulation were taught in French. The first lesson lacked supports for language learners while the second lesson incorporated research-based supports for language learners in science (see Lee & Buxton, 2013). In doing this, the simulation demonstrated and connected to the following constructs related to *opportunity to learn*: quality of instruction and technology (i.e., science materials; Tate, 2001). Figure 1 contrasts these lessons.

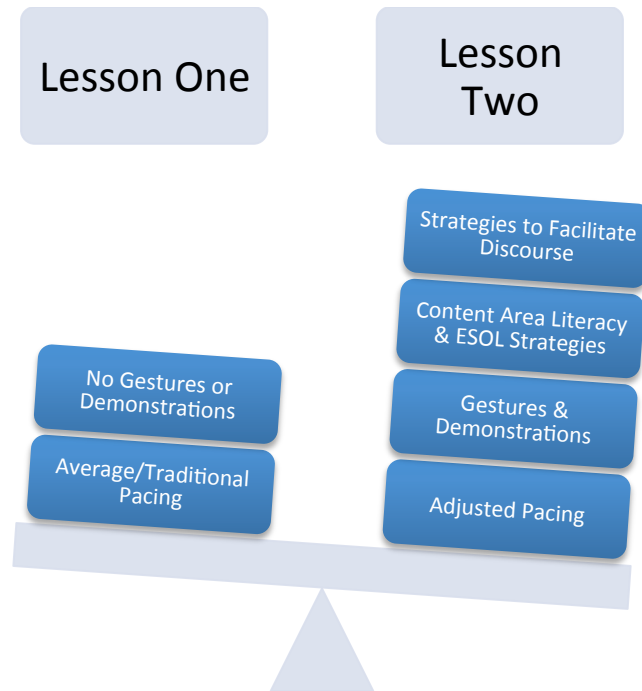


Figure 1. Contrasting components of Lesson One and Lesson Two of the simulated language learner experience.

Lesson One was designed to mimic a traditional science class. The teacher spoke quickly as if to native speakers, scribbled a few rough pictures and diagrams of series and parallel circuits on the board, quickly checked for understanding from time to time, and then distributed an assessment with high language demands. Before the start of the lesson, the teacher planted two or three “pleasers” in the class. These students were instructed to respond, *oui* (yes) each time the teacher asked, *Vous comprenez, oui?* (You understand, yes?). As might be expected, responses of *oui* (yes) spread among students with each subsequent question during this fast-paced lesson (Webb, 2016; Webb, Barrera, & Calderon, 2014).

The assessment for Lesson One placed high language demands on the students, asking them to write a paragraph describing series and parallel circuits and to draw one of each. To mimic assessment during a traditional science class, students were given only a few minutes to complete the assessment. The time given would have been sufficient for a native French speaker but posed problems and caused anxiety for the students in this simulated lesson (Webb, 2016; Webb et al., 2014).

Lesson Two taught the same content as Lesson One, but was designed to demonstrate the science learning that could take place if/when language learners are provided appropriate supports. This lesson was slower paced and the teacher used realia (i.e., objects from everyday life used as teaching aids), gestures and demonstrations, and an interactive word wall in her instruction. For instance, when introducing the term *pile* (battery), the teacher showed a picture of a battery from the interactive word wall as well as an actual C-cell battery. Similarly, when introducing the term *allumer* (to light), the teacher switched the classroom lights on and off while repeating the term. She also used an interactive word wall to review new vocabulary by having students direct her placement of pictures beside the French words for battery, wire, light bulb, danger, and to light. Then using these materials (two bulbs, six wires, and a C-cell battery), students worked in small groups to construct series and parallel circuits.

The assessment for Lesson Two evaluated students’ understanding of the same science concepts as the first assessment but placed lessened language demands on students. This served to scaffold the academic language demands required of students to demonstrate their understanding while still maintaining content-knowledge expectations. For this assessment, students were asked to draw a series

and parallel circuit. Images of a battery and two light bulbs were provided to scaffold each drawing. Instead of creating the whole drawing themselves, students were asked for only the accurate arrangements of wires (Webb, 2016; Webb et al., 2014).

Researching the Simulation

As mentioned previously, over 200 preservice elementary teachers have participated as students in this simulated language learner experience during their science methods course. Prior to the start of Lesson One, they were asked to answer the following questions: (a) What struggles do you think ELLs face during science class? (b) What instructional strategies do you think are effective for ELLs? Following the simulation (after Lesson Two), the preservice elementary teachers considered the following questions: (a) What were your impressions of the first lesson? (b) What were your impressions of the second lesson? (c) What supports provided during the second lesson facilitated your science learning? (d) What did you gain from participating in these lessons with regard to teaching ELLs?

After the first iteration of the simulation, Stan (second author), a teacher educator with expertise in literacy and English as a second language, joined the team to debrief the simulated lessons and students' engagement during the lessons as well as emergent themes in students' responses to the pre- and post- experience questions. In both phases of our research on enhancing preservice elementary teachers' awareness of the science learning experiences of ELLs, we endeavored to characterize the preservice elementary teachers' perceptions of and reactions to the lessons in the simulated language learner experience. Extending this, the second phase of our research explored the parallels and disconnects between the preservice teachers' experiences as language learners in the simulation and their expectations for ELLs' science learning experiences. Following, we highlight findings from the two phases of our research (Webb et al., 2014). Then, we tie our work back to social justice in science education.

Concrete Experiences Through Simulated Learning

In the first phase of our research, we investigated the experiences and perceptions of 180 preservice elementary teachers who participated in the simulated language learner experience in their science methods course. The most common reaction to Lesson One, which lacked supports for language learners, was feeling lost and confused. Some students reported feeling frustrated because they *"only comprehended a few words"* of the lesson. Still others felt intimidated, discouraged, and even dumb, *"shut[ting] down as learner[s] during the lesson and assessment."* Such reactions were due to the preservice teachers' limited understanding of French, use of insufficient or indiscernible visuals during the lesson, and the fast pace of the lesson. Although some preservice teachers checked out or shut down during this part of the simulation, others utilized coping strategies to make it through the unfamiliar and uncomfortable learning situation. That is, they *"picked up on familiar words," "respond[ed] even if [they] did not know the question or answer,"* and *"copied answers from the board to please the teacher"* to counter feelings of confusion and frustration.

Conversely, Lesson Two, which included research-based supports for language learners, was better received. The preservice teachers were more satisfied with the lesson and surprised they actually understood the science concepts that were taught. They attributed this primarily to the lesson being interactive, including *"real-life examples"* and *"actual objects,"* and incorporating a hands-on activity to help *"show concepts"* and *"make connections."* The lessened language demands on the assessment for Lesson Two did not go unnoticed, with preservice teachers commenting, *"the activity prepared us for the assessment"* and *"the assessment mirrored what we did."*

These concrete experiences as language learners, albeit brief, afforded the preservice teachers a unique perspective on the science learning experiences of ELLs. Participating in this simulation fostered empathy for ELLs as concurrent science learners *and* English learners, and encouraged the preservice teachers to make instructional considerations when teaching science to ELLs (Webb et al., 2014).

Real Emotions Through Simulated Learning

We found it noteworthy that preservice teachers' experiences of the simulation ignited empathy for the unique challenges ELLs face as science learners. This led us to further explore the preservice teachers' emotional reactions during the simulation. In the second phase of the research, we investigated the emotional reactions of 37 preservice elementary teachers to the simulation.

Prior to the simulation, preservice teachers were asked to anticipate ELLs' struggles during science class. Unsurprisingly, 32% of the preservice teachers thought ELLs would struggle with science-specific vocabulary, a challenge even for native English-speaking students. Similarly, 46% of preservice teachers expected ELLs to struggle with communication, namely reading, speaking, and listening. Just one preservice teacher (2.7%) anticipated ELLs would have an emotional reaction to learning science, specifically a struggle with "*motivation to succeed*" (Webb, 2016).

These predictions stood in stark contrast to the preservice teachers' own reactions to being positioned as language learners during the simulation. Notably, 35% of preservice teachers declared an emotional reaction to Lesson One while 16% mentioned an emotional reaction to Lesson Two, demonstrating that the preservice teachers had less of an emotional response to learning when they received research-based language supports in the simulation. Whereas the preservice teachers' own brief experiences as language learners during the simulation were laden with emotions, they failed to consider the emotional responses ELLs might have during science class. Although our sample of 37 preservice teachers is small, it seemed evident they were unaware of the emotional aspects of learning, especially for ELLs (see Darling-Hammond, 1997), highlighting one of the ways in which "meeting the needs of ELLs in the mainstream classroom was even more complex than expected" (Buck et al., 2005, p. 1026).

Across these two phases of our research, the simulation was successful in offering a contextualized learning experience through which preservice teachers came to acknowledge the need to provide ELLs equal *opportunity to learn* science. Not only did preservice teachers experience how to use research-based supports for language learners in their science teaching, the simulation also fostered empathy for the unique positions of ELLs as science and English learners in the science classroom. The simulation prompted them, if only momentarily, to experience emotions and reactions similar to ELLs in science, drawing attention to supports and the quality of instruction necessary to provide ELLs meaningful *opportunity to learn* science.

Social Justice in Science Education for ELLs

Science education can and should be viewed as a civil right for all students; yet, ensuring this right for non-mainstream students, such as ELLs, takes special care and attention. To afford ELLs meaningful *opportunities to learn* science they should be provided sufficient time to learn a quality science curriculum that incorporates the tools and technologies of science (Tate, 2001). Preparing teachers to accomplish this starts in their preservice teacher education program.

The simulated language learner experiences discussed here provide a meaningful and authentic, yet safe, context in which preservice elementary teachers can acknowledge and start to act on the important and necessary work of supporting ELLs in their mainstream classrooms. Our research has shown that this simulation is effective in increasing preservice elementary teachers' empathy to the experiences of ELLs during science class. It is one thing to read about ELLs' learning experiences and the teaching practices that can support ELLs in the science classroom; it is another thing entirely to experience feelings of frustration or support based on whether teachers incorporate supports for language learning into their science lessons. In considering the quality of instruction they provide ELLs in science, it is imperative for preservice teachers to understand this gatekeeping role of emotions (Krashen, 1982, 2003). That is, the negative emotional responses to science instruction that lacks language supports can block learning; conversely, lowered emotional responses can result in greater investment in learning when supports are present.

Although preservice elementary teachers are not fully prepared for the realities of teaching science to ELLs in the mainstream elementary classroom (Banilower et al., 2013, 2015; Buck et al., 2005), the simulation discussed here provides one tool or stepping stone to enhance preservice teachers' preparation in this area. This, however, cannot and should not be done in isolation. Our future work in preparing preservice teachers to provide quality instruction, as an *opportunity-to-learn* construct, focuses on the ways in which preservice teachers teach science to ELLs in their student teaching placement and beyond. That is, how are they structuring learning for ELLs to provide equal *opportunity to learn* science? More broadly, such a commitment to equality and social justice should become a more integral aspect of the elementary teacher education program in order for our preservice teachers to develop a philosophy and frame of mind around social justice and education, particularly science education, as a civil right (Tate, 2001).

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SOCIAL JUSTICE DRIVEN STEM LEARNING ($S_{\text{TEM}J}$): A CURRICULAR FRAMEWORK FOR TEACHING STEM IN A SOCIAL JUSTICE DRIVEN, URBAN, COLLEGE ACCESS PROGRAM

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Abstract

This article presents the curricular framework for a social justice driven STEM curriculum (i.e., $S_{\text{TEM}J}$) within an out-of-school time program for Boston Public high school students (i.e., College Bound) at Boston College. Starting with a discussion of the authors' ideological positionality within critical social justice discourses, the authors share how Bronfenbrenner's (1994) General Ecological Model provides a conceptual framework for operationalizing social justice inquiry with and through STEM. Positioning this curriculum within the College Bound program's overall design gives readers a sense of how the program's College and Career, Identity and Society, and $S_{\text{TEM}J}$ curriculums work in tandem to support the programs desired outcomes of students' increased critical consciousness and college matriculation. Lessons learned and future directions are also included in acknowledgement of the necessity of ongoing reflection and adaptation to fulfill the program's ambitious goals.

Introduction

Urban students of color living in poverty face systemic oppression daily. From environmental racism causing elevated asthma rates (Brugge, Durant, & Rioux, 2007; Brugge et al., 2013), to unequal access to nutritious food contributing to health inequality (Zenk et al., 2011), to an educational opportunity gap, particularly in relation to STEM (Presidents Council of Advisors on Science and Technology, 2014; Maltese & Tai, 2011) impoverished students of color are at an inherent disadvantage. In a society with a proud rhetoric of equality, these institutional deficits accumulate, and the social debt owed to students of color and their communities increases annually. In relation to education, Ladson-Billings (2006) has coined this perpetual deficit as an educational debt in recognition of the accumulated effect of disadvantage on students of color living in poverty.

In attempts to ameliorate these inequities federal agencies such as the National Science Foundation and the National Institutes of Health have established specific programs with the goal of broadening access to STEM learning experiences for underrepresented students. Acknowledging that many youth opt out of STEM subjects and fields because school-based STEM learning is often seen as uninspiring, confusing, and irrelevant (Millar, 2008 as cited in Villanueva & Hand, 2011), a number of well-designed approaches are underway to create STEM learning environments that build on youth's prior knowledge, experiences, and ways of being and knowing in their communities, with the goal of improving their interest and motivation to study STEM (Tan & Calabrese-Barton, 2010). However, although STEM can be made more relevant and interesting, social injustice is often overlooked as a relevant, lived, and complex reality that oppressed students are already innately motivated to resolve, and which builds upon their and their communities' knowledges and experiences.

As such, in this paper, university-based researchers and practitioners from the disciplines of STEM education and counseling psychology will present a curricular framework for an out-of-school time program, that is, College Bound, where social injustice is illuminated, analyzed, and acted upon with and through the development of STEM knowledge and skills (S_{STEM}J). S_{STEM}J is a unique approach to STEM learning as social justice inquiry and action drives STEM learning. Although appropriate and important in other contexts, this is different from programs that focus on teaching STEM to close the opportunity gap (although this happens concurrently in S_{STEM}J) or teaching STEM in reference to its applicability to illuminating/resolving social injustices. Rather, this program is explicitly designed for students to first to come to understand social injustices within their local communities *with* STEM knowledge and skills and then to act upon these understandings *through* STEM knowledge and skills.

Overall, we aim to explicate how we support a learning environment where students both learn to address larger social injustices and gain the STEM knowledge and skills that Moses and Cobb (2001) have argued is a civil right and potential gatekeeper to college, careers, and full citizenship itself in the 21st century. More specifically, within a cohesive program geared towards students' increased knowledge of STEM, college and career, and identity and society, we aim to increase both urban high school students' college access and critical consciousness.

In presenting our curricular framework we will describe the authors' ideological positionalities, the curriculum's conceptual framework, the program's design, and its desired outcomes. Throughout this presentation, examples of how each element of the curricular

framework shapes STEM teaching and learning will be highlighted. Lessons learned and future directions will also be included in acknowledgement of the necessity of ongoing reflection and adaptation to fulfill the program's ambitious goals.

Program Description

Prior to 2009, the College Bound (CB) program's mission was to prepare underserved students for college. In 2009, the program's access-oriented mission shifted towards a more expansive view of social justice that sought to engage students in coming to understand and act upon the roots of systemic oppression. Currently, CB has evolved to include three main program components: Identity & Society, to help students illuminate the historical and material construction of systems of oppression on the macro-level to support the de-internalization of oppression and the development of a positive identity; S_{STEM}J, to help students illuminate and transform local instantiations of systemic oppression through STEM knowledge and skills; and College & Career, to prepare students to matriculate to and succeed in college, and to develop their emerging social justice oriented vocational identities (see Figure 1).

The CB Program engages up to sixty 9th -12th grade students annually from our partner Boston Public high schools. All of our students will be first generation college students, almost all are students of color, roughly half identify as women, and over half are multilingual. Further, as our recruitment efforts do not target the top performing students, the grand majority of our students are originally "low to middle performing" students who may otherwise not get the attention, resources, or support to matriculate and succeed in college.

Every other Saturday, these students arrive at Boston College to participate in the full-day (8:30 am to 3:00 pm) CB program. In the morning, students participate in S_{STEM}J activities. In the afternoons, students attend their College & Career and Identity & Society sessions.

Instructors from each component, along with the leadership team engage in joint decision-making regarding the implementation and adaptation of the curriculum for the students. As a program with a diverse student population, we understand that each student's context matters. Consequently, we make necessary adjustments to the curriculum as needed as the program progresses. This commitment to serving and respecting the students' identities allows them to actively participate in deep discussions with respect to social justice issues, STEM, and their future careers. Throughout the program students are provided opportunities to give ongoing feedback. In this way modifications, adaptations, and additions to the curriculum can be made, so that not only future students can be directly impacted, but also the current students.

What makes this program unique is that because the mission ties the whole program together, the components parallel and complement each other. The Identity and Society component helps students understand the structures that promote oppression, starting with prompts to reflect on their own historical (past and present) contexts and experiences. Here, the goal is for students to develop a transferable ability to critically analyze the way that institutional and structural power reifies existing inequities. This works reciprocally with the S_{STEM}J component, which also teaches about social justice, but with and through STEM-implicating issues like environmental and food justice. As students are given the opportunity to study issues that may impact their communities directly, their emerging self-efficacy is buttressed by the College and Career component as it helps students see how college and career choices can help them organize their life's energy for social justice. Further, while students are examining who they are and how systems of oppression limit the flourishing of all beings in both of these sections, they are also learning how to access and navigate the educational and societal barriers

that can hold them back from successfully accessing college and attaining a viable STEM or STEM-enabled career within the College and Career Development curriculum.

As a whole, the program provides the youth with the opportunity to be transformative change agents within their community. As the program exposes the youth to societal challenges and provides them with experiential support in finding possible resolutions, students over time begin to realize that they can effect change not only in their schools and communities, but also beyond.

Curriculum Framework

Curriculum development is a process that is rooted in philosophy (Emans, 1966), guided by the contexts and beliefs regarding student learning (Bransford, Brown, & Cocking, 2000), and implemented by teachers. In order to explain how the curriculum came to be, we are explicit in the process in which the curriculum developed. The first section describes the team's ideological positionality. In this section, we thoroughly describe and explain the critical, anti-oppression discourses that guide our approach to programming.

The second section, the conceptual framework, explains how we chose to organize the information in a way that students can readily understand and reflect on. We chose Bronfenbrenner's (1994) Ecological Model to help students understand systemic oppression within a multidimensional context. Third, the program design section illustrates how we implement the program's mission and curriculum. Finally, our desired outcomes of the curriculum are presented with related, anecdotal data.

Team Positionality

CB at Boston College is a program explicitly committed to social justice. As STEM educators and counseling psychology researchers and practitioners of varying social locations committed to social justice, we agree with Rivera Maulucci (2012) that science educators teaching for social justice should clearly articulate both their social and *ideological* positioning. However, because social justice drives STEM in this program, the S_{TEM}J curriculum – though related to what Rivera Maulucci (2011) describes as critical discourses in teaching science for social justice (p. 40) – is ideologically positioned within broader anti-oppressive educational discourses. Specifically, our ideological positioning most aptly fits within the teaching for anti-oppression discourse that Kumashiro (2000) titles: “education that is critical of privileging and othering” (p. 36).

Within this approach to teaching for anti-oppression, educators aim to develop students' “knowledge about oppression and critical thinking skills” so that they can become “empowered to challenge oppression” internally, interpersonally, institutionally, and ideologically (Kumashiro, 2000, p. 37). As such, the program's S_{TEM}J curriculum is designed for students to learn STEM-related content and skills in order to engage and enhance their critical thinking skills for both the purposes of illuminating systemic oppression and empowering them to challenge it within their own communities and beyond. For instance, in relation to institutionalized oppression, students research and document food deserts in local urban communities, and how these food deserts exacerbate institutionalized health disparities (Food Research and Action Center, 2011). In response to this, students learn the mathematics, biology, physics, chemistry, and engineering content and skills necessary to design, build, harvest, distribute, and educate others in their or similar communities about how to grow local, affordable, and nutrient-dense

vegetables with solar-powered hydroponic gardening systems.

In relation to internal, interpersonal, and ideological oppression students come to understand and vocally resist the projected imagery and ways of being within STEM fields, which elevate an emotionally-detached, rationalistic, male, and White embodiment of STEM. Given the historical and present ideological positioning of mathematical and scientific knowledge and skills as the metrics for intelligence and superiority (Semali & Kincheloe, 1999) this projected embodiment needs to be addressed directly if Otherized students (e.g., students of color and women) are not to internalize individual or group-level inferiority.

One critique of this approach to teaching for anti-oppression is that the goal of “empowering” students with knowledge and critical thinking skills may imply that systemically impoverished students of color and their communities are deficient with respect to knowledge and critical thinking skills. This critique is a response to the legacy of “traditional interpretations of Bourdieuean cultural capital theory” which blames systemically impoverished students of colors’ lack of “normative cultural knowledge and skills” as being responsible for their “poor academic performance,” while absolving larger systems of power and privilege (Yosso, 2005, p. 70).

Instead, we believe that STEM educators need to grapple with how to engage, build from, and connect students’ “community cultural wealth” when teaching STEM knowledge and skills (Yosso, 2005, p. 77). Yosso (2005) defines “community cultural wealth” as “an array of knowledge, skills, abilities and contacts possessed and utilized by Communities of Color to survive and resist macro- and micro-forms of oppression,” which can be used to “transform education and empower People of Color to utilize assets already abundant in their communities” (pp. 77, 82). These abundant assets are undergirded by “at least six forms of capital such as aspirational, navigational, social, linguistic, familial, and resistant capital” (p. 77).

Within our program STEM educators are encouraged to tap into students’ “aspirational capital,” whereby students continue their communities’ legacy of seeking ambitious solutions to seemingly insurmountable systemic problems, for example, systemic health inequality (Yosso, 2005). With these ambitious goals, students are encouraged to use their “linguistic capital” and “social capital” to mobilize school and community members to support their social justice efforts through and with STEM. In conjunction with school and community members, students leverage their “familial capital,” rooted in their communities’ ways of knowing and being and their expanded notion of family/community, and their newly acquired STEM knowledge and skills, to co-create new possibilities for the well being of all beings (Yosso, 2005, pp. 79-80). In grappling with actualizing these new possibilities, STEM educators are implored to engage students “resistant capital,” that is, the “knowledges and skills fostered through oppositional behavior that challenges inequality” to help sustain long term engagement with social change in the face of adversity (Yosso, 2005, p. 80).

Collectively, the aim is to engage students as reflective, illuminating, co-participants who can navigate institutional and ideological barriers to support anti-oppressive work by intertwining their STEM capital with their cultural community wealth. It should be noted that, although we acknowledge the multiplicity of knowledges and the culturally-mediated approaches to science, we also understand the necessity of Otherized students to code-switch into normalized, Western scientific discourse to navigate material barriers to survival, for example, standardized tests, college, public hearings, etcetera (Apple, 2008). This calls upon both students and teachers to become increasingly multi-lingual and multi-epistemic in our pursuit of new possibilities within the materiality of oppression.

Conceptual Framework

Using the team's positionality with regards to social justice (see Figure 1), we wanted students to have an introspective understanding of the world they live in in order to be agents of transformation within it. In order to reflect this in the curriculum, we utilized Bronfenbrenner's (1994) *General Ecological Model*.

This theoretical framework was written to offer a new theoretical perspective (ecological) of human development. In his model, Bronfenbrenner (2009) depicts the "conception of the developing person, of the environment, and especially of the evolving interaction between the two" (p. 3). He assumes that an individual continuously interacts with the environment, and that this interaction informs what and how something is learned. What is particularly unique about his model is that he fuses tangible objects and settings (such as houses and schools) with intangible concepts such as culture and politics, and relationships:

Within any culture or subculture, settings of a given kind—such as homes, streets, or offices—tend to be very much alike, whereas between cultures they are distinctly different. It is as if within each society or subculture there existed a blueprint for the organization of every type of setting. Furthermore, the blueprint can be changed, with the result that the structure of the settings in a society can become markedly altered and produce some corresponding changes in behavior and development. (Bronfenbrenner, 1994, p. 4)

Furthermore, Bronfenbrenner (2000) stresses that in order for developmental influences to be visible, there needs to be a model for students to be able to observe what these influences are. Because of this, we chose his framework to slowly expose students to the various systems that interact with them so that they can produce long-lasting changes in their broader community.

This model depicts how different peoples' beliefs, culture, and identity are shaped by the different systems with which they frequently interact. The microsystem is,

a pattern of activities, social roles and interpersonal relations experienced by the developing person in a given face-to-face setting with particular physical, social, and symbolic features that invite, permit, or inhibit engagement in a sustained, progressively more complex interaction with, and activity in, the immediate environment. (Bronfenbrenner, 1994, p. 39)

Included in this system are settings such as the school, family, peer group, and workplace.

The next system—the mesosystem—consists of the interactions between two or more settings in the microsystem such as the home and the school. The third system, the exosystem,

comprises the linkages and processes taking place between two or more settings, at least one of which does not contain the developing person, but in which events occur that indirectly influence processes within the immediate setting in which the developing person lives. (e.g., for a child, the relation between the home and the parent's workplace). (Bronfenbrenner, 1994, p. 40)

The macrosystem is the pattern of combined micro-, meso-, and exosystems of a culture or subculture in relation to beliefs, knowledge, and economics. Finally, the chronosystem,

encompasses change or consistency over time not only in the characteristics of the person but also of the environment in which that person lives (e.g., changes over the life course in family structure, socioeconomic status, employment, place of residence, or the degree of hecticness and ability in everyday life). (Bronfenbrenner, 1994, p. 41)

The different systems in Bronfenbrenner's (1994) ecological model provide students with a comprehensive understanding of the varying aspects of society that they affect and are affected by. Because of this, the progression of the STEMJ curriculum initially begins with the self and moves outwards towards interconnected, society-level systems of oppression to help students build both a STEM and social justice oriented identity.

Locating identity development within a social system is consistent with a conceptualization of identity as enacting certain behaviors, ideas, and ways of relating in order to be recognized as a particular type of person (Farnsworth, 2010). However, this is not to say that sociopolitical identities such as race, gender, and class are fluid markers that students can choose to take up or put aside. These aspects of one's identity, although socially constructed, are historically and materially connected to "structural causes and material relations that create 'difference'" for the purposes of hierarchical stratification for dispossession (Grande, 2015, p. 159). Understanding that one's identity is influenced by an unjust society may allow young people to deconstruct the network of social relations from which identity and subjectivity continuously emerge. In doing so, students' ability to grapple with what DuBois (1907) termed a "double consciousness," which in broader terms names the identity paradox of subordinately positioned peoples who need to know how they are constructed by superiorly positioned peoples as less than, while understanding who one is and who one can become. Grappling with this paradox is critical for students who wish to engage with identities previously viewed as unavailable to them, such as, a social change agent or STEM person.

One example of how Bronfenbrenner's (1994) ecological model is put into practice is with our 11th and 12th grade food justice STEMJ curriculum. As such, when working on the problem of food injustice, students start with the microsystem, reflecting on what they eat day-to-day and learning the necessary biology and nutrition to assess how their diet may be impacting their long-term health. As students discover both what is healthy and unhealthy in their diet they naturally begin to question why, within the mesosystem of their school and family, they are eating food that may be deemed unhealthy.

Consequently, student angst is channeled into uncovering causes of poor nutrition and patterns of an oppressive exosystem begin to emerge. Using mathematics, they uncover lower prices, but higher calories per pound between potatoes chips and potatoes; higher average prices at smaller convenient stores, especially for the most nutritious food; and the plethora of these stores in impoverished communities. Further, the contradiction of the most impoverished communities needing the most expensive transportation options (i.e., a car or cab) to get to the most affordable food vendors is illuminated as students learn how to use geographic information systems (GIS). As such, students are able to employ technology to map the presence of "food deserts," that is, geographic areas without access to affordable and nutrient-dense food.

Quickly students are able to connect their understanding of how this oppressive exosystem, that is, food deserts, limits the nutritional quality within their micro- and meso-systems. Seeing the relationship between these multiple systems facilitates their comprehension of how oppressive macrosystems operate. Further, students readily connect how food deserts

interact with unequal access to high-quality health care to further exacerbate health disparities by race and class. Finally, students learn about how this interacts on the chronosystem level by organizing and tracking data about how demographics, income, and food production have changed over time, and how this contributes to oppressive conditions.

Collectively, as students progress and oscillate through this ecological model they are asked to reflect on how oppression operates on internal, interpersonal, institutional, and ideological levels. For example, students discuss how national nutrition campaigns targeted at schools and communities with less access to affordable and nutritious food obscures the institutional forces that have produced food deserts, creating a damaging false-illusion of self-determined negative health outcomes, which consequently dampens resistance.

Moving beyond critique, as students increase their awareness and understanding of systemic oppression, they are offered ways to move towards action to improve society. For example, in relation to the food deserts, students suggested creating a market in these areas, which led our project staff to examine ways to support the youth in reaching their solution. This work soon led to a hydroponic food project (growing food with water and minerals as opposed to soil) in which the youth grow produce that they then sell at local farmers' markets. To advance this project, students began designing and creating solar-powered hydroponic garden systems in order to produce and distribute local, affordable, and nutrient-dense food that can be grown on barren land, concrete backyards, or roof tops. In an effort to make this a sustainable social enterprise, students learned the biology, chemistry, mathematics, physics, technology, engineering, business, economics, and education skills necessary to design, create, market, manage, and sustain their endeavor.

As illuminated, the conceptual framework of the S_{TEM}J curriculum clearly supports the program's goal of increasing students' critical consciousness, as they learn STEM skills and knowledge while leverage their community cultural wealth to move from increased awareness of food deserts to increased efficacy towards resolving them, and finally to action. Although seemingly indirectly related, it has been our experience that this process also motivates and empowers students to pursue and access college, which is the program's other key objective.

As students' feelings of empowerment increases, their increased interest in planning for college and careers seems to increase. Students begin to articulate college and careers as vehicles for promoting their vocational interests in social transformation. As opposed to college as an abstract and external goal that disconnects students from their communities' ways of knowing and being, attending and graduating from college becomes a highly personal goal directly connected to their desire for increased well being for their community and beyond.

Desired Outcomes

As mentioned previously, the program's desired outcomes are both the development of critically conscious students and their successful matriculation to two-year or four-year colleges (see Figure 1).

The process for developing critical consciousness is based on Freire's (2007) theory that through a dialogical approach to fostering critical literacy, individuals gain understanding of the societal conditions that impact their lives, and because of this new understanding, take action to change their world. Watts, Diemer, and Voight (2011) identified three components of critical consciousness: critical reflection, political efficacy, and critical action. These components correspond with the grade-level progression in the CB curriculum for developing an activist identity. That is, facilitators work with 9th and 10th graders to develop critical reflection, 11th

graders to develop political efficacy, and 12th graders to develop and sustain critical action. Although critical consciousness is not conceived of as a developmental or stage model, and theoretically, these three components emerge reciprocally, scholars (Watts & Hipolito-Delgado, 2015) have noted that facilitating critical action is generally more difficult than critical reflection. With this in mind, our framework seeks to build critical reflection and political efficacy first, with the presumption that students are more likely to take social action if they know what they want to change and how they want to change it. Finally, even though activities are primarily tailored to one component of critical consciousness each year, facilitators and program administrators embed opportunities for reciprocal development of all three components throughout the life of the program. For example, while students in grades 9-10 learn how to analyze data from air quality sensors to expose the causes of differential asthma rates by race and class, students in grades 11 (after exposing the presence of food deserts using GIS) develop a sense of political efficacy as they are mentored by students in grade 12 who are engaging in critical action to transform food deserts through hydroponics.

Qualitative content analysis of semi-structured interviews presented evidence of students' development of critical reflection, political efficacy, and critical action within the program (Kozan et al., in review). As designed, although there was evidence of students' critical reflections throughout the S_{TEM}J curriculum, they found the strongest evidence of students' increased political efficacy and movement towards critical actions in grades eleven and twelve within the food justice curriculum (Kozan et al., in press). Interestingly, they also illuminated connections between students increased feelings of empowerment with their increased interest in planning for college and career, which they hypothesized to be mediated by students' increased sense of vocational purpose driven by their desire for social transformation (Kozan et al, in press). Even with these hopeful findings, longitudinal qualitative studies are desired to illuminate how this critical consciousness fostered within CB manifests itself during and after college.

Beyond this qualitative content analysis, the authors of this article have consistently heard students claim that: (1) they want to meaningfully give back to their community, and (2) they want to learn how to solve social and environmental justice challenges that affect their neighborhoods. In fact, it was our high school students work in using geographic information system technologies to explore environmental justice issues in their own neighborhoods that students realized the existence of food deserts to which they proposed using hydroponic gardening to provide affordable and locally grown greens to their communities.

In relation to college access we have had a 100% college attendance rate with 3 Gates Millennial Scholars in the past nine years. In addition, we have been trying to track our students who participated in our program and of the 75 graduates we have tracked 41 are still majoring in a STEM field in college. This is significant in light of the National Science Foundation Indicators (2010), which provided evidence that although the proportion of Blacks (5%) and Hispanics (5%) have increased in nonacademic science and engineering occupations positions, they are still much lower than the general population. In many ways we believe that this reflects students' connection with STEM as a vehicle for social change.

Although objectives related to critical consciousness, college, and career within the context of gendered and racialized global capitalism may seem contradictory from the perspective of a Marxist critique, they are quite harmonious from the perspective of oppressed students within our program. Our students have seen firsthand how their skills and knowledge, which could be further developed in college, could contribute towards social transformation and

as such have felt vocational callings towards these ends. The pursuit of a college education and a career can be for the purpose of justice, as it can be for the purposes of injustice. Rarely though, is life so binary. Rather, systems of oppression are longstanding and complex, and their resolution will require long-term commitment, rigorous preparation, careers that can sustain action and survival, and a diversity of skills and occupations (some of which are STEM-related).

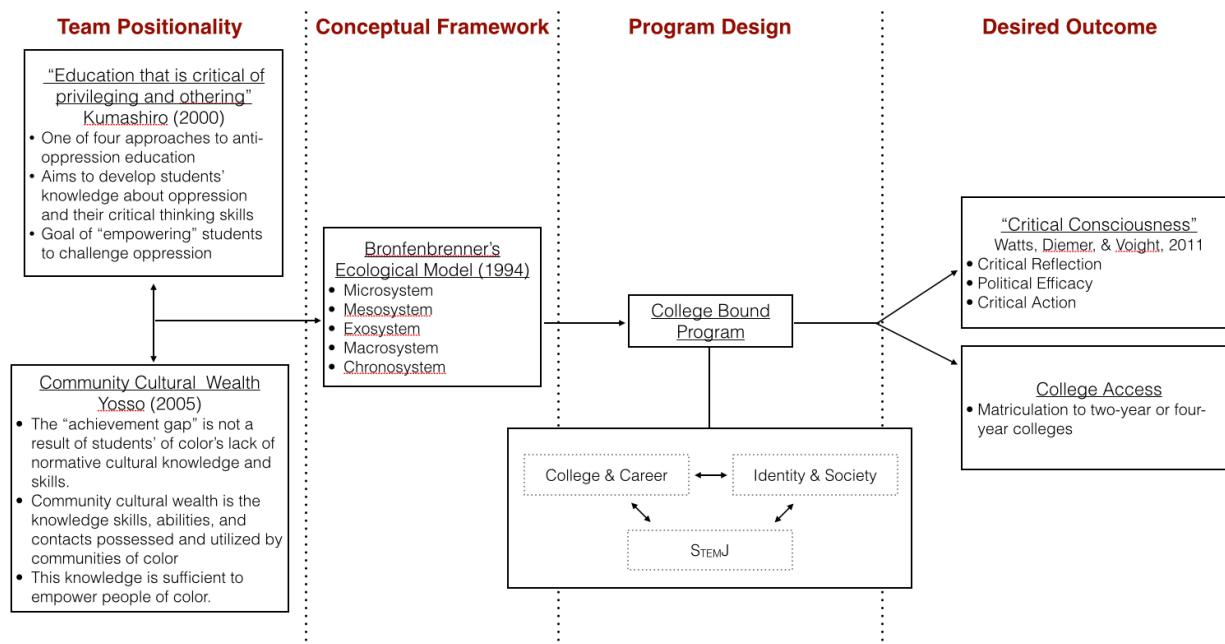


Figure 1. CB curriculum framework

Lessons Learned

Since 2009 there have been a few key lessons learned that have, in our humble opinion, enhanced the STEMJ curriculum's vitality. Below are suggestions that may be helpful for other programs who seek to implement a similar curricular model.

Allow Time and Provide a Community for Students to Develop Their Critical Consciousness

Participating in deep discussions about systemic oppression does not happen instantaneously. Many students have internalized their social conditions as innate to their communities and/or sociopolitical groups, often blaming themselves and their communities for their systemic oppression (Helms, 1995), and generally unconvinced that they can be agents of change. For example, although students of color may have greater epistemic purview in relation to systemic racism (given its visible effects on their life choices and circumstances), the internalization of racial inferiority necessitates coming to understand one's experiences as connected to material, structural forces which, despite their individual agency, shapes the options and choices of individuals in such a way that, on the whole, replicate inequality (MacLeod, 2008). Moreover, few students are immediately ready or comfortable to share their personal experiences to adults and peers whom they are unfamiliar with. As such, we have found that trust

formation, through a safe socio-emotional learning environment is a necessary first step. Learning this lesson means that teachers must engage students in activities that promote a sense of community before they can engagement develop their critical consciousness.

Engage Student Leaders and Alumni Leaders

One of the CB program's strengths is its engagement of student leaders and alumni. While most college access programs track their graduates' college matriculation and completion rates, CB continuously reaches out to alumni to enhance our students' experiences. With varying amounts of engagement, some alumni act as guest speakers, sharing their college experiences, while others serve as alumni leaders who work with our instructors, helping to facilitate group activities, support individual students, and even plan lessons. We have found that when students see and engage with someone young who looks like them and who has had similar experiences as themselves, they are more willing to participate in personal and intense conversations about systemic oppression. In addition, as college students they serve as role models, sounding boards, and guides for our students, all of whom are first-generation college students, who greatly appreciate their navigational capital.

Bring in Community Activists and STEM Professionals

In an effort to expand CB students' knowledge about systemic oppression and its manifestations locally, nationally and globally, the College Program has incorporated opportunities for CB students to hear from college students, community activists, and STEM professionals who engage in social justice work. Their lived, concrete examples increase students' ability to imagine how their increased critical consciousness, in tandem with college completion, can create new possibilities for mutual well being. In particular, we have found that students, although always engaged, are particularly motivated to explore a potential career if someone with a similar background to them has shared their work, college going, and social justice experiences with them. This personal identification with a guest seems to trigger a feeling of vicarious self-efficacy and instills a sense of vitality and urgency to our collective work that is miraculously beautiful.

Allow Space for Healing and Reflection Resulting from Current Events

While we are confident in the program's design and curricular components, we recognize the importance of illuminating current instantiations of systemic oppression, especially the ones that are weighing heavily on students minds and hearts. Pausing the curriculum to discuss instances of injustice that impact our students lives, such as, police brutality, its connection to systemic racism, and the Black Lives Matter movement's responses to systemic violence enacted against Black bodies, is important to building a community of trust. Students and staff need to vent their frustrations, share their insights, pose questions, and sometimes share similar experiences. Listening and facilitating these community discussions has not always been comfortable, but allowing space for vulnerability deepens trust and a feeling of community. Further, in our experience, we have found that these sessions help students process how these events are instantiations of systemic oppression, which is not only illuminating, but seems to increase students' sense of political efficacy. In turn, this increased political efficacy seems to re-energize their emerging college and career interests related to their social justice oriented vocational identities.

Future Directions

The CB program started in 1987, as a collaboration between Boston College and the Boston Public Schools. The intent of the program was to identify students who were struggling academically and socially, and offer them an integrated program of academic and social support. Over the years, the program has evolved to respond and adapt to an ever-changing society. In 2007, an important shift from a subject-based academic enrichment, college-preparation program to a social justice and critical inquiry focused program occurred. In 2009, it expanded to a four-year program starting in the 9th grade, adding a STEM component in recognition of STEM's importance to advancing social justice both individually and collectively. Since this time we have continuously revised what it means to have STEM within a social justice oriented program. Social justice driven STEM (S_{TEM}J) is our most recent iteration.

Over the next few years, the CB program will expand to include 7th to 12th grades. We believe that earlier intervention in relation to both critical consciousness and college access is important and necessary. In our experience it takes at least two years for students to significantly develop their critical consciousness and college readiness; for most students this is their junior year, which in relation to college access is far too late.

By adding the middle school grades, teaching for social justice with and through STEM will expand and change. Our students are interested in coding and robotics, which is reflective of these technologies increased presence within our realities. Arguably, understanding these specialized technologies are increasingly critical to full participation in our society, and as such mirrors the motivation behind Moses and Cobb's (2001) earlier call to acknowledge STEM knowledge and skills as a civil right.

Thus, although we are not sure how coding and robotics will ultimately be brought to serve social justice within our program, we believe our students need and should have access to this increasingly important knowledge and skills. Nonetheless, we are confident that together we can uncover what is possible. Our students' material experiences with social injustices in combination with their community cultural wealth have always helped us to teach for social justice with and through STEM. As always, our learning is reciprocal. Throughout this process, our team will constantly examine and re-examine what it means to promote social justice driven STEM learning, and how we can reflect that in the program and implement it throughout the curriculum.

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TOWARD A THEORY OF TEACHER EDUCATION FOR JUSTICE-ORIENTED STEM

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Abstract

Among the multiple perspectives as to the focus of education policy, there has been much recent attention paid to both STEM and social justice education. While these approaches are often seen in opposition with each other, in this paper we explore the possibility of combining these two aims as we begin to develop a theory of teacher education for justice-oriented STEM education.

Introduction

In our nation's current debate about education and equity, there has been much attention to both STEM and social justice education. While these approaches may be seen in opposition with each other, in this paper we explore the possibility and importance of combining these two aims as we begin to develop a theory of teacher education for justice-oriented STEM education.

Each of us work as faculty in an undergraduate elementary teacher education program at North Carolina State University (NCSU) with the dual mission to prepare elementary teachers with deep content and methods knowledge in the STEM fields as well as the commitment and capacities to teach towards social justice. The path by which our teacher candidates develop knowledge within each of the STEM disciplines has been well established. In their freshman and sophomore years, candidates take 27 credit hours of mathematics, science, and engineering design content courses, including calculus and physics courses designed specifically for elementary teachers. Once the candidates enter our program in their junior year, they take two mathematics courses, two science courses, and one engineering methods course. Technology is infused across the program through computer presentation software, video and audio recording, science probeware, and student online interactions.

Our teacher candidates' trajectory in their development as social justice educators is, to date, less established. Because of the number of STEM-related courses we fit into our program, there is no official Foundations or School and Society course, and the bulk of justice-related content and concepts are addressed in a two-credit seminar students take in their junior year, officially titled "Connections: Identity, Social Justice, and Diverse Learners." In addition, and to varying degrees, members of faculty incorporate justice-oriented concepts and content in literacy, social studies, and STEM-related methods courses. We have recently begun to assess this incorporation, systematically, as a program. In order to meet our dual mission, we believe it is necessary to take seriously the task of more intentionally incorporating the components for the development of social justice educators into our STEM courses.

In what follows, we use Marilyn Cochran-Smith's (2009) theory of teacher education for social justice as a launching point and draw on our own experiences when possible, to explore the multiple ways in which the aims of STEM and social justice education can serve each other. In doing so, we present a new model for aligning the undergirding missions and assumptions of these two, often-divergent fields.

The Divergent Assumptions of STEM and Social Justice Education

STEM is conceptualized in a variety of ways, yet is anchored by the notion that global competition requires a workforce prepared in science, technology, engineering, and mathematics (e.g., National Academy of Sciences, 1995, 2007, 2010). In the interest of global competitiveness, there has been increasing governmental emphasis on national progress in STEM fields. This includes a series of reports and studies on the preparation of students for STEM careers across the U.S. and in comparison to other countries (e.g., Kuenzi, 2008; Martin, Mullis, Foy, & Stanco, 2012; OECD, 2014). In 2010, for example, the "Rising Above the Gathering Storm" report (2007) claimed that jobs of the future will be STEM driven and further, that the foundational STEM knowledge gleaned from K-12 education will have direct links to the prosperity of the U.S. Subsequently, we have seen growing attention to the development and monetary support of STEM education in K- post graduate education.

Relatedly, the widely held view that prosperity and education are directly connected has brought increased attention to educational inequality, especially along lines of race and socio-

economic status. While research links the majority of variations in student achievement to out-of-school factors such as poverty and lack of access to resources (e.g. early childhood education and health care) (Berliner, 2013; Rothstein, 2007), public discourse reflects a general consensus that schools and teachers must be held accountable for the alleviation of inequities (Berliner & Glass, 2014). This recent attention has brought emphasis to programs that attempt to alleviate inequalities and those that identify as social justice in nature. Subsequently, the term “social justice” has been used to promote a multitude of concepts and programs (North, 2006). The theoretical foundation of this field, however, is anchored by the notion that the purpose of education is in service of human enlightenment and human liberation (Ayers, Quinn, & Stovall, 2009). As such, social justice educators are committed to promoting and protecting the recognition of people’s intersectional identities (Leonardo, 2009; Stovall, 2006), interrupting the reproduction of social inequalities, and preparing “justice-oriented citizens” (Westheimer & Kahne, 2004) who have the capacities and consciousness to understand and actively respond to the root causes of systemic inequities (Adams, Bell, & Griffin, 2007; Freire, 1971; Kumashiro, 2015; North, 2006).

Scholars and the public have also begun to address and attempt to alleviate the challenged access to STEM education and careers among women and people of color as an issue of access and equity (Brown et al., 2015; Diekman, Weisgram, & Belanger, 2015; Wilson, Bates, Scott, Painter, & Shaffer, 2015). To that end, there are clear overlaps across the fields of STEM and social justice education, namely in their intention to create equitable opportunities for all students. There are, however, also glaring discrepancies, namely that STEM approaches to equity are primarily concerned with the creation of pathways by which individuals can gain access to the economy and experience social mobility. Alternatively, social justice education is concerned with preparing citizens with the capacities and commitments to interrogate and rearrange the very structures that maintain a stratified society in service of the common good.

Critical mathematics and science education scholars have pointed out that it is possible to teach towards social justice in and through mathematics and science education (i.e. Barton, 1998; Bianchini, Akerson, Barton, Lee, & Rodriguez, 2012; Dimick, 2011; Felton & Koestler, 2015; Gutstein, 2006; Leonard, Brooks, Barnes-Johnson, & Berry, 2010, Rodriguez, 1998). For example, the study of mathematics, according to Gutstein (2003), provides opportunities for students to understand relations of power, resource inequalities, and disparate opportunities between different social groups and “examine these various phenomenon both in one’s immediate life and in the broader social world” (p. 45). Yet, teachers are too often likely to complete credentialing programs without knowledge or experience with this approach (Blanchett, 2006) and in-service teachers rarely receive professional development specifically on how to develop culturally relevant pedagogy in their mathematics classes (Leonard, Brooks, Barnes-Johnson, & Berry, 2010). School districts and teacher education programs too often assume that the achievement gap in STEM fields results entirely from teachers’ lack of disciplinary knowledge. Instead, this gap could be caused by teachers’ deficit perspectives and internalized racism and bias (Delpit, 2012) or their lack of cultural competence and ability to make curriculum relevant to students’ lived experiences (Ladson-Billings, 2009). In addition to an equity orientation, Gutierrez (2013) claims that teachers’ efforts to provide equitable opportunities in math are stymied by their socio-political contexts:

What is lacking in these approaches is a model of teacher development that includes giving teachers the skills to form a deep connection to students and

political knowledge: negotiating the world of high stakes testing and standardization, connecting with and explaining that mathematics to community members and district officials, and buffering themselves, reinventing, or subverting the system to be an advocate for their students (p. 37).

To that end, Cochran-Smith's (2009) theory of teacher education for social justice serves as a framework as we attempt to envision how to prepare teachers for the arduous task of justice-oriented STEM.

Towards a Theory of Teacher Education for Justice-Oriented STEM

In her theory of teacher education for social justice, Cochran-Smith (2009) begins with an articulation of justice that goes beyond simple notions of "non discrimination and equal opportunity to participate" (p. 450). Instead, she argues, we must define justice through terms that are democratic, anti-oppressive, multi-perspectival, and rooted in critical theory. Drawing primarily on the work of critical, feminist theorist Nancy Fraser (Fraser & Honneth, 2003), Cochran-Smith argues that justice is only possible at the intersection between equitable distribution of resources and the recognition of individuals and social groups based on culture, race, gender, religion, nationality, language, sexual orientation, and ability/disability. In Fraser's other work (1997), she similarly claims that remedies to inequality must pay attention to how *both* "economic disadvantage impedes equal participation in the making of culture, in public spheres and in everyday life" and "[c]ultural norms that are unfairly biased against some are institutionalized in the state and the economy" (p. 15). In simple terms, and as related to schooling, scholars of social justice education (North, 2006) have taken up this theory to assert that the curriculum must provide students with pathways to access economic resources without expecting them to sacrifice their identities. Further, Cochran-Smith continues, schools must prepare students to recognize inequalities and identify ways in which they can participate in and contribute to recreating a more just and democratic society.

If the ultimate aim is education for justice, then Cochran-Smith contends, teacher education programs must first diversify the teaching force and recruit teachers whose "beliefs, experiences, and values are consistent with social justice goals" (p. 459) and provide candidates with opportunities to work alongside and learn from mentors, parents, and community members who are committed to justice. In addition, Cochran-Smith argues that course work should serve to help candidates (re)conceptualize teaching as the amalgam of the following: 1) content **knowledge related to equity and justice** as well as the ability to critically analyze the construction of said knowledge; 2) a mindset, or **interpretive frames**, that support a justice-oriented practice; 3) the teaching **methods, strategies, and skills** to engage *all* students in meaningful learning; and 4) a sense of **advocacy** and alliance with students, parents, colleagues, and communities (p. 454).

Even as some may believe that the work of preparing teachers for a social justice practice does not belong in the STEM fields, others have provided argument and evidence that both mathematics (Gutstein, 2003; 2006) and science education (Basu & Barton, 2007; Meyer & Crawford, 2011) provide opportunities to develop students' critical capacities and skills of justice-oriented citizenship. To that end, we contend that preparing teachers for a justice-oriented practice is not only possible, but also essential, in STEM methods coursework. In what follows, we will draw on Cochran-Smith's framework to envision methods courses in a teacher preparation program with **justice-oriented STEM** as the aim. To do this, we will discuss how to

facilitate teaching candidates as they cultivate the **knowledge; interpretive frames; methods, strategies, and skills**; and sense of **advocacy** necessary for a justice-oriented STEM practice.

Knowledge

In terms of knowledge development, Cochran-Smith contends, candidates must be prepared with the body of **knowledge** generally agreed upon in the field to teach students in meaningful ways (i.e. Darling-Hammond & Bransford, 2005). In addition, they must develop the capacity to “critique the very idea of a knowledge base and understand its limitations” (p. 455) and draw on the “the knowledge traditions and lived experiences of marginalized and oppressed groups” in order to challenge the status quo (p. 451). STEM methods courses have the potential to provide ample opportunities to prepare candidates to develop and practice these skills by asking questions from the field of critical pedagogy (McLaren, 2009) including: ‘What kind of knowledge is valued?’ ‘Who decides?’ ‘Who benefits and who is marginalized?’ and ‘What other approaches could we take?’ Further, STEM methods courses provide opportunities to prepare candidates to teach their students to grapple with similar questions.

First and foremost, the STEM fields inherently foster the critical and analytical skills necessary to problematize and interrogate the construction of knowledge. Scientific practices (NGSS, 2013), for example, lend themselves to the exploration of how knowledge is cultivated, what counts as evidence, and who decides. Additionally, there is an opportunity here to compare this process of knowledge development with socially constructed “knowledge” including stereotypes and biases. For example, students in our diversity seminar watch sections from the PBS special “Race: The Power of an Illusion,” to look at the lack of scientific evidence for our socially constructed concept of race to help them understand the ways in which scientific practices and knowledge, like all knowledge, are constructed within a socio-cultural context.

Mathematical computation also lends itself to exploring different ways of approaching problems and provides a structure for young learners to learn multiple perspectives and solution paths (Koestler, 2012). This fosters opportunities to interrogate how knowledge is valued differently by individuals and groups. For example, in their mathematics methods course, our candidates examine what the “traditional” algorithms are in various cultures around the world. Candidates are typically surprised to learn that the traditional algorithm in the United States for division, for example, is not the predominant algorithm in all countries. Activities and discussions such as these serve as a launching point for further interrogation of the cultural relativity of knowledge.

A focus on STEM also provides opportunities to explore how access to knowledge is differentially distributed, and how this access manifests as economic inequality. As mentioned, there is already much documentation of differential access to STEM education and representation in STEM careers (Brown et al., 2015; Diekman et al., 2015). By looking directly at contemporary research on this topic and situating this opportunity gap in historical contexts (Mohr-Schroeder, Cavalcanti, & Blyman, 2015), candidates can develop understanding of systemic racism and the ways in which inequitable educational access continues to reproduce racial and economic inequalities (Kozol, 2005; 2012). Further, this analysis will help candidates understand the necessity for making STEM fields accessible, especially to those students who have been historically marginalized.

Yet to develop a justice orientation, the very focus on STEM itself needs to be problematized and candidates should grapple with the ways in which knowledge is “historically and socially

rooted and interest bound” (McLaren, 2009, p. 63). Even as students are learning the importance of making STEM content accessible, there is also room to interrogate the focus on STEM and problematize the ways in which technocratic and quantifiable skills continue to be valued over the humanities in our current reform context (Apple, 2004; Hursh, 2000). As Lisa Delpit has argued (1995), especially those students from marginalized communities must be explicitly taught about the “culture of power,” or the tools (knowledge, beliefs, and skills) valued by those in the dominant majority such as STEM in this case. At the same time, they must be given opportunities to critique these tools and recognize that they are not better, but rather necessary because they are valued by those in the dominant majority. In simpler terms, teacher candidates, and subsequently their students, would understand that STEM content knowledge is essential, not necessarily because this knowledge is superior to the humanities, but because it is valued more in society.

Finally, in any justice-oriented STEM program, students should learn about the ways in which perceived scientific knowledge has and continues to be used to perpetuate systems of oppression. Learning the history of the eugenics movement (Gould, 1996), for example, or about the ways in which technological developments (Bigelow & Peterson, 2002) contribute to the wealth gap and the diminishing middle class, could provide students with an opportunity to critically answer questions such as, ‘whose interests are served by particular forms of knowledge?’

Interpretive Frames

In addition to knowledge, Cochran-Smith discusses *interpretive frames*, or the “filters through which teachers make decisions, form relationships, and support learning, [which] are the powerful mediators of practice and thus of students’ opportunities and experiences” (p. 456). Candidates, she contends, must develop an **assets-based view** of their students and the communities from which they come, a **sense of inquiry** about themselves and others, and the **understanding that teaching is deeply entrenched in a socio-political context**. STEM methods courses are perhaps ideal places to shape candidates’ interpretive frames. For example, and as we will describe here, the development of each of these interpretive frames is easily abetted through analysis of the common practice of ability grouping, or tracking, in mathematics classes.

To teach for social justice, it is essential for candidates to challenge any deficit-based thinking and instead develop **assets-based perspectives**, with the ability to recognize and draw on students’ prior knowledge and past experiences (Leonard, 2008; González, Andrade, Civil, & Moll, 2001; Oyler, 2011). Investigating tracking in mathematics classes can contribute to candidates’ development in this area through an exploration of the tangible and differential outcomes of assets-based and deficit perspectives. In our current mathematics methods courses, for example, we attend to and problematize the language often heard in schools to talk about students and their performance in mathematics (i.e., “low” and “high”) that typically determines their placement into groups. We explore research that articulates how this cultivates a “fixed mindset,” or notion that people are born smart, or either as a “math person” or not a “math person” (Boaler, 2016; Dweck, 2006). Candidates also learn how tracking results in disparities in educational experiences as students in “lower” tracks often receive lower-quality instruction (Gamoran & Carbonaro, 2002), which can result in students giving less effort to their academic work in comparison to students in “higher” tracks (Carbonaro, 2005). Further, research has suggested that students have very little chance of moving to a different track throughout their K-

12 schooling (Dixon, 2002). All of this, candidates understand, has significant implications for students' long-term academic outcomes (Hoffer, 1992), as well as their levels of anxiety and confidence (Butler, 2008). Alternatively, candidates learn, that when students are not placed into tracks and heterogeneous grouping is utilized, assumptions about student ability and expected performance are less prevalent. Hence, students are more likely to have a growth mindset (Dweck, 2006) about their ability to do mathematics (Boaler, 2016), perhaps explaining why the use of heterogeneous grouping has been positively linked to academic achievement and the probability of completing advanced mathematics courses (Burris, Heubert, & Levin, 2006). Through learning about this research on the use (or not) of tracking, the realities of deficit-based thinking become clear to teacher candidates. Then, by discussing the ways in which deficit perspectives differentially and negatively influence students from marginalized communities, as tracking practices tend to segregate by race and class (Oakes, 1990) even when we control for assessment data (Stiff, Johnson, & Akos, 2011; Faulkner, Stiff, Marshall, Nietfeld, & Crossland, 2014), candidates become more aware of systemic racism and the tangible effects of deficit versus assets-based thinking.

We have some evidence to suggest that teacher candidates' experiences in our program push them to develop a more assets-based perspective of elementary children. As a part of large, longitudinal, evaluative study of our program, we have systematically collected data on our teacher candidates' evolving perspectives on why children living in poverty tend to do less well in school than children from middle or upper class backgrounds. By asking this question to a subset of our candidates during interviews at three time points of the program, the resulting data indicates that they may move away from deficit perspectives of children living in poverty. For example, at the beginning of the program, the candidates tend to focus on what the students do not have, often placing the blame on the parents:

I think it has a lot to do with the parents. I think lower income generally the parents aren't as involved because for one they're usually working more because they don't have as much income.... Also, there's probably a lot of low-income people who didn't go to college and didn't grow up valuing education, so they can't pass that onto their child.

As they progress through the program, their perspective tends to shift to blaming either societal structures or teacher biases for why children in poverty tend to do less well in school. For example, one teacher candidate, near completion of the program, focused on the inequity of the structure of funding and resources when she said, "I think that a lot has to do with resources, the kind of the schools that typically are in that area and who, what kind of teachers they attract." Another candidate's rationale centered around teachers' expectations: "I think the biggest [reason] is the stereotypical expectations that teachers apply....to children who come in with less money." This candidate, among others, emphasized that teachers tend to have biases that naturally impact their expectations of academic performance of students living in poverty.

Looking at tracking through this socioeconomic and racial lens can also be leveraged as a tool to motivate teacher candidates to take an **inquiry stance** toward their biases and stereotypes. First, teacher candidates can examine their own experiences with tracking in school and analyze whether they were privileged or neglected by these practices and how this reflects the research on the ways in which race and class are manifested in tracking practices. From there, teacher candidates must be encouraged to critically analyze their own assumptions, biases, and misconceptions about who is "good" at mathematics and explore further where they developed

stereotypes and biases and how this influences their relationships with students and their families.

A discussion of tracking also provides an opportunity to explore the **socio-political context** of teaching and schooling. A critical analysis of the ways in which tracking translates individual bias into systemic inequality provides a framework through which to look at the myriad of ways in which schools have the potential to perpetuate (i.e., unequal funding, segregation, ethnocentric curriculum) or interrupt cycles of inequality (i.e. culturally relevant pedagogy, multicultural curriculum, integration programs). Further, an exploration of tracking in mathematics provides an example of the degree to which teachers have agency in their classrooms. Even as our candidates learn about the negative outcomes of ability tracking, they too often complete their student teaching in schools where tracking occurs, given the pervasiveness of these practices. If we are to assume that teachers are neither evil nor ignorant, investigating why teachers continue to track (e.g., it is easier, it is required by the school, it makes parents happier), we can address the multiple pressures put on teachers' time and practice. As teacher candidates come to understand the socio-political nature of teaching, approach the work with an inquiry stance toward themselves, and view their students with an assets-based perspective, there are simultaneous efforts to develop their methods, strategies, and skills to have a justice-oriented approach to education in the STEM disciplines.

Methods, Strategies, and Skills

Cochran-Smith (2009) explains that teaching *methods, strategies, and skills* that support social justice are anchored in *guiding principles* rather than specific techniques or best practices, including the ability to: **develop caring relationships** with students (Witherell & Noddings, 1991), provide **culturally relevant content and pedagogy** (Ladson Billings, 2009) for all students, include English language learners and students labeled "at risk" (Oakes, Rogers, & Lipton, 2006), and make the development of students' **critical consciousness** an explicit part of the curriculum. Science methods courses provide multiple opportunities for preparing candidates to educate *all* students in science, emphasizing the relationship between science education and public engagement in science.

In order for candidates to learn to connect science with all students, they must first learn to **develop caring relationships**. Again, learning to teach science can support this process. Our candidates spend time in multiple classrooms in partner schools that have been intentionally selected to offer candidates, among other things, experiences with a diversity of student populations. During science methods courses, candidates explore issues related to science and make connections with how current events related to science impact children's lives. In addition, candidates interview children about their everyday science content understandings. The interview allows candidates to examine cultural influences that children bring to the classroom and to connect both personally and academically with children. Such experiences emphasize candidates' and children's shared interactions through science engagement. During data collection in the aforementioned longitudinal, evaluative study of our program, one candidate explained a student's enthusiasm about sharing his learning in science using drawings; "He was so excited to share and you could see how special that was to him." This candidate's realization of the process students go through in learning science, instigated within her an emotional understanding of, and connection to her student. She explained her realizations, "Kids are so curious...they want to know how things work, they want to know the science behind things." She

acknowledged that as she learns more about science education, she and her students will begin to discover science together.

Some candidates enter their teacher preparation programs with an admitted aversion to science and mathematics. These aversions may stem from past personal experiences with science instruction or cultural/family disconnections with science, yet science methods classes are fertile pathways for sharing the **cultural relevance of science content and pedagogies**. By creating a safe space for candidates to share their aversions and describe personal pathways toward connecting with science content, such relationship building helps candidates envision the importance of presenting culturally relevant science content in order to see themselves and their future students engaging in science.

Throughout our program, candidates are asked to reflect on the degree to which science was made relevant to them as students. Often a lack of relevance can be connected to commonly held stereotypes of scientists as White males. To counteract these stereotypes, candidates consider the contributions of scientists of various ethnicities and genders such as environmentalist Rachel Carson, botanist George Washington Carver, and physicist Shirley Ann Jackson, modeling practices for empowering children to build personal connections to scientists from shared ethnic or racial backgrounds. Additional course readings ask candidates to examine how students in low-income urban areas use and identify with science (Basu & Calabrese Barton, 2007; Tan & Calabrese Barton, 2010), thus expanding candidates' vision of science beyond a focus on careers in science. Moving away from science education as solely preparing students for the "pipeline" to careers in science, Feinstein, Allen, and Jenkins (2013) emphasize the role of science education for arming "competent outsiders" (p. 314) with the skills to navigate issues for everyday engagement in science.

In addition to exposing candidates to diverse populations of scientists and the plethora of science that surrounds us, Cochran-Smith (2009), Ladson-Billings (1995; 2009), Reich (2002), and many others recommend teaching practices that foster the development of critical consciousness, or the creation of safe spaces to identify and openly discuss topics of equity/inequity and respect/disrespect for individuals and social groups. Science methods courses, for example, can help build teacher candidates' **critical consciousness** and understanding of the "social function" of knowledge (McLaren, 2009, p. 63), or how knowledge can and must be used to interrupt systems of inequality (Freire, 1971). More importantly, they can develop the skills to incorporate opportunities for their future students' critical consciousness into their curriculum and practice. Candidates in our science methods courses, for example, discuss the civic purpose of scientific inquiry and the contributions of science literacy to inform voting practices. Societal issues such as the public water crisis in Flint, Michigan illustrates how understanding of science issues informs public decision-making. Science methods courses are also an ideal space for candidates to learn the ways in which knowledge, including rigorous scientific inquiry, can be used to understand and address systemic inequality. Environmental justice issues such as the absence of grocery stores in communities experiencing poverty or the propensity of landfills near high-poverty communities inhabited by racial minority populations illustrate the connections of social issues with areas of science such as chemistry, ecology, climatology, and geology (Bigelow & Swinehart, 2014; Dimick, 2012). Further, by learning about social entrepreneurship or "eco-justice" in the STEM fields, or about the ways in which advances in the sciences or technology have provided solutions for social ills, candidates can imagine how to help their future students apply their STEM knowledge to issues of inequity and navigate issues connected to their lives.

Engineering design also lends itself well to simulation activities that help young learners explore contemporary issues. In their current social studies methods course, for example, candidates participate in an engineering simulation to interrogate the effects of economic inequality. Adapted from a lesson written by Bill Bigelow (2002), students work in groups with differential amounts of materials with which they must build the tallest tower. While participants struggle with limited materials or excel with excess materials, the professor presents the rhetoric of meritocracy; “If you work hard you can win,” and “Your success is entirely up to you.” In the debrief, candidates reflect on how their experience mirrored the reality of the current socio-economic context. Moving from identifying the ways in which science and engineering can serve the development of critical consciousness, we begin to empower candidates toward envisioning how STEM knowledge can support analysis, action, and advocacy.

Advocacy

Finally, Cochran-Smith (2009) explains, candidates should develop a sense that it is within their scope of responsibility and in their best interest to conceptualize themselves as *advocates* and work alongside their students and community in order to contribute to systemic change in education and society. Again, STEM courses can support this process. As candidates learn about inequities, they can simultaneously use their burgeoning expertise to engage in the creation of solutions. Currently, one of our faculty members facilitates a tutorial support service within the Latino/Latina community in which our candidates are trained to serve as literacy tutors for children who attend an afterschool program. It could be a powerful addition to provide tutorial services in STEM fields in centers such as this in communities where STEM is not being adequately addressed in schools. In doing so, it would not only provide a service of increasing access to resources, but also give candidates the experience of working towards change in collaboration with communities.

Candidates must also learn that social justice advocacy goes beyond providing charitable services (Westheimer & Kahne, 2004), and includes working alongside members of the community to advocate for more equitable policies. Again, by analyzing tracking and the socio-political context within which this happens, candidates are provided further opportunities for advocacy. Specifically, after discussing how the school, local, and national context contribute to the practice of ability grouping, candidates could and should discuss what it would look like to influence systemic change beyond their classrooms. In our current program, candidates learn directly from a teacher who has successfully advocated for a school-wide policy for the end of tracking and the start of heterogeneous grouping. Candidates further learn directly from a local teacher who has collectively developed a social justice caucus (Organize2020) of the state teachers’ union to enact the Schools Our Students Deserve campaign to challenge privatization, segregation, and the defunding of public education.

In addition, in the diversity seminar, candidates begin to imagine themselves as advocates through discussions of how to shift the school, district, state, and federal practices and cultural norms that perpetuate tracking, segregation, and systemic racism. For example, we discuss the possibility of writing OpEds, speaking at school board meetings, working alongside students and parents to lobby for policy change, and pulling in the media to positively represent what is happening in their classrooms especially when they are teaching in schools serving students from marginalized communities.

Further, in their analysis of how to use STEM fields to develop students’ critical consciousness, as described above, candidates are provided with another opportunity to explore

means by which they can work alongside communities to initiate systemic change. Through an investigation of environmental injustice, for example, candidates can explore what communities are already doing to address these inequities and explore ways in which to further collaborate and work collectively in the pursuit of justice.

Looking Forward

Having both a STEM and social justice mission can be a complicated task. If both of these goals are to be taken seriously, they cannot be treated separately. Yet, as we hope we have begun to illustrate, through a reframing towards justice-oriented STEM, there is room to use the individual disciplines and integrated STEM for the purpose of developing much of the content and capacities necessary for social justice education. In doing this, however, there must be a fundamental shift in the purpose of STEM from preparing individuals for competition in a global market to preparing citizens who understand and are capable of using their STEM skills towards the alleviation of inequity in service of the common good. Without this shift, STEM education will, at best, provide individual students with potential access to an unequal labor economy without fully preparing them to transform the structural inequalities that plague our society.

There are, of course, many challenges in developing a justice-oriented STEM program. A primary limitation, we have noticed, is that our candidates enter our program with a lack of awareness of issues related to systemic inequity and injustice. This is exacerbated by the nature of teaching in North Carolina, where teachers are not highly compensated and subsequently, it is difficult to recruit students of color who potentially bring a level of cultural awareness and justice orientation (Cochran-Smith, 2009). In addition, given the decreasing support for teacher education programs and the rise in alternative credentials (Kretchmar, Sondel, & Ferrare, 2016; Zeichner & Pena-Sandoval, 2016), to remain competitive, it would be difficult to expand the length of our program. To that end, it would help justice-oriented STEM programs to require students to take courses related to sociology, public policy, and anthropology as a part of their general education requirements.

In addition, even as there are many highly competent teachers in our county, it is difficult to identify mentors with whom our students can observe and participate in both high-quality STEM and social justice education. To that end, for a justice-oriented STEM program, supervision of field placements should incorporate opportunities for candidates to engage in deep reflection on their classroom observations and include attempts to incorporate justice-oriented STEM experiences alongside university personnel (Zeichner, 2009).

As a department, we are not yet fully engaged in justice-oriented STEM teacher education; however, we remain hopeful given that our department is committed to these aims. Our next step in continuing to move towards this approach is in using this article, along with the Cochran-Smith's vision from which we draw, to create a systematic evaluation of and re-imagining of our program. We hope that other departments with similar aims will be inspired to do the same.

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