Examining Changes in African American Students’ Epistemic Agency as STEM Learners

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ABSTRACT

Despite reform efforts to broaden historically underrepresented populations across STEM disciplines, the data continues to highlight gaps of achievement across racial demographics. In an effort to address educational inequity, current reform efforts have touted the implementation of learning progressions as a promising strategy that can produce equality of outcomes across racial groups in STEM. Despite this promising effort, few studies have examined how to integrate practices of equity within learning progressions for groups such as African Americans that have been traditionally excluded from science and STEM. This study argues that an equity oriented learning progression should be responsive to sociohistorical factors of epistemic injustice that dissociated African Americans identities from being producers of knowledge. This study argues that the construction of a learning progression to advance the epistemic participation of African American students is aligned with goals of social justice related to diversifying STEM. The aims of this study explored how African American students progressed toward epistemic agency as STEM learners as a result of identity transformation through the engagement of the epistemic practices of engineering. This study used qualitative methodology to explore how student participants demonstrate epistemic development in their artifacts and discourse when engaging in engineering activities across a learning progression designed to develop epistemic agency. The findings from this study contribute to a broader understanding of how equity-oriented learning progressions can be designed to promote epistemic justice, how sociocultural positionings influence epistemic communities, and how students can become epistemic agents to raise STEM awareness within their local community. Advancing students epistemic practices of engineering
and epistemic agency as STEM learners is key to creating meaningful pathways into STEM for students in K-12.
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GENERAL AUDIENCE ABSTRACT

National imperatives to broaden the STEM participation of underrepresented groups remains a prominent priority across educational research. Due to marginal effectiveness associated with racialized minorities, researchers continue to explore equity oriented initiatives. In an effort to address educational inequity, current reform efforts have touted the implementation of learning progressions as a promising strategy that can produce equality of outcomes across racial groups in science and STEM. Educational inequity prevents underrepresented populations, such as African Americans, from having the types of educational experiences that position them as significant contributors in STEM and more specifically engineering. This study argues that the construction of a learning progression to advance the epistemic participation and agency of African American students in STEM is a sociohistorical response to a legacy of epistemic injustice. Qualitative methodology was used to explore how African American students progressed toward epistemic agency as STEM learners as a result of identity transformation through the engagement of the epistemic practices of engineering. The findings indicated that the engineering design activities within the curriculum positively influenced students’ identity, self-efficacy, and demonstration of epistemic agency across the learning progression. Additionally, the findings indicated the effectiveness of using the epistemic practices of engineering to facilitate the cognitive development of the engineering habits of mind. Lastly, the findings indicated the significance of using the epistemic practices of engineering to reposition African American students’ identities as epistemic contributors both within the classroom and within their local community.
Dedication

This dissertation is dedicated to my father Alton Taylor and my mother Debra Taylor.

What an amazing path you have trailblazed for me to follow!

This dissertation is also dedicated to my paternal grandmother Bessie Mae Taylor and my maternal grandparents James and Bertha Rodges.
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Half a decade ago, I decided to go into education on a whim until I could figure out what direction I wanted to take for my career. I became a biology teacher at Arabia Mountain High School, and it was by far the most incredible and rewarding experience that I have ever had! In that classroom the students taught me how to be the science teacher that I always wanted. Teaching those students was an honor and learning from those students was an even greater honor. I would not be where I am today without my students. Our class motto was, “We don’t meet expectations, we exceed them!” I carry that motto with me wherever I go.

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Chapter 1: Introduction

National imperatives aimed toward providing STEM access for all students continues to be a priority because “…without the participation of individuals of all races and genders, the increasing demands for workers in STEM fields will not be met, potentially compromising the position of the United States as a global leader” (National Academy of Sciences, 2007a, 2007b). Creating access to STEM programs for African American students in K-12 is a critical component of national imperatives intended to broaden STEM participation for underrepresented groups. In alignment with John Dewey’s notion of equitable participation (Williams, 2017), a pre-engineering robotics project titled, “Actualizing STEM Potential in the Mississippi Delta” (ASP), was designed in response to systemic barriers for African American students in the Mississippi Delta. The ASP project is an afterschool program for high school students in an underserved, predominantly African American school district. The project is situated in a region where a marginal percentage of students pursue STEM careers, and an even smaller percentage persist after entering college (Taylor & Brand, 2021). The school district where the program is implemented is under resourced with limited options for high school science courses and even fewer options for accessing AP courses. The systemic barriers experienced by African American students in the Mississippi Delta are aligned with national trends discussed among researchers across educational literature. King et al. (2021) note that these national trends are “supported by data from The United States Government Accountability Office (2018) which revealed that access to advanced mathematics and science courses in high school decrease as poverty levels increase” (p.1101). The economic landscape related to educational funding is severely challenged resulting in inequitable access to resources and programs that generate STEM capital for African American students in that region. Lack of curricular exposure to STEM prohibits
students from experiencing the type of sustained engagement that leads to identity formation and a developed sense of self-efficacy. Identity formation and a well-developed sense of self-efficacy are critical dispositions needed to fulfill the roles and tasks of scientists and engineers. The academic limitations in the school district construct a glass ceiling regarding students’ capabilities to explore STEM careers. Therefore, situating the ASP project in the Mississippi Delta was essential to addressing structural and sociocultural factors that influence STEM participation for African American students.

The curricular component of the ASP pre-engineering robotics program was aligned with *A Framework for K-12 Science Education* (2012) which emphasized the integration of disciplinary knowledge with practices necessary for authentic engagement in scientific inquiry and engineering design. The ASP curriculum engaged students in a range of engineering design activities intended to influence their dispositions toward STEM. The foundational design of the ASP robotics program focused on identifying factors and components of the program that influenced changes in identification as scientists and changes in self-efficacy beliefs. The research design for the ASP project was a mixed methods longitudinal case study. Quantitatively, changes in the students’ identification as scientists were assessed through the Attitude Toward Science Survey Inventory (ATSI). Quantitatively, changes in engineering self-efficacy were assessed through the Longitudinal Assessment of Engineering Self Efficacy (LAESE). Annual pre and post t-tests were conducted and analyzed. Analysis of both quantitative surveys indicated statistical gains. Qualitatively, changes in students’ orientation towards science, efficacy, and participation were assessed through open ended semi-structured interviews. The qualitative findings mirrored the quantitative findings in which students’
responses indicated enhanced dispositions related to science identity and an enhanced sense of self-efficacy related to engineering.

The curriculum was instrumental in influencing dispositional changes. In continuation with the research design for the ASP project, a pilot study was conducted to explore the development of epistemic agency in which students took ownership of their learning by using the engineering design process to solve issues within their local community (Taylor & Brand, 2021).

Zivic et al. (2018) define epistemic agency as students’ involvement in directing and monitoring the knowledge building process. Zivic and colleagues (2018) further state that epistemic agency entails students identifying problems, devising the methods of inquiry that will be used to solve problems, and partnering with teachers to reach a consensus for the implications of their work. Lastly, Zivic and colleagues (2018) note that for learners to take up agency and autonomy during learning, students must identify themselves as capable and believe that they can engage in the intellectual work of knowledge construction. Therefore, the goal of influencing identity formation along with the development of self-efficacy was significant to positioning students to enact epistemic agency as they interacted with engineering design activities throughout their engagement with the curriculum. Researchers acknowledge that providing academic and curricular tools for students does not ensure that students will automatically enact epistemic agency upon receiving the tools (Zivic et al., 2018); epistemic agency is developed over time. In response to the literature, the goal of developing epistemic agency was integrated as a learning objective within a learning progression which allowed me to evaluate growth over time during the pilot study.

Preliminary findings from the pilot study indicated the effectiveness of implementing the development of epistemic agency in relation to changes in identity and self-efficacy within a
learning progression. Quantitative findings from the Attitude Towards Science Inventory (ATSI) and the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) survey indicated statistical gains in dispositional changes in their identification as scientists and their self-efficacy beliefs in engineering as they progressed toward epistemic agency. In addition, qualitative findings supported quantitative findings in that the students’ responses reflected identity formation and an enhanced sense of self-efficacy in tandem with the development of epistemic agency. During the pilot study, students demonstrated epistemic agency in the design of engineering prototypes to address science related issues within their local community.

From the pilot study, it was evidenced that students were actively engaged in learning experiences that enabled them to envision themselves as potential STEM contributors, especially in relation to engineering. The engineering design activities that were centered around epistemic agency focused on positioning students to use the engineering design process to solve science related issues within communities. Using the curriculum as a guide, students constructed models of levees in response to hurricane Katrina, constructed models of bridges in response to the Florida International University bridge collapse, and designed agricultural drones in response to the agricultural industry in their local community (Taylor & Brand, 2021). While the use of the engineering design process was pivotal in developing students’ identity, self-efficacy, and epistemic agency, I questioned if they were developing an authentic picture of the engineering discipline beyond project based learning. I also questioned if these activities had cultivated the level of epistemic sophistication needed to foster long-term engagement with STEM once they entered college, which is of particular significance for African American populations.

The findings from the pilot study indicated that the engineering design activities within the curriculum positively influenced their identity, self-efficacy, and engagement of epistemic
agency. With these findings questions still arose regarding how to pedagogically identify and assess students’ epistemological development as students engaged in engineering design activities across the learning progression. These questions were of particular importance because situating epistemic agency as a learning objective is a semi novel discussion within educational research for science and engineering curricula in K-12 classrooms. The demonstration of epistemic agency is the byproduct of developing students’ cognitive understanding of practices related to knowledge construction. Krist et al. (2020) elaborate on these pedagogical challenges in stating “Engaging students in…knowledge–building practices— and knowing how to determine whether and how students are participating in them meaningfully rather than by rote—is challenging, in part because our understanding of how this kind of participation in practices develops is underexplored” (p.421) In addition, educational researchers have discussed challenges that teachers face related to recognizing and assessing practices associated with epistemic agency during learning and how to create learning opportunities that facilitate the development of epistemic agency (Zivic et al., 2018; Stroupe, et al., 2019; Stroupe, 2014). Thus, for this study, an operational definition of epistemic agency was developed from a compilation of research.

In reviewing the literature, three critical components were identified in relation to the cultivation of epistemic agency. Zivic et al. (2018) and Barton and Tan (2010) note that an agent directs and monitors the knowledge building process due to their perception of their identity and efficacy. Stroupe et al. (2018) and Damşa and colleagues (2010) note that an agent is more prone to demonstrate epistemic agency when actively engaged within a community of practice. Miller et al. (2018) note that the demonstration of epistemic agency occurs when an agent uses knowledge, practices, and resources for their interest, to influence systems that they are acting in.
In response to the research, I developed and implemented the term epistemic agency for STEM learners within this study as a working conceptual definition which is comprised of identity formation, a community of practice, and a sense of autonomy related to how epistemic tools will be used.

Additionally, for this study, I explored how to identify specific cognitive markers necessary for the development of students’ epistemic sophistication so that they can more accurately demonstrate epistemic agency across the learning progression. In their research, Cunningham and Kelly (2017) list a set of cognitive practices, known as the epistemic practices of engineering, which characterize the habits of mind that engineers possess across disciplines. These practices are essential to broadening students’ knowledge and skills in engineering. The pilot study was instrumental in influencing students’ identity and self-efficacy in engineering through their engagement with engineering design activities; however, there is a difference between potentially seeing yourself as an engineer and possessing the habits of mind as well as the epistemic sophistication of an engineer.

Enhancing African American students’ epistemic positioning as knowledge builders within a community of practice is an act of social justice in response to a legacy of epistemic injustice. Bullock’s (2017) research shows that ill-structured STEM initiatives aimed toward broadening the participation of underrepresented groups in K-12 have had marginal effects because they do not disrupt systemic barriers in STEM for African American populations. These systemic barriers are the byproducts of a legacy of historical practices that maintain educational inequity (Ladson-Billings, 1998). Educational inequity prevents underrepresented populations such as African Americans from having the type of educational experiences that position them as significant contributors in STEM. London et al. (2021) note the importance of having early
exposure to engineering in K-12 because research indicates that early exposure is a strong predictor of students choosing engineering as a potential career pathway. London et al. (2021) further assert that the lack of engineering exposure within K-12 acts as a gatekeeper to exploring engineering as a possible career pathway. Cunningham and Kelly (2017) invite researchers to explore how to integrate notions of equity within engineering education for K-12 classrooms so that traditionally underrepresented students are positioned to see themselves as potential engineers within epistemic communities.

The purpose of this study is to explore African American students’ development of epistemic agency as STEM learners as they engage in engineering activities across a learning progression designed to advance epistemic practices of engineering. There is little research that explores the relationship between equity oriented learning progressions, dispositional factors, and the epistemic development of African American students engaged in engineering activities. Evaluating the development of epistemic practices of engineering in tandem with the development of identity and self-efficacy provide a richer context for how students develop epistemic sophistication as they progress toward epistemic agency. This study used qualitative methodology to answer the following question: What epistemic practices of engineering do student participants demonstrate in their artifacts and discourse when engaging in engineering activities across all three anchors of the learning progression designed to develop epistemic agency for STEM learners? This study also encompasses three sub-research questions that explored the development of identity formation, the development of a community of practice, and the development of autonomy related to how epistemic tools are used across the learning progression. The sub-research question for the entry anchor was: How does the inclusion of learning about young African American students engaged in STEM research impact the
perception of STEM and use of epistemic practices of engineering for African American student participants engaged in engineering design activities? The sub-research question for the intermediate anchor was: How do African American student participants engage in the use of epistemic practices of engineering when exploring engineering activities in collaboration with a local computer scientist and how is their sense of identity and efficacy impacted? The sub-research question for the target anchor was: What epistemic practices of engineering do African American student participants adopt when building prototypes and how can their prototypes contribute to the advancement of their community and larger society? Each sub-research question examined the critical components embedded within the concept of epistemic agency for STEM learners.

This study is divided into eight chapters. In chapter 2, the literature review seeks to answer two questions. The first question is: Within the current era of educational reform various frameworks and pedagogical strategies are being offered, but how many of these initiatives explicitly draw upon solutions that appropriately address sociohistorical inequities? The second question is: What type of reform-based practices can be implemented to address educational inequity as it relates to access of educational resources and impartial access to the curriculum? Surveying the literature to answer those two questions was significant for defining and justifying the design of an equity oriented learning progression that is responsive to a legacy of epistemic injustice. Chapter 3 explains the theoretical framing the study. Because this study is designed to explore a trajectory of identity formation, epistemic practices, and epistemic agency which are all socially negotiated within a community of practice, I used sociocultural learning theory. Sociocultural learning theory provides a lens to explore how political, social, and cultural factors impact learning and development. In this chapter, I drew from multiple sociocultural conceptual
frameworks such as Cunningham and Kelly’s (2017) epistemic practices of engineering, Holland et al.’s (1998) figured worlds, and Wegner’s (1998) community of practice to make meaning of the participants' experiences in this study as they developed cognitive practices within an epistemic community. Chapter 4 explains the research design and methods that were used to answer the overarching research question and sub-research questions embedded in the anchors of the learning progression. Chapter 5, 6, and 7 discuss the findings related to participants' demonstration of practices reflected in discourse and artifacts for the entry, intermediate, and target anchor of the learning progression. Chapter 8 uses multiple conceptual frameworks from sociocultural learning theory as a scholarly foundation for making meaning of the findings as well as contextualizing the significance of these findings within educational research. Additionally, chapter 8 uses the limitations and implications to discuss the potential impact of this study within educational research as it relates to equity oriented learning progressions with an epistemic focus.

The findings indicated that the engineering design activities within the curriculum positively influenced students’ identity, self-efficacy, and demonstration of epistemic agency across the learning progression. Additionally, the findings indicated the effectiveness of using the epistemic practices of engineering to facilitate the cognitive development of the engineering habits of mind. Lastly, the findings indicated the significance of using the epistemic practices of engineering to reposition African American students’ identities as epistemic contributors both within the classroom and within their local community.
Chapter 2: Examining Equity Oriented Learning Progressions for Epistemic Agency

The performance outcomes and educational ranking of U.S. students on national and international assessments has ignited mandates for educational reform to address students’ underperformance in science and STEM related disciplines with respect to global competition (Jerald, 2008). Concurrently with stagnant achievement data, “the U.S. ranked high in inequity, with the third largest gap in science scores between students from different socioeconomic groups” (Jerald, 2008, pg. 5). Significant achievement gaps in science proficiency are severely present across racial demographics, leaving African Americans with one of the largest educational proficiency gaps (U.S. Department of Education, 2011). As a result of ongoing evaluations of academic performance and proficiencies and a desire to drastically improve educational outcomes, educational reform has been a reoccurring theme in public education since the Reagan era (DeBoer, 1991). The educational commission report, *A Nation at Risk*, called for an overhaul of public education which was heavily motivated by global competitiveness (United States National Commission on Excellence in Education, 1983). Despite this era being ushered in by the civil rights movement, educational mandates during the Reagan era were silent about creating equality-based solutions that would explicitly address structural access and impartial access to the curriculum in order to address gaps of achievement between White and Black students within public education. Two decades later during the Bush era, the *No Child Left Behind Act* (NCLB) attempted to address economically disadvantaged and racially marginalized students through strict accountability measures and federal incentives for state schools to set ambitious performance and proficiency standards to enhance the overall quality of public education (Corcoran et al., 2009, p. 7). Unfortunately, NCLB failed to create accountability measures for how to specifically address and reform inequitable practices within public
education which promote lower academic expectations through the implementation of an inferior and watered-down curriculum for African American students. Therefore, under the Bush administration the educational inequities that prevented equitable engagement and access to science remained present as gaps of achievement (Ladson-Billings, 2013; Szostkowski & Upadhyay, 2019).

Within the last decade, the Obama era introduced the Race to the Top program that created national competitiveness among schools in which states across the nation would compete for federal money. The states that demonstrated the most effective educational reform in the upgrade of state standards, advances in state curriculum, and display of large gains in educational proficiencies indicated by state assessments (especially among underperforming schools) would be in the front running for winning federal funds and creating a model for other states to adopt (Szostkowski & Upadhyay, 2019). This educational reform also included an agenda to broaden the participation of underrepresented groups in STEM; thus, educational equity became of prominent economic interest (Hrabowski, 2012). However, in similar fashion to previous administrations, an underdeveloped reform plan for how to explicitly address educational disparities from its origin has led to minimal progress in broadening the participation of marginalized students in STEM. As a result, policy makers did not have an adequate plan of how to properly institute complementary solutions that address sociohistorical issues of inequity as it relates to structural access to educational resources and an academically rigorous curriculum. In the article, Moving the Needle, Raising Consciousness: The Science and Practice of Broadening Participation, McNeely and Fealing (2018) recommend that policies designed to broaden participation in STEM should explore social systems and institutions that stifle participation. McNeely and Fealing (2018) further state, “Disparities in representation and participation do not
just happen; they are the result of complex processes reflecting broader social conditions and dynamics” (p.556). Disparities for marginalized representation and participation in STEM are the result of a series of collective historical inequities within education in which African Americans are denied equal and equitable access to a quality education (Ladson-Billings, 2006). Ladson Billings (2006) notes that while other disparities related to gender are beginning to recede, racial inequities persist in education. The persistence of racial inequities in education continue to center equity as an imperative within education reform. In the current era of educational reform various frameworks and pedagogical strategies are being offered. However, how many of these initiatives explicitly draw upon solutions that address sociohistorical inequities? And what type of reform-based practices can be implemented to address the high-ranking status of the U.S. regarding educational inequity as it relates to structural access to educational resources and impartial access to the curriculum?

Within the current educational reform movement, the goal continues to focus on upgrading public education by advancing standards, curriculum, and assessment. Concurrently, questions still arise regarding how initiatives within current reform will support and actualize equity and equality of outcomes within the public education system. Various educational frameworks have been touted as promising tools to enhance the existing science curriculum. Learning progressions have gained recent traction for its research-based approach and systematic method of explicitly aligning curriculum, instruction, and assessment (Hmelo-Silver & Duncan, 2009). In addition, some researchers have alluded to the idea that learning progressions have the ability to close racial and economic achievement gaps by creating learning goals to progress academic mastery and to aid teachers in implementing impartial instructional practices and learning experiences to complement such goals. Corcoran et al. (2009) discussed that in past
reforms far too many classrooms implemented the “soft bigotry of low expectations”, and they state that learning progressions “can offer a much more realistic and effective way of setting high standards for all students” (p. 19). While Corcoran et al. acknowledge that learning progressions support applications of learning which offer equitable potential within this framework, they also note “that there is a need to explore how diversity affects the development and application of learning progressions…and how progressions can help us close achievement gaps in science” (p.51). Closing achievement gaps in science is critical for influencing STEM participation. Researchers continue to engage in dialogue about how learning progressions have the ability to provide a more equitable curricular framework. However, when looking across the literature very few research studies on learning progressions are conducted with marginalized or racial groups such as African American students. In addition, there are very few studies that explicitly address issues of equity within learning progressions because the curriculum is framed with a universalist perspective for all students which do not recognize nor address inequity. Thus, what fundamental components are needed to create an equitable learning progression that recognizes the sociohistorical disenfranchisement of African Americans in science and STEM?

This research aims to accomplish a series of objectives. The first objective of this research is to examine current and historical initiatives concerning how equity is defined and to identify what conceptual components are required to actualize equity. The second purpose is to synthesize research in an effort to conceptualize epistemic agency as an equitable component for reform-based initiatives. Zivic et al. (2018) define epistemic agency as “students’ involvement in directing and monitoring knowledge building processes” (p.25). Building from the idea of epistemic agency as an equitable component, this research seeks to explore the liberatory potential of positioning epistemic agency as a learning objective to address the sociohistorical
effects of educational inequities that yield underrepresentation and stifle epistemic contributions of African Americans in science and STEM. The third purpose of the research is to examine existing literature to explore how learning progressions address equity and to propose integrating epistemic agency as an equity oriented initiative within the current curricular framework. Lastly, this chapter concludes with an examination of research that indicates the potential effectiveness of integrating epistemic agency within a learning progression for African American students.

Throughout this review of the literature there are references made to science, STEM, and engineering in relation to how educational reform initiatives aimed toward equity impact each subject in relation to one another. I refer to science, STEM, and engineering to emphasize the interrelationship between these three disciplines. This is not to overlook the epistemological differences between science, engineering, and STEM as they are quite distinct in nature. I intentionally examine how equity initiatives have influenced science education because science acts as a gatekeeper to engineering education in K-12 and beyond. Embedding engineering education within science curricular frameworks is a novel practice introduced by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). Current reform imperatives that prioritize STEM education position engineering as a core discipline to be taught alongside of science (National Research Council, 2012; NGSS Lead States, 2013). Even within states that have adopted modified versions of the NGSS framework, engineering education is still structured within the curricular framework of science education. Exploring the historical trajectory of equity within science education sheds light on ways that equity can be actualized within science classrooms that integrate engineering education within the current reform initiatives. This is particularly salient as there continues to be a “concerted effort to raise the visibility of engineering within K-12 science education” (Moore et al., 2015). Challenges
associated with actualizing equity within science education have severely impacted STEM pathways for underrepresented groups especially within the engineering discipline. Thus, deconstructing the equity agenda within science education is significant to understanding and addressing current underrepresentation in STEM and engineering for groups such as African Americans.

**Deconstructing the Equity Agenda**

The National Research Council (1996) emphasizes the need to prioritize excellence and equity for all students and note that high academic performance as it relates to the curricular objectives are not achievable “without access to skilled professional teachers, adequate classroom time, a rich array of learning materials, accommodating workspaces, and [access to] the resources of the communities surrounding their schools” (p.2). While the National Research Council outlines vital protocols for achieving equity, many educational researchers argue that these objectives, while lofty, are far from being actualized (Allen 1998; Ferreira, 2002). Lynch (2001, p. 623) states “NAEP data shows that, although there have been modest increases in student achievement in science over the last 5 to 10 years, achievement differences between Whites, Blacks, and Hispanics, and between high- and low-SES students, remain a huge concern (National Center for Educational Statistics, 1999, 2000, p.623). Additionally, despite reform efforts to broaden participation in science or STEM disciplines for economic gains, the data continues to highlight gaps of achievement across racial demographics. McNeely and Fealing (2018, p.553) note, “As reported by [National Science foundation] NSF (2017), although some increases are apparent in the STEM participation of underrepresented groups, significant disparities in educational attainment remain relative to white students.” The efforts to close achievement gaps have not been met with sizeable success; thus, the dialogue of equity continues
to occur across educational research from a variety of perspectives. The ongoing dialogue in educational research has been significant in that the term equity continues to undergo reformation to include aims such as social justice, fairness, and meeting the needs of the labor market which all serve as a road map for where the educational system intends to go. The commonly accepted definition of equity derives from the National Research Council (2012) in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and is described as the following:

> The term “equity” has been used in different ways by different communities of researchers and educators. Equity as an expression of socially enlightened self-interest is reflected in calls to invest in the science and engineering education of underrepresented groups simply because American labor needs can no longer be met by recruiting among the traditional populations. Equity as an expression of social justice is manifested in calls to remedy the injustices visited on entire groups of American society that in the past have been underserved by their schools and have thereby suffered severely limited prospects of high-prestige careers in science and engineering. Other notions of equity are expressed throughout the education literature; all are based on the commonsense idea of fairness—which is inequitable is unfair… (p.278).

While notions of fairness seem simple in definition, creating an educational system that is accessible in terms of resources and impartial curriculum has been a historical challenge that continues to prevail to this day.
Historical Challenges Associated with the ‘Science for All’ Equity Movement

Discussions about how to actualize equity across educational initiatives is a trending topic; nonetheless, educational inequity is a longstanding and historic issue in the United States. Currently, science education continues its ascent to prominence from the 1950s and is significant to educational discourse under the equity reform initiative commonly known as science for all. However, the inequitable landscapes that yield unequal achievement outcomes in science education mirror historical gaps of achievement due to educational inequality that existed before the 1950s and beyond. Lee (1999), in an analysis of education reform documents on achievement, highlighted critical definitions of equity by Secada (1994). Secada (1994) notes that "equity in education refers to the scrutiny of social arrangements that undergird schooling to judge whether or not those arrangements are consistent with standards of justice" (p. 22). Such a statement suggests that the sociocultural and sociopolitical structures reflected in society that encompass partiality should be interrogated in order to properly frame equity within educational institutions. The science for all movement while aspirational, is ahistorical related to the unique sociocultural and sociopolitical positioning of African Americans within education. Aspirations of implementing equity across educational initiatives have sometimes been obfuscated by superficial solutions to address equity without delving into authentic investigations that focus on inequities that have been historically present. Barton (2002) notes that the “historical call of science for all tended to reside in the policy and planning sector rather than in any systematic line of inquiry” (p.2). Barton (2002) further notes that the policies that were designed to foster the science for all initiatives were alienated from decades of educational research that highlighted educational inequities with respect to people of color. Thus, the science for all concept has historically resulted in educational initiatives that have been beneficial for those who
already have access to a quality education but for people of color such as African Americans, it results in sustained achievement gaps.

In the book, *Moving the Equity Agenda Forward*, DeBoer (2013) chronicles the historic science for all movement around two periods: science for all before the 1960s and science for all beyond the 1960s. His choice to chronicle the science for all movement around these two periods was specifically to place emphasis on the punctuated change of the democratization of science education. Prior to the 1960s, DeBoer lays out the progression of the science for all movement from being an elitist activity to a legitimized secondary subject of study stimulated by a need for pragmatic science and influenced by surge of technological advances due to World War II and the launching of Sputnik. DeBoer points out distinct changes for how the science for all movement changed prior to the 1960s and after noting that,

…there was rare mention of race, class, or gender in discussions of science education equity policy, whereas after 1960 it has become a dominant theme. Before 1960, the discussions around fairness and equity centered around the appropriate science for future science experts on the one hand and science for citizenship on the other. After 1960, the discussions tended toward the rights of underrepresented and underserved groups, sometimes linked to the moral failure of the society to provide those groups with the same opportunities as others, but more often linked to economic arguments about the failure to locate exceptional talent within those underrepresented groups and the need to maximize national economic potential (p.6).

Later DeBoer goes on to list landmark supreme court cases such as *Brown vs. Board of Education of 1954* and a host of legislative civil rights policies designed to mitigate racial
segregation so as to legitimize equality and encourage equity within education. Such landmark cases and civil rights policies were mentioned so as to acknowledge the progression of equity in the science for all movement after the 1960s. However, within DeBoer’s historical discussion it is vital to add, so as to not overlook, that the science for all movement has always been distinct and juxtaposed to the sociohistorical movement of African Americans fighting against structural inequality in education and impartial access to the curriculum in an effort to simply receive a quality education. In addition, the challenges associated with moving the needle related to equity in the science for all movement is rooted in the historical and cultural backdrop of inequities in education prior to the 1960s and beyond.

In the midst of the science for all movement, Brown vs Board of Education of 1954 was significant in that educational inequity, both structural and formal, became undeniably visible. Prior to this landmark case, Plessy vs Ferguson of 1896 sanctioned educational segregation as permissible under the separate but equal doctrine in which the educational conditions both structurally and formally (as it relates to the curriculum) were required to be equal. While segregation was one issue, the gross lack of equality promised under the equal protection clause of the fourteenth amendment was a significantly larger issue than segregation. A prevailing argument during the 1950s amongst a cadre of African American leaders was how to pressure the courts for equality which would necessitate access to a quality education for African Americans rather than integration (Patterson, 2006). Many leaders did not feel that integration would guarantee a quality education; rather many believed that structural inequities which prohibited impartial access to a quality education was the issue on the table. However, several cases brought before the supreme court in addition to Brown vs Board of Education of 1954 highlighted the deplorable conditions in which African American students were educated as
compared to their well-resourced White counterparts (Patterson, 2006; Bell, 2004). In addition, this case highlighted the underdeveloped and inferior curriculum that was offered to African American students. This supreme court case ruled that racial segregation in education perpetuated inequality and thus educational segregation was determined to be unconstitutional (Bell, 2004). The ruling of this court case clearly declared that educational segregation was inherently unequal, however, there was no clear promise nor plan on how to eliminate residential segregation which is a significant variable in controlling racial segregation in schools.

For African Americans, the educational inequities that persisted prior to the 1960s during the science for all movement remained after the 1960s despite Brown vs. Board of Education of 1954 and other civil rights policies. Despite the ruling against legally sanctioned educational segregation, the unequal distribution of wealth post slavery maintained through a legacy of racial discriminatory practices such as redlining continues to mechanize educational segregation (Noguera et al., 2016). Redlining, originating in the 1930s, is a practice whereby financial institutions inflate financial services beyond the economic capability of the consumer in an effort to racially and economically construct neighborhoods (Pearcy, 2020). Thus, wealth inequality stemming from slavery served as a tool for de facto segregation that historically and currently fulfills the dichotomous task of simultaneously segregating according to race and economics (Ladson-Billings, 1998). This dichotomy upholds an educational advantage for a majority of White students by granting access to a better education, thus enabling opportunities for continued upward mobility while providing African American accrued disadvantages that tether them to the bottom caste. Despite decades of educational reform initiatives post Brown vs Board of Education, Pfeffer (2018) notes a surplus of studies that discuss how educational opportunities continue to be stifled due to wealth inequality and are linked to growing achievement gaps in
education. In 2019, analysis of longitudinal data conducted by economists, political scientists, the National Assessment of Education Progress (NAEP), the Program for International Student Assessment (PISA), and the Trends in International Mathematics and Science Study (TIMSS) concluded that

Performance disparities are both large and extraordinarily persistent. The SES-achievement gap within the United States has remained essentially as large as in 1966 when James Coleman wrote his report on Equality of Educational Opportunity and the United States launched a national “war on poverty” in which compensatory education was the centerpiece. In terms of learning, students at the 90th percentile of the SES distribution are three to four years ahead of those at the 10th percentile by 8th grade. These SES-achievement gaps are amazingly large and unwavering (Hanushek et al., 2019, p. 14).

Such research demonstrates that the vision of educational equality and equity promised through the legislation of Brown vs Board of Education is blindsided by underdeveloped policies to unearth the socially and economically constructed achievement gaps due to wealth inequality. Wealth inequality not only ensures racial segregation in schools; wealth inequality also feeds into cycles of distributive injustice as it relates to educational resources. A lack of educational resources stifles authentic academic engagement.

**Examining conceptualizations of equity needed to achieve ‘science for all’**

Participation in science post Brown vs Board of Education has been structured by a lack of equal access to educational resources. Rawls (1999) conceptualizes equity as an issue of distributive justice in which he suggests that the allocation of educational goods should be in response to structural inequalities in education with the mission of creating equality. Distributive
injustice is maintained through the segregation of income within public education which earmarks resources and access to science and STEM for White students. Critical race scholars have discussed at length systemic barriers of distributive injustice as it relates to inequitable school funding, lack of resources, and inequitable access to communities that create and distribute knowledge as compared to their White counterparts (Ladson-Billings, & Tate IV, 1995; Russell, 2005). In an effort to counter racialized distributive injustice in education, race conscious policies were implemented to curtail de facto segregation; however, such policies were severely challenged within the courts by the public. In response, race neutral policies such as income integration policies were instituted to encourage racial integration thereby ensuring a more equitable distribution of educational resources. Income integration is a model whereby students of various socioeconomic backgrounds are integrated into schools in an effort to improve academic achievement across all economic groups especially those who are economically disadvantaged. Despite these mandates, careful analysis of the outcomes by educational researchers, Reardon et al. (2006) reveal that, “…that even under the most stringent form of income-based integration policies…income integration does not guarantee even a modest level of racial desegregation” (p. 67). Reardon et al. (2006) further state, “The only situation in which income integration would necessarily produce racial desegregation is if the White and Black income distributions were far more different than they are in fact” (p.67). Their findings indicate the ineffectuality of creating race neutral policies intended to address socioeconomic segregation as opposed to creating policies that openly address the intersection of race and poverty.

Additional reform-based initiatives such as constructing STEM based schools in impoverished communities were implemented to provide structural and formal access to
marginalized students. Bullock (2017) notes that this STEM based school initiative in Memphis was muddied by meritocratic admission policies that weeded out the attendance of impoverished students from the community. In addition, Bullock (2017) further points out that socioeconomically privileged students from other areas were given access and that shortly after the school served as an asset to initiate gentrification which resulted in the displacement of marginalized students into even worse schools. Such educational displacement due to gentrification ensured continual inaccessibility to science or STEM resources for African American students in the community. While educational policies post the 1960s outlawed legal segregation, *de facto segregation* which upholds distributive injustice of educational goods and resources ensures that science continues to be used as a tool to regulate racial representation and participation across STEM disciplines. Equity initiatives for achieving the aims of *science for all* would need to be grounded in a reconceptualization of equity that addresses inequitable practices of distributive justice that inhibit participation in science and STEM.

Shea and Sandoval (2020) take Erickson’s (1998) conceptualization of equity within science education in stating, “… equity in science education can be best understood through an exploration of the political histories of marginalization that shape in group/out group distinctions in science” (Shea & Sandoval 2020, p. 28). Shea and Sandoval expand upon this idea in stating that “Learning is shaped by both broad systems of sociopolitical power and local interactions that reify, repurpose, or resist and reimagine ways of knowing …” (Esmonde & Booker, 2016, p. 28). In addition to structural inequalities, impartial access to the curriculum was obfuscated by an educational philosophy during the 1950s of essentialism which favored a Eurocentric cultural transmission of particular cannons of knowledge that conflated epistemological activities (whereby knowledge is constructed) with whiteness. Progressive education eventually replaced
the educational philosophy of essentialism post the 1950s, but the practice of a Eurocentric
cultural transmission of knowledge that positions Whites as the primary constructors of
knowledge remains ever present across all educational frameworks even within the *science for
all* movement. Szostkowski and Upadhyay (2019) discuss how other researchers critique
sociocultural partiality in the curriculum in stating, “scholars who look from more critical or
sociocultural perspectives point out that the scientific establishment has reflected larger power
structures since the so-called Scientific Revolution: in this dominant narrative, most celebrated
practitioners of science have been Euro-American white men” (p. 341). Mutegi (2011) points out
that current western or [Eurocentric] cultural transmission within science education perpetuates a
curriculum that implies that the best intellectual products are found in a culture that does not
reflect the identity, cultural interest, nor values of African American students. In addition, Bang
et al. (2012) argue that epistemological interactions in the classrooms are often structured by
deficit-oriented discourses related to the intellectual capacity of students of non-dominant
groups. Bang and colleagues assert that deficit-oriented discourses serve to “…control the scope
of what constitutes an acceptable explanation, argument, or analysis” and characterize “what
‘smart’ looks and sounds like” based on the normative characterizations of legitimate
practitioners of science. Lastly, Bang and colleagues note that deficits assigned to non-dominant
groups related to their capacity to epistemologically contribute when engaged in social practices
of science “restrict the intellectual and expressive opportunities” of marginalized students within
the learning environment (p.303).

Deficit narratives surrounding the intellectual capacity of non-dominant groups such as
African Americans are embedded within the microstructures of the education system which
influence how students are able to participate in science and STEM. Other researchers have
noted that the substandard quality of instruction is associated with a racialized stereotype that characterize these students as incapable of learning (Wallace & Brand, 2012). Atwater (2000) notes that even in schools with equal racial demographics of African American students and White students, a large percentage of African American students lack appropriate access to honors or advanced placement courses resulting in curricular and academic segregation. Such segregation practices bar African American students from receiving access to a quality science curriculum that would enhance the acquisition of science knowledge and practices that aid in college preparedness (Ford et al., 2008; Holdren & Lander, 2012). Historically, research has displayed an overrepresentation of African American students in special education (Harry & Anderson, 1994; Ford & Russo, 2016) and despite the legislative action across the last few decades, this remains a persistent challenge (Zhang & Katsiyannis, 2002). While African Americans are readily tracked and labeled as remedial (Lynch, 1994; Mosteller et al., 1996; Atwater, 2000), they are underrepresented in gifted or talented education programs within the schools (Peters & Engerrand, 2016). Inequitable practices associated with tracking and labeling of African American students has created a segregated educational and curricular experience that is unjust and undermines educational reform efforts to diversify STEM. Equity initiatives regarding achieving the aims of science for all would need to be grounded in a reconceptualization of equity that addresses inequitable practices that inhibit the intellectual and epistemological participation of African Americans in science and STEM.

**Educational Inequities Feed into Cycles of Epistemic Injustice**

The accumulation of distributive injustice and lack of access to an equitable curriculum not only results in an underrepresentation of African Americans in science and STEM; it also stifles epistemic participation and perpetuates epistemic injustice. Schmidt (2019) defines
epistemic participation as an agent’s ability to give relevant contributions when engaging in social interactions in which knowledge is generated (p.53). Schmidt builds upon the concept of epistemic participation from Miranda Fricker’s theoretical notion of epistemic injustice coined in 2007. Fricker (2007) notes that within a myriad of social institutions are practices of epistemic injustice which is defined as a distinctively epistemic kind of injustice, in which someone is wronged specifically in their capacity as a knower. Kidd et al. (2017) note that epistemic injustice encompasses the exclusion, silencing, distorting, misrepresenting, and devaluing of ones meaning and contributions within social interactions due to power differentials exhibited across macrostructures such as institutions and systems and microstructures that subsume transactional societal interactions. According to Fricker, uneven distributions of power determine who is credible and reliable with regards to constructing knowledge, which is known as epistemic credibility. Epistemic reliability and credibility are reified through access to epistemic goods and resources within institutions. The theoretical stance on epistemic injustice also includes a critical examination of inequities of distributive justice which includes equitable and fair access to all epistemic institutions and goods such as education and all resources needed to engage in authentic inquiry.

Being positioned epistemologically as the knower denotes the ability to create knowledge which encompasses a type of power while epistemic injustice is a discriminatory act resulting in loss of power in a myriad of social institutions that exacerbate inequities. Epistemic injustice can be seen in Sheth’s (2019) discussion in which he states “…science institutions and scientists systematically have guarded the boundaries of science through gatekeeping mechanisms such as excluding the perspectives of communities of color and/or coopting the scientific work of people of color while erasing their contributions” (p.40). The denial of access to science through the
denial of educational goods both in institution and in access to the curriculum reflects decades of epistemic injustice for African Americans. Toft (2008) states, “The offence caused by epistemic injustice therefore constitutes a real problem in an economy in which knowledge, credibility and trust have become currencies equivalent to, as well as means to obtain, social status” (p. 117).

The lack of epistemic credibility manifest as a bidirectional deficit in which the educational institution divests resources and educational goods that undergird a quality education. In return, the divestment of epistemic goods causes the marginalized to internalize racialized deficits that mar their participation due to dissociated identities related to constructing knowledge in science. Mutegi (2011) argues that the sociohistorical positioning of African Americans necessitates a unique and transformative approach if equity is to be achieved in science education. He further discusses that the science for all mantra encompasses ideologies of universalism that are ahistorical to the unique sociocultural and sociopolitical positioning of African Americans. In addition, such universal ideologies do not address epistemic injustice and do not meet the needs of African American learners. Thus, to achieve equity, curricular reform must include components that address the dispossession of epistemic credibility in science that was imposed through slavery, reconstruction, and across decades of socially constructed achievement gaps. A compatible and just curriculum for African Americans would reflect a transformative approach that centers science identities and efficacy to influence and cultivate their epistemic participation within the science and STEM enterprise which goes far beyond just equalizing achievement.

Epistemological structuring of knowledge is a social activity that not only provides a social space for identity construction but also provides a community to enact basic science practices (Grasswick, 2017). Grasswick also notes that the community of practice is conflated with power differentials and biases. She asserts, “Because science is a human practice that takes
place in a social context …, it is not surprising that background assumptions about the social order are reinscribed within specific scientific practices as scientists generate scientific hypotheses, employ scientific reasoning, and eventually produce scientific results” (Grasswick, 2017, p.314). The curriculum that is used within science education was historically constructed with the exclusion of African Americans and other minorities as known contributors to the scientific enterprise. Critical race scholars argue that the curriculum reflects a master script in which voices, experiences, and contributions of the “other” such as African Americans are silenced and made invisible (Ladson-Billings, 1998). The historic invisibility of African Americans within science curriculum infers deficit credibility regarding who can construct knowledge and contribute within the scientific enterprise. Sheth (2019) notes that students of color are constantly negotiating their identity as they navigate negative characterizations stemming from stereotypes and “cultural dissonance from dominant conceptions of who is capable of science and who belongs in science” (p. 38). In addition to critical race scholars, Grasswicks (2017, p.313) notes bodies of research that have documented historical and systemic barriers that impeded the participation of racial minorities within the scientific enterprise while “disproportionately favoring white males” epistemic positioning (p. 313). Thus, those who have epistemological credibility reflected within the science curriculum and STEM enterprise continue to conserve their power and identity as the knower and the creator of knowledge. In addition, such a position enables the knower to have the power to determine how knowledge will be constructed and for what purposes. Historically, positions of epistemic power have enabled wide bodies of scientific knowledge to be produced from the “unethical treatment and exploitation of the bodies and knowledge of communities of color for the benefit of White institutions and individuals” (Sheth, 2019, p. 40). From this perspective, the historical
exploitation of marginalized populations as variable objects within science (Montoya, 2011; TallBear, 2007) positions such populations to only exist as informers of science but not as knowers that possess epistemic credibility.

**Identifying Components for Epistemic Justice within an Equitable Curriculum**

Atwater (2000) suggest that equity has to go beyond notions of equality to notions of fairness that includes a mission of social justice that atones for the structural inequities in science education. Many ongoing dialogues from educational researchers continue to discuss what is needed to establish equity. Building from Kahles’s (1996) work, Lynch (2000) takes on a unique perspective of defining equity through the examination of educational outputs (such as achievement) as indicators for measuring whether equity has been achieved on a three-tiered system. Upon the first tier, Lynch suggests that if educational outputs do not reflect equality of achievement, then educational inputs have to be examined for equity. The second tier encompasses examining unequal educational inputs such as educational resources to determine how to design strategic policies to address issues of inequity. While structural mandates or educational policies that distribute resources may be outside of a teachers’ reach, Lynch suggests that on the third tier teachers can seek ways to offset structural inequity by enacting alternative instructional or pedagogical practices of fairness through interpersonal actions and moral deliberations in their classroom (Szostkowski & Upadhyay, 2019). From this perspective, the instruction and curriculum serve as explicit tools of actualizing equity.

Lynch (2000) makes it clear that teachers can implement equity oriented instructional practices within the curriculum that serve to create appropriate access in science education for all students. She asserts that establishing equity in science education “reflects broader responsibility, embodied by the social justice model: the obligation to prepare all students to participate in a
postindustrial society with an equal chance at attaining the accompanying social goods—rights, liberties, and access to power” (Lynch, 2000, p. 21). Young (2013) argues that curriculum on its own does not have the ability to significantly reduce inequities because the quality of educational access is proportional to socioeconomic status in which the rich will always have the opportunity to buy the “better” education (thus reproducing social inequities). However, Young (2013) asserts that our mission in designing a curricular framework “…is to develop curriculum principles that maximize the chances that all pupils will have epistemic access (Morrow, 2008)—or access to the best knowledge we have in any field of study they engage in.” (p.114).

Furthermore, Young (2013) posits that the curriculum should go beyond prioritizing practice based learning that only serves the labor market, rather that students should experience the type of academic integration that positions them as legitimate participants in the discipline in which they have knowledge of the rules of the games, norms, values, and how to create knowledge within that community. Young’s idea of ‘curriculum principles’ opens the dialogue related to the necessary components to meet the aims of equity within curricular frameworks.

Creating equitable access to science does not only entail creating structural access or physical access, but it also encompasses access to what Delpit (1988) refers to as the “culture of power.” Delpit’s concept of the culture of power within a discipline is in alignment with Lynch’s goal regarding how equity should subsume active participation and an access to power. Delpit’s (1988) concept of culture of power refers to the culture and constituting rules, norms, and virtues established by those who have the power to shape and influence the social practices and dynamics of the community. Amidst this culture of power, those that are communally estranged from the discipline are those who do not bear the declarative knowledge, procedural knowledge, practices, or tools exclusively embodied within the culture of the community. Thus,
deficit credibility is assigned to those of estranged positioning and require enculturation to validate their participation within the community (Delpit, 1988, p.281-282). Paulo Freire also draws upon the relationship between knowledge, participation, and power but to these concepts he adds agency. Freire (2000) in his seminal work *Pedagogy of the Oppressed*, suggests that learning the culture of power is an act of social justice in which individuals acquire knowledge of the dominant syntax so that they are empowered to not only name the world but interpret and analyze their position in it. Freire (2000) also notes that the creation of knowledge is connected to power and liberation in which the learner develops epistemologically and hermeneutically while developing agency in which they have the autonomy to regulate how the dominant syntax will be used. Creating equitable access into the culture of power of science for students would subsume creating epistemic access for them to enact agency in which they are positioned to create and use knowledge in a way that reflects the aims and desires of the knower. Researchers conclude that science education must go beyond assimilatory practices of learning that are rote for confirmatory science (Stroupe et al., 2018), to meaningful engagement that encourages independence and autonomy that empowers them to enact epistemic agency. Stroupe (2014) argues that current educational reform objectives should encompass, “that students, in addition to learning concepts and methods, should become legitimate participants in the social, epistemic, and material dimensions of science” (p. 488). Creating curricular frameworks within current education reform has the ability to be to equity oriented if such a curriculum is informed by the sociohistorical factors that influence and structure participation of underrepresented populations within science and STEM. In addition, equity-oriented frameworks intended within current reform should be designed to enhance the epistemic participation of underrepresented groups in an effort to progress epistemic agency as a social justice initiative.
Epistemic Agency as a Tool of Equity for Curricular Frameworks

If the collective historical educational disenfranchisement of African Americans led to a lack of representation that resulted in mitigated epistemic contributions, then a compensatory educational or curricular framework should prioritize epistemic agency as a tool of social justice. Stroupe et al. (2019) echo the significance of using epistemic agency in their following statement:

We argue that unless teachers provide students with openings to take up some form of epistemic agency through the use of tools, and if students do not perceive and act on such openings, then the rhetoric of the Framework and NGSS—focused on participation in practices—is empty and aims to perpetuate the status quo of inequitable science teaching and learning (p.1-2).

Structuring epistemic agency into existing educational frameworks serves as a response and strategy to explicitly address the collective historical acts of epistemic injustice that marginalize the participation of disenfranchised populations. Fricker (2007) suggests that epistemic injustice impels intellectual courage and causes the disenfranchised to devalue their abilities and voices thereby marring their public participation. While the goals of science for all within the science education framework prioritizes and encourages participation in science for all students, it bears a neutrality that is blind to constitutive sociohistorical issues associated with epistemic injustice. Such sociohistorical issues have material effects that structure epistemological participation through the social construction of dissociated identities in science for African American students. Thus, a sociohistorical responsive curriculum would center the transformation of identity, equitable epistemic participation, and student autonomy in science and STEM discovery for the cultivation of epistemic agency.
The concept of epistemic agency within current reform has gained recent traction in science education within the last decade despite its initial appearance in educational literature by Scardamalia and Bereiter (1991). Its recent traction is due to its theoretical alignment with constructivism which mirrors current science reform objectives in which students actively engage in constructing knowledge within a community of practice. The epistemological focus within epistemic agency aims to enhance students’ cognitive abilities in an effort to deepen students understanding of science and science practices. Corcoran et al. (2009) assert that “engaging in complex cognitive tasks such as inquiry, argumentation, and explanation”, which are epistemic processes, are fundamental to developing a sophisticated understanding of science as well as demonstrating scientific practices (p.12). The agency aspect within epistemic agency refers to how epistemic activities are inherently social and are therefore constrained and influenced by social, cultural, and physical structures (Miller et al., 2018). In addition, Miller et al. (2018) expound upon the notion of agency in stating “Agency, then can be conceptualized as an actor’s ability to mobilize resources for their own goals, shape the systems that they are acting in (Varelas et al., 2015) and if necessary, disrupt structures and re-figure available resources” (p. 1057). This conceptualization of agency gives rise to a type of epistemic justice in which one’s epistemological participation and contributions could be used to impact inequitable landscapes within the science community and STEM enterprises.

While the aims of epistemic agency are aligned with the goals of NGSS, many teachers struggle with how to actualize this concept within the curriculum. Ko and Krist (2019) argue that within most classrooms the power dynamics related to the authority of knowledge is given to the teacher in which they occupy the position as the epistemic agent. Ko and Krist (2019) suggest using a curricular approach in which epistemic agency is redistributed from traditional positions
of power and given to students. Such a curricular approach is instrumental when considering that epistemic agency within the science curriculum encompasses the social exclusion of African Americans in science and that such a curricular approach has to address socially constructed power dynamics associated with epistemological participation. Miller et al. (2018) support the aims of NGSS that prioritize the changing the roles of students from being consumers of facts to producers of knowledge; however, they assert

Unless the field tackles significant questions around precisely how students can become active epistemic agents in knowledge construction, we will likely continue to create learning environments that position students as receivers of scientific facts and practices, even as districts adopt the goals and language of the NGSS (p. 1056).

Furthermore, several studies have highlighted challenges associated with how to pedagogically place students in an epistemological position that enables them to shape the knowledge construction process and to determine how such knowledge is used (Russ, 2014; Stroupe et al., 2018). Learning progressions, a pedagogical method that exists within the NGSS framework, are designed to enhance students’ conceptions of science through strategic processes of cognitive development. Learning progressions continue to shift beyond broadening students understanding of science concepts to a more epistemic centered curriculum thus aligning with the goals of epistemic agency. The integration of epistemic agency within learning progressions offers a promising model whereby students’ epistemological positioning is enhanced, and their participation is prioritized which is of particular significance for African American students that exhibit marginal participation in science.
Shifting to Epistemic Focused Learning Progressions

Learning progressions are the product of multiple theoretical shifts across “psychological, philosophical and pedagogical frameworks in science education” (Duschl et al., 2011). The cognitive shift in psychology from behavioral theories to constructivist principles prioritize students’ active position of constructing knowledge through experiences as opposed to passively acquiring disciplinary knowledge from an expert (Brooks & Brooks, 1993). Philosophically, there was a shift from positivism to post-positivism, a revelation that science occurs over discontinuous and continuous phases, and that the construction of theoretical knowledge occurs as a dynamic process that can be approximated but not fully known (Duschl et al., 2011; Kuhn, 1970). Pedagogical frameworks shifted to student-centered models that positioned students as actors of science in which they engage in the nature and practices of science as a method of discovering science content and concepts (Llewellyn, 2013). Within this pedagogical shift teachers act as facilitators or guides while successively assessing the performance of students’ content knowledge and practices as they traverse the curriculum and grade levels (National Research Council, 2012). The structure of learning progressions reflects constructivist principles that position learning on a continuum driven by cognitive development in which students construct and reconstruct knowledge and engage in reasoning to construct meaning. Such structure provides various opportunities for epistemological development in which students come to understand how scientific knowledge is constructed through the engagement of science practices.

Learning progressions have typically been defined across the literature as “descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time” (National Research Council, 2007, p. 219). The structure of learning progressions is designed to methodically chart a
path of learning for students in which they move from novice to expert in similitude to actual scientist. Learning progressions include a multilevel system designed to both assess and facilitate learning across sequenced anchors. The framework is designed as a product of cognitive research that examines students’ development of learning across science topics, curricular benchmarks, and performance standards. The lowest anchor or bottom tier of the progression is designed to formatively assess student’s prior knowledge, alternate conceptions, discourse, and performance of science practices as it relates to a particular science concept. Next, the intermediate anchor or middle tier anchors include learning targets that examine students’ cognitive development as they acquire content, develop discourse, and demonstrate performance expectations related to practices. While the goal of intermediate anchors is designed to progress learning successively, the intermediate anchor is not a linear process and has a “messy middle” (Gotwals & Songer, 2010, p. 277). This “messy middle” reflects constructivist approaches to learning in which students cycle through constructions and reconstructions of knowledge that include organization of knowledge according to assimilation, viability, functional fit, and pragmatism or direct utility of knowledge (von Glasserfield, 2001). Lastly, at the target anchor or highest tier students can demonstrate mastery of science content by providing a sophisticated explanation of science concepts as a result of an enhanced performance of science practices. Kaldaras et al. (2021) summate the objectives of the anchors within learning progression as such, “The levels of an LP are expressed as learning performances that summarize what students should be able to do with the scientific knowledge they have (Reiser et al., 2003)” (p.592).

There are two distinct categories of learning progressions: the top-down approach and the bottom-up approach based on the scientific themes within the discipline and how students learn science respectively. The top down approach is from the perspective of the scientist and
encompasses designing learning targets according to the fundamental themes or big ideas that cut across science disciplines (Alonzo & Gotwalls, 2012). Within the top down approach instructors assess and design the learning progression framework according to what knowledge and skills are required to master learning targets associated with particular themes of science. The bottom up approach organizes content according to how students develop in their understanding across topics in science. Within the bottom up approach, the selection of topics and overall arrangement of content is based on the instructors’ iterative assessment analysis of how students acquire content in science (Duschl et al., 2011). Typically, learning progression grounded in the bottom up approach focuses on how students can model a specific scientific concept that is associated with the topic. The third approach is to combine both top-down and bottom-up methods within a learning progression (Duschl et al., 2011) in which teachers use the top down approach with respect to themes but arrange the topics within the themes according to how students develop in sophistication and understanding of science concepts. All approaches in terms of curricular organization for learning progressions is the result of an extensive collaboration between scientists, educators, and researchers and is informed by data from all areas.

**Evolving Participatory Aims of Learning Progressions**

While the aims of learning progressions have been explicit in terms of charting students’ path in developing content knowledge through the engagement of science practices, the implementation of progressions have reflected an imbalance of content knowledge and disciplinary practices. Pierson et al. (2019) state, “Tensions have emerged as science education researchers and practitioners have increasingly prioritized students’ development of, and engagement in, science practices over students’ acquisition of declarative knowledge about science concepts and processes” (p.833). In addition to critiques concerning how to balance
knowledge and practices, scientists, researchers, and educators discussed the need to orient learning progressions toward science literacy in an effort to have students develop content knowledge with science practices in conjunction to their everyday lives (Alonzo & Gotwalls, 2012). Mohan et al. (2009) designed a multi-year learning progression for carbon cycling in socio-ecological systems. In their design they explicitly outlined environmental literacy learning targets in that they established environmental literacy as an explicit content knowledge learning objective as opposed to assessing environmental literacy as a result of content knowledge and practices. Feinstein (2011) notes that the goals of science literacy within learning progression are often taken for granted and are assumed to manifest as result of the curriculum thereby making the aims of science literacy rhetorical. Feinstein (2011) argues that unless science literacy is clearly defined objective wise, students will gain skills in science as well as disciplinary knowledge with an underdeveloped application of knowledge and decontextualized practices. Gunckel et al. (2012) conducted a study in which a learning progression was designed to engage students in citizen participation in addressing socio ecological issues related to water. The learning progressions were designed to cognitively develop students' conceptions of water across grade levels; however, the overall goal was grounded in civic participation. As research discussions continue, the focus on science literacy places emphasis on participation in science related issues relevant to individual decision making, cultural and civic decision making, and economic decision making with respect to the scientific enterprise (Sharon & Baram, 2020).

Current curricular approaches such as learning progressions continue to evolve to better support epistemic aims within the Next Generation Science Standards (NGSS). Learning progressions are complementary to the aims of NGSS because they encompass a strategic curricular approach in which students develop in expertise and mastery of content as well as
literacy for science practices across various science domains over extended periods of time (Smith et al., 2006). Objectives for science literacy require that learning progressions center participation through the engagement of science practices that foster habits of mind. The goal within the NGSS framework supports learning progressions that place emphasis on science literacy, however many of the learning progressions that are designed have a heavy focus on developing content knowledge. As a result, researchers have noted and critiqued learning progressions that are explicitly oriented towards science content while placing less emphasis on assessing performances of science practices (Gotwals, 2018; Pierson et al., 2019). In addition, researchers have questioned the utility of learning progressions and have discussed the need to develop progressions that are also practice oriented to emphasize the epistemic aims of science (National Research Council, 2007). Learning progressions have been effectively used for standard and curricular development, modes of assessments, and benchmark anchors of achievement which serve to enhance conceptual knowledge (Kobrin et al., 2015); however, research suggests that epistemic influence and participation occurs through the engagement of science practices within a relevant context (Ryder, 2002). Kelly (2018) argues for the developmental expansion of learning progressions in stating, “the development of learning progressions needs to examine ways that epistemic aims are tied to the learning and justification of disciplinary knowledge” (p.246).

Additionally, developing a refined focus for epistemic oriented learning progressions is needed to transition students from rote engagement in the science discipline and practices to engaging students in the construction of knowledge through the practices of science for inquiry (Stroupe et al., 2018). Sandoval (2015) describes the epistemic aims or epistemic goals of science as, “…to construct causal accounts of the natural world…” through the nature of science
and justifying causal accounts of the world through “…an array of epistemic strategies, empirical methods, and inferential strategies for satisfying that goal” (p.1). Kuhn et al. (2017) discuss how the practices of science listed as “…a range of activities that include posing questions, developing hypotheses, designing and conducting experiments, examining and interpreting data, constructing arguments and counterarguments and debating conclusions” are key to students “epistemological foundations of science” and necessary for engaging in science inquiry (p.233). Progressing epistemic practices does not entail students “mimicking what scientist do” rather it is to create a curricular environment that allows them to participate in the discovery and construction of knowledge using the tools and practices of scientist (Settlage & Southerland, 2019, p.1111). Additionally, research suggests that epistemic development and participation occurs through the engagement of science practices within a relevant context (Nazar et al., 2019). Epistemic based learning progressions are context dependent (Pierson et al., 2019) and authentic engagement of science is most effective and meaningful when it is relevant to the lives and experiences of students and proves to be both of functional use and pragmatic (Sharon & Baram, 2020).

Córdova & Balcerzak (2016) suggest that learning progressions have to include sociocultural dimensions in which “…teachers… situate the learning of scientific practices within meaningful, community oriented curricular foci and content” (p.1240). Furthermore, they state, “Learning Progressions research has yet to show how the core knowledge of the disciplines is embodied in the perspectives of children as they grow into and develop scientific practices across the K-12 experience” (p. 1226). Within their study, they implement a theoretical orientation of interactional ethnographic research to explore how the inclusion of cultural landscapes allow students to engage in science literacy practices with their local community
within a learning progression. Including cultural or community dimensions is an effective method of contextualizing science content while providing a site of practice for engaging in science practices in a purposeful and meaningful context. Beyond the cognitive development regarding their understanding of geological concepts, the transformational shift of a science identity evidenced in their written reflection of themselves revealed the effectiveness of engaging students in epistemic oriented learning progressions within their relevant science phenomena in their local community of place. Intersecting epistemic oriented learning progressions to promote a sense of agency as it relates to the students’ historical and cultural communities is significant to structuring authentic participation of science practices within relevant and real world contexts.

Learning Progressions and the Promise of Equity Through a Proposal of Epistemic Agency

There are countless studies on learning progressions that continue to push barriers to enhance the learning experience and academic achievement of students. As previously mentioned by Corcoran et al. (2009), learning progressions have the ability to advance learning for all students thereby addressing issues of inequity regarding the curriculum. In keeping with the goals of equity within current reform, Delgado and Morton (2012) performed an analytical literature review to examine to what extent does current educational research on learning progressions address equity. Within the analytical review, Delgado and Morton explored what characteristics of learning progressions and corresponding instructional practices were significant for closing achievement gaps between ethnic/racial groups (p.205). Their findings indicate that most educational literature regarding learning progressions do not address or explicitly discuss equity. Furthermore, when looking across the literature very few research studies on learning progressions are conducted with marginalized or racial groups such as African American students. In their analysis Delgado and Morton found that “…implicit in most
[learning progressions/learning trajectories] LP/LT work is a definition of equity as equal
treatment for all students” (p.204) In response Delgado and Morton (2012) “propose an alternate
definition involving responsive instruction and materials that contemplate individual differences”
(p.204). Delgado and Morton examined a case study to understand how equity could be
addressed within learning progressions. Their findings indicate that progressing equity requires a
framework that prioritizes the ideas and participation of disenfranchised students as well while
enhancing foundational knowledge and performance practices. Making science accessible to all
by including epistemic agency within learning progressions have the ability to meet the needs
proposed by Delgado and Morton as well as other critical components significant to African
Americans advancing in science.

Epistemic agency provides a more accurate depiction of the nature of science in that
students are actively engaged in the practices of professional scientists. Miller et al. (2018) state
that “more meaningful learning occurs when students construct knowledge” (p.1067). Miller and
colleagues further point out that science is dynamic and creating new knowledge is crucial to the
progression of science as a discipline. Shifting the role of students from passive recipients of
knowledge to students that communally participate in the construction of knowledge requires
epistemic agency. Epistemic agency provides students with the opportunity to engage in self-
directed inquiry as well as decide on how the investigation of inquiry should be carried out
(Reiser et al., 2017). Zivic and colleagues (2018) point out that while students may be given
epistemic tools and resources their engagement and epistemic agency is determined by their
personal beliefs regarding their own epistemic capacity as well as beliefs regarding their power
to make decisions within the science community. Other researchers have discussed the link
between student engagement in science and student perceptions of the self in the science
community. Renninger (2009) defines science identity as “general sense of self with reference to groups or particular content” (p. 109). Carlone and Johnson (2007) who designed the framework of science identity positions science identity as multidimensional which encompasses competence, performance, and recognition. Embedded within NGSS curricular framework is an implicit affirmation of competence, performance, and recognition as well as epistemic credibility and epistemic contributions of Eurocentric populations. Thus, a science identity and epistemic credibility that would produce epistemic agency is implicitly built into the curriculum for the dominant culture. Likewise, a curriculum that fosters engagement in epistemic agency through the transformation of a science identity would require a curriculum that affirms the competence, performance, and recognition of African American students. The integration of equity within a learning progression designed to develop epistemic agency is a method of addressing equity in that it ensures that a historically estranged population can repossess epistemological ownership that has historically been denied to them in science and STEM.

**Defining Epistemic Agency for STEM Learners**

The concept of epistemic agency in research is interdisciplinary and requires disciplinary clarity so that the objectives associated with epistemic agency can be actualized. Implementing epistemic agency into a curricular framework necessitates clearly defined objectives that outline what is needed to conceptualize epistemic agency for STEM learners. Kelly and colleagues (2020) note that teachers possess varying conceptions and definitions of what epistemic agency is and in turn pedagogical strategies regarding how to develop epistemic agency vary and are open to interpretation. Upon an examination of research, a definition of epistemic agency for STEM learners has been compiled from the literature and in turn the curricular objectives and pedagogical practices can be in alignment with the definition of epistemic agency for STEM.
learners. While researchers conclude that epistemic agency is students’ ability to participate and influence the knowledge building process (Miller et al., 2018), expanding this definition enables specificity for identifying and measuring whether or how epistemic agency for STEM learners is expressed during learning. In examining the research, the construct of epistemic agency for STEM learners encompasses three distinct components. These three components differ from the epistemic aims within NGSS as epistemic agency for STEM learners are actualized through identity transformation. The first component of epistemic agency for STEM learners refers to students constructing their identity through engaging in the practices of knowledge construction. The second component of epistemic agency for STEM learners refers to students’ negotiating their identity by influencing the knowledge building process within the community of practice. The third component of epistemic agency for STEM learners refers to adopting disciplinary knowledge and practices for their own purposes as a result of an internalized change in identity.

Zivic et al. (2018) note that developing students’ identities and enhancing the beliefs or efficacy during the knowledge building process is key to students enacting epistemic agency. Barton and Tan (2010) note that the actions or agency that students enact in a community of practice is constrained by social structures within society and are mirrored in the community of practice. Their study further demonstrates that students will enact agency when they see themselves as capable experts or agents. Identity which gives way to agency therefore can be socially mediated through tools that support social engagement when learning. Tools that foster social engagement during learning can include discourse and practices that are demonstrated while engaging with peers or while engaging with experts in the field within a community of practice. Miller et al. (2018) consider how students identities influence the knowledge building process during learning and discuss how to expand students’ cultural identities and experiences
so that they can be leveraged as intellectual resources. From this perspective their identity is expanded to include a role in which they are positioned as a knower and a constructor of knowledge. These studies demonstrate the significance of negotiating and developing and enhancing students’ identities in an effort to support the development of epistemic agency for STEM learners as they engage in a learning community. Thus, the second component of epistemic agency for STEM learners encompasses an agent that participates in a community of practice due to their perception of their identity and efficacy during the knowledge building process.

Stroupe et al. (2018) note that “When students are framed as technicians, they learn that the teacher is the solitary epistemic authority in the classroom” (p. 1177). Their research indicates that including students in a community of practice with teachers and scientist is a necessary component of aiding in the development of epistemic agency for STEM learners. Damşa, et al. (2010) note that knowledge is created collaboratively within a community of practice. While their research recognizes studies that focus on the individual development of epistemic agency, their study clearly points out that knowledge related activities often occur as a social practice. From this perspective a community of practice is essential to the development of epistemic agency. Thus, a second component of epistemic agency for STEM learners is expanded to encompass an agent authentically engaging in the use of disciplinary knowledge and practices within a community of practice (i.e., classroom, community of scientists or engineers).

The last component of epistemic agency for STEM learners includes deconstructing ideas related to epistemic agency as it relates to autonomy and free will. While the concept of epistemic agency is gaining traction within education, challenges arise regarding how to align the curriculum with epistemic agency as a learning objective as it relates to student autonomy of
learning. Miller et al. (2018) note that the concept of agency historically included a definition of an individual’s ability to enact free will, however, they note that with regard to epistemic agency there is a responsibility on the students’ behalf to engage in knowledge building processes. Furthermore, they argue that within classroom students always have agency; they are able to engage their free will to engage in learning or resist learning. Stroupe et al. (2018) note students enacting epistemic agency is often challenged in classrooms because they are often bounded by the topics within the curriculum. From this perspective epistemic agency for STEM learners would encompass using the disciplinary knowledge in a way that reflects the interest, aims, and values of the knower. Thus, a third component of epistemic agency for STEM learners is expanded to encompass students adopting disciplinary knowledge and practices for their own purposes. Creating learning objectives for epistemic agency for STEM learners as an integrated component of learning progressions necessitates that students develop in their sense of identity and efficacy within a community practice so that they are able to use the tools of science and STEM for their interest.

Conclusion

The previous discussion covered reconceptualizing critical components of equity from the perspective of addressing epistemic injustice in an effort to foster epistemic agency. Within this discussion the integration of epistemic agency was offered as a response to a legacy of political histories that perpetuate the exclusion of epistemic participation for African Americans in science. The legacy of exclusion reproduces historic inequalities of representation thereby mitigating epistemic contributions. Stroupe et al. (2019) assert that building a classroom that cultivates epistemic justice to disrupt historic norms of participation requires that teachers understand (a) the role of cognition within the social community of learning (b) how learning
process are structured by social and cultural contexts (c) how to provide collaborative engagement with communities of practice to facilitate authentic agentive experience (d) how to provide opportunities of shared participation of agency. Engaging students in authentic inquiry in which students epistemologically construct knowledge with agency requires teachers to critically think about the learning environment. Teachers have to consider how macrostructures of power that exist in society influence discourse and behaviors within the microcosm of communities of practice in classrooms and how those dynamics influence epistemic credibility and participation. In addition, creating collaborations in which students are able to negotiate an identity within the communities that construct and distribute knowledge is significant. Meeting the goals of epistemic agency for STEM learners includes the act of students charting their path of learning to support and progress toward self-regulated learning. Charting a curricular path for the development of epistemic agency for STEM learners is possible through the design of carefully constructed anchors across a learning progression that center identity formation.
Chapter 3: Theoretical and Conceptual Framing

Centering learning objectives around advancing the epistemic participation and agency of African American students in STEM is a sociohistorical response to a legacy of epistemic injustice. Cultivating epistemic agency across a STEM oriented learning progression necessitates a method for how to accurately characterize and evaluate cognitive development. Simarro and Couso (2021) point out that some researchers think epistemic development related to engineering education is the key to improving students’ learning in science and math (p.1). Simarro and Couso (2021) further assert that prioritizing engineering education within K-12 goes beyond the production of engineers, engaging students in the epistemic practices of engineering centers how knowledge is constructed in relation to science, mathematics, technology, and other disciplines. The Next Generation Science Standards (NGSS) combine science and engineering practices together to provide curricular guidance for science teachers who are responsible for teaching engineering as a disciplinary core idea. This combination of science and engineering practices enable teachers to see epistemic similarities across the two disciplines but not the epistemic difference. Cunningham and Carlsen (2014) argue the pairing of science and engineering practices within the structure of NGSS does not reflect the epistemic differences between the two disciplines (Simarro & Couso, 2021). Antink-Meyer and Meyer (2016) conducted a study in which they identified four major misconceptions in regard to science and engineering distinctions for elementary and high school teachers. Antink-Meyer and Arias (2022) conducted a professional development study that developed teacher epistemological understandings of engineering. The findings displayed in the teachers’ reflections indicated that there were “changes in their views about the nature of engineering knowledge… and they were able to design instruction with appropriate epistemic practices while not necessarily understanding
related features of the nature of engineering” (p.357). The epistemic practices of engineering are not only providing opportunities for teachers to engage students in more authentic practices of engineering, it also is providing opportunities for students to understand how science practices are a complement to engineering processes.

Epistemic Practices of Engineering

Cunningham and Kelly (2017) present the epistemic practices to address practical and theoretical voids in engineering education. On the practical end they note “Given the paucity of knowledge most K–12 teachers currently have about engineering, clearly describing engineering practices is essential for communicating educational goals for engineering education” (p. 487). On the theoretical end they note that the presentation of engineering in NGSS did not reflect the “engineering knowledge and practice” and in addition provided a limited range of practices of engineering (p. 487). Cunningham and Kelly (2017) offer a unique approach in their presentation of epistemic practices of engineering. The epistemic practices draw from Vygotsky’s (1978) sociocultural learning theory in which cognitive development is mediated through social processes. Epistemic practices are “socially organized and interactionally accomplished ways that members of a group propose, communicate, justify, assess, and legitimize knowledge claims” (Cunningham & Kelly, 2017, p. 487). Within their conceptual framework they present sixteen practices as compared to the eight science and engineering practices listed in the NGSS framework, reflected in Table 1. The epistemic practices of engineering in comparison to the science and engineering practices provide a broader context of engineering. These sixteen practices are classified across four categories that provide a more authentic view of engineering in practice. The categories are engineering in social context, using data and evidence to make decisions, tools and strategies for problem solving, and finding solutions through creativity and
innovation. While these practices fall within these categories there is significant overlap between the practices.

Table 1.

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Epistemic Practice of Engineering</th>
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</thead>
<tbody>
<tr>
<td>1. Asking questions (for science) and defining problems (for engineering)</td>
<td>Developing processes to solve problems</td>
</tr>
<tr>
<td>2. Developing and using models</td>
<td>Considering problems in context</td>
</tr>
<tr>
<td>3. Planning and carrying out investigations</td>
<td>Envisioning multiple solutions</td>
</tr>
<tr>
<td>4. Analyzing and interpreting data</td>
<td>Innovating, processes methods, and designs</td>
</tr>
<tr>
<td>5. Using mathematics and computational thinking</td>
<td>Making trade-offs between criteria and constraints</td>
</tr>
<tr>
<td>6. Constructing explanations (for science) and designing solutions (for engineering)</td>
<td>Using systems thinking</td>
</tr>
<tr>
<td>7. Engaging in argument from evidence</td>
<td>Applying math knowledge to problem solving</td>
</tr>
<tr>
<td>8. Obtaining, evaluating, and communicating information</td>
<td>Applying science knowledge to problem solving</td>
</tr>
<tr>
<td></td>
<td>Investigating properties and uses of materials</td>
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<tr>
<td></td>
<td>Constructing models and prototypes</td>
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<tr>
<td></td>
<td>Making evidence based decisions</td>
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<tr>
<td></td>
<td>Persisting and learning from failure</td>
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<tr>
<td></td>
<td>Assessing implications of solutions</td>
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<tr>
<td></td>
<td>Working effectively in teams</td>
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<td></td>
<td>Communicating effectively</td>
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<tr>
<td></td>
<td>Seeing themselves as engineers</td>
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</table>

Note. Science and engineering are taken from Appendix F of the Next Generation Science Standards (2013).


The epistemic practices of engineering were developed through the compilation of empirical studies that reflected practices that engineers engage in across disciplines. This comprehensive list of engineering practices not only has the ability to cultivate depth of knowledge for engineering education, but they also provide a wealth of instructional possibilities for science educators that do not have sufficient background knowledge in engineering. Additionally, developing the epistemic practices of engineering is critical to enhancing epistemic agency in which students direct the knowledge building process. As student progress in their practices related to knowledge production in engineering, they can be positioned to use those practices in a way that reflects that aims, values, and ethics of the knower. Thus, the conceptual
framework for the epistemic practice of engineering are aligned with the goals and objectives of this study related to progressing student epistemic agency as STEM learners.

Perhaps one of the most intriguing components in the epistemic practices of engineering is the focus on the social practices of engineering. Cunningham and Kelly note identity formation, *depicted as seeing themselves as engineers*, as essential for the development of epistemic practices. This component is also aligned with Taylor and Brand’s (2021) study that identified identity and self-efficacy as critical components for developing epistemic agency. Cunningham and Kelly (2017) also note that as individuals adopt the cultural practices in the community of practice they are recognized as legitimate participants within that knowledge building space. As legitimate members within the community of practice they now have the epistemic tools to influence or direct the knowledge building process thus they are positioned to enact agency. These practices are aligned with Vygotsky’s (1978) sociocultural theory related to the zone of proximal development that posits that development occurs as they co-construct knowledge with a peer that has more knowledge or an expert. Within this concept of zone of proximal development, students mediate cultural practices of learning through social interactions with a peer that has more knowledge or an expert. As the students continue to engage in social interactions within the community of practice, they adopt the cultural practices and progress to a level of mastery in which become the peer that has more knowledge or an expert. Some researchers have discussed that while this concept of identity formation within a community of practice is theoretically sound, developing epistemic identities is challenged when intersected with sociocultural positioning. Barton and Tan (2010) state

It is also important to recount that many youth from low-income communities do not have direct access to traditional networks of resources, such as experts in the
field or materials, and when they do have access they are often positioned as
recipients of the expertise rather than participants in the use and further
construction of expertise (p. 190).
Thus, epistemic development within legitimate communities of practice becomes a thing of
privilege and access and are not rendered to those who experience structural inequality that
diminishes social and material capital related to educational goods. Because identity construction
plays such a critical role in engaging in epistemic practices and developing epistemic agency,
researchers have discussed how students navigate sociocultural barriers within epistemic spaces.
Holland et al. (1998) developed the concept of figured world to explain the identity formation in
social and cultural spaces.

Figured Worlds

The conceptual framework of figured worlds was discussed in the book, *Identity and
Agency in Cultural Worlds* by Holland et al. (1998). Figured worlds is a concept that derived
from sociocultural learning theory that situates identity formation within sociocultural
dimensions. Figured worlds can be physical or spatial realms and serve as “frames of meaning in
which interpretations of human actions are negotiated” (Holland et al., 1998, p. 271). The realms
of figured worlds are organized by social and cultural practices that create social norms and
positionality of the actors that occupy it. Figured worlds are typically defined as “socially and
culturally constructed realm[s] of interpretation in which particular characters and actors are
recognized, significance is assigned to certain acts, and particular outcomes are valued over
others” (Holland et al., 1998, p. 52). While Holland et al. (1998) notes that figured worlds are “as
if” realms they are not void of social and cultural realities nor are they void of power relations
(Urrieta, 2007). Consequently, because figured worlds are realms of interpretation, the actors that
occupy it have agency in how they will exist in the realm related to social and cultural norms. In this way the realm itself becomes a site of possibility for identity work. Hines-Datiri and Carter Andrews (2020) state that in figured worlds, individuals “figure who they are through the activities…in relation to the social types that populate their figured world and in social relationships with people who perform these worlds” (p. 1430). Urrieta (2007) notes the significance of identity formation related to cultural production and heuristic development because it diverts from notions of cultural determinism and situational totalitarianism. In the figured world the actor’s ability to reject cultural determinism is tied to agency in which they can enact self-authoring through activities. Urrieta (2007) notes that Holland et al.’s concept an actor embodying a “space of authoring” draws from Bakhtin’s influence in which people make meaning of their identity through internal dialogues (p.111).

Because figured worlds are not completely void of social or cultural realities related to narratives, power relations, hierarchies, or sociohistorical positioning, actors may through their space of self-authoring accept, reject, or negotiate to varying degrees their identities (Urrieta, 2007). This space of self-authoring is vital for marginalized populations that engage in identity formation in epistemic spaces in STEM in which their sociocultural identities have been structurally, socially, and historically estranged from epistemic communities. Prime (2019) argues that racial hierarchies reflected in STEM participation is produced and maintained by structural arrangements, policies, and practices. Racial hierarchies in STEM profoundly impact identity construction and cultivation of self-efficacy. Shea and Sandoval (2020) note that students’ participation and internalization of intellectual capabilities within the classroom is influenced by “political histories of marginalization that shape in group/out group distinctions” (p.28). The historic invisibility of African Americans within science and STEM related
curriculum infers deficit credibility regarding who can construct knowledge and contribute within the scientific enterprise. Sheth (2019) notes that students of color are constantly negotiating their identity as they navigate negative characterizations stemming from stereotypes and “cultural dissonance from dominant conceptions of who is capable of science and who belongs in science” (p. 38). Across literature, researchers use various conceptual frameworks related to sociocultural theory to explain how marginalized populations negotiate the construction of identity while encountering situated norms, inequitable distributions of power, or epistemic injustice within intellectual spaces. Barton and Tan (2010) used the concept of figured worlds in their study to discuss, “…how the youth asserted themselves as community science experts in ways that took up and broke down the contradictory roles of being a producer and a critic of science/education” (p. 187). Vågan (2011) used the conceptual of framing of figured worlds to understand how medical students engaged in learning and meaning making of their own identities in relation to cultural norms assigned to doctors while engaging in a community of practice. For my study, using the concept of figured worlds with the epistemic practices of engineering provided a broader context for understanding how identity formation occurs for marginalized populations in knowledge building spaces.

The concept of figured worlds can be used to explore how individual identities form within the context of epistemic practices of engineering. However, identities are negotiated within the social interactions within a community of practice. Cunningham & Kelly (2017) note that identity formation in which students see themselves as engineers is a byproduct of their demonstration of the epistemic practices within a community of practice. Thus, adding Wenger’s (1998) concept of community of practice is a necessary component for understanding how African American students negotiate identity within a community of practice when
demonstrating the epistemic practices of engineering. Studying the community of practice in which African American students negotiate their identity is critical to understanding the development of epistemic agency as STEM learners. Furthermore, including Wenger’s (1998) concept of community of practice within this research may provide insight when exploring collective identity transformation and collective agency for marginalized populations in epistemic spaces.

**Communities of Practice**

Wenger’s (1998) draws upon Vygotsky’s (1978) sociocultural learning theory in which learning is mediated through a series of social interactions. Wenger et al. (2011) define the community of practice as a “learning partnership among people who find it useful to learn from and with each other about a particular domain. They use each other’s experience of practice as a learning resource” (p. 9). Wenger (2004) notes that a community of practice encompasses three integral components which are the domain, the community, and the practice. The domain is what constitutes the social organization of a group around an issue or body of knowledge. The community constitutes the social group for which the domain is relevant for. The practice constitutes the definitive cultural and social methods that are shared and operationalized within the community of practice. Smith et al. (2017) note “that individuals’ engagement in a community of practice always entails a process of negotiation of meaning which takes place in the convergence of two processes: participation and reification” (p. 212). Participation within a community entails the social and cultural practices as well as all social and cultural interactions while reification entails creating socially mediated artifacts within the community of practice. The members of the community ascribe meaning and value to the artifacts. The community of
practice is also socially constructed and organized realm like the concept of figured worlds and also acts as a site of possibilities of shared identity transformation and agency.

Collaborative engagement within a community of practice goes far beyond a group of people who engage in collective practices. The collaboration of knowledge construction and artifacts requires epistemic activities in which members congeal around the collective advancement and progression of knowledge. As individual members experience identity formation they collectively work together as agents to enact epistemic agency. Scardamalia (2002) notes that epistemic agency is significant to social processes that enable the “creation and improvement of ideas via collective contributions in which students take cognitive responsibility for their learning” (Damşa et al., 2010, p. 146). Damşa et al. (2010) conducted a study in which they found that a community of practice that demonstrates epistemic agency “expresses learners’ intentional, goal-directed, and sustained involvement in knowledge-driven, object-oriented, collaborative activities” (p. 149). This type of community of practice is essential for marginalized populations because they have autonomy and ownership related to how the knowledge will be used.

**Conclusion**

The aims of my research entail exploring how African American students progress toward epistemic agency as a result of identity transformation through the engagement of epistemic practices of engineering. While Cunningham and Kelly (2017) note that seeing oneself as an engineer is an integral part of the epistemic practices of engineering, independently it does not account for the sociocultural and historical influences that can impede identity formation in epistemic spaces. Thus, Holland et al.’s (1998) concept of figured worlds enables marginalized populations to negotiate identity formation and challenge situated norms associated with
dissociated identities. While identity formations occurs within the individual it is the byproduct of social interaction that occurs within a community of practice. Wenger’s (1998) concept of a community of practice offers the ability to cultivate a collective identity transformation through the engagement of practices that advance epistemic agency. The combination of these conceptual frameworks (epistemic practices of engineering, figured worlds, and community of practice) which collectively derived from Vygotsky’s (1978) sociocultural learning theory are essential for framing and discussing the results of this study.
Chapter 4: Methodology

Research Design

This chapter discusses the research design for examining how participants develop epistemic agency as STEM learners as they engage in activities across a learning progression designed to advance the epistemic practices of engineering. This chapter includes the aim and purpose of the research, the research questions, and qualitative research design. Qualitative methods were used in this study to explore three integral components across the learning progression. The first integral component was centered around the relationship between personal dispositions and cognitive development. Per the first component, this study explored how participants experienced changes in their identity and self-efficacy as they engaged in the epistemic practices of engineering during engineering activities. The second integral component was centered around the relationship between cognitive development and social and experiential learning. Per the second component, this study explored how participants developed in their demonstration of the epistemic practices of engineering in response to working within a community of practice. The last integral component was centered around the relationship between dispositional changes and cognitive development and the demonstration of personal agency and ownership during learning experiences. Per the last integral component, this study explored how participants demonstrated epistemic agency as STEM learners as a result of changes in identity and enhanced demonstration of the epistemic practices of engineering. The premise for this study was that increasing African American students’ engagement and agency in STEM required the enhancement of their identity and sense of self-efficacy through meaningful engagement with curriculum that centered their epistemic participation.
Stroupe et al. (2018) assert that “disrupting epistemic injustice, and promoting epistemic agency requires much more public, principled, and adaptive forms of pedagogy than in the past” (p. 950). They further assert that pedagogical approaches have to shift to prioritize equitable participation and epistemic agency, especially for populations that have been traditionally marginalized within classrooms. The aims for this study sought to understand how changes in African American students’ epistemic agency as STEM learners occurred through identity transformation as they engaged in the epistemic practices of engineering. The learning progression which included the curricular structure for this study was framed from a previous pilot study (Taylor & Brand, 2021). The structure of the learning progression mediated intellectual activities that supported epistemic participation. Schmidt (2019) defines epistemic participation as an agent’s ability to give relevant contributions when engaging in social interactions in which knowledge is generated (p. 53). Thus, epistemic participation for students in this study encompassed active engagement reflected in discourse, demonstration of epistemic practices of engineering, and the co-construction of knowledge within a community of practice.

The curricular structure for the anchor of the learning progression was informed by Vygotsky’s (1978) concept of the zone of proximal development. The activities associated with each anchor were designed to progress participants epistemic participation. As participants engaged in the activities associated with each anchor they were positioned to advance from assisted learning to self-regulated learning. This progression enabled participants to increase in their demonstration of the epistemic practices of engineering as they moved toward epistemic agency as STEM learners. The zone of proximal development for epistemic agency as STEM learners is shown below in Figure 1.
Figure 1.

Zone of Proximal Development for Epistemic Agency as STEM Learners

Target Anchor Phase 3:
Engineering design activities that participants can perform with minimal assistance to no assistance

Intermediate Anchor Phase 2:
Engineering design activities that participants can perform with instructional assistance

Entry Anchor Phase 1:
Engineering design activities that participants cannot perform without instructional assistance

Note. The diagram above shows the conceptual structure of the curricular design of the learning progression for progressing epistemic agency in relation to the zone of proximal development. Participants develop more independence and autonomy as they increase in knowledge and skill through their engagement with engineering related activities at each anchor.

The learning progression for this study reflects the concept of social constructivism which encompasses collaborative, experiential, and active learning. The anchors within the learning progressions were theoretically aligned with the concept of sociocultural learning theory that prioritizes social interactions as a fundamental driver of student learning. The learning trajectory for this learning progression was designed to mediate learning through a community of
practice in which the student grows in knowledge and skill in relation to their social interactions with a more knowledgeable other known as an expert in the field or peer that has more advanced knowledge. The curricular layout of this learning progression modeled Lave and Wegner’s (1991) concept of legitimate peripheral participation. Legitimate peripheral participation is a learning participation model that explains how learning occurs through social interactions between the apprentice, practitioner, and expert. Within this model the apprentice is a novel learner that learns the cultural practices and ways of being from the practitioner who is a more knowledgeable other. The learner is on a trajectory to becoming an expert by learning and modeling the cultural practices of the expert in the community of practice. As participants demonstrate growth in their knowledge and skills related to the cultural practices assigned to community of practice, they legitimize their identity and position as practitioner or expert. As participants progressed through the learning progressions they cycled through phases of participation as a byproduct of identity development and enhanced self-efficacy beliefs.

Research Questions

The overarching research question in this study was: *What epistemic practices of engineering do student participants demonstrate in their artifacts and discourse when engaging in engineering activities across all three anchors of the learning progression designed to develop epistemic agency for STEM learners?* Participants engaged in a six week learning progression divided into three anchors. The learning progression provided a learning trajectory for the development of epistemic agency as STEM learners across three anchors. The three anchors of the learning progression included the entry anchor, intermediate anchor, and target anchor. Each anchor encompassed specific curricular activities designed to progress the development of identity and self-efficacy, in tandem with the epistemic practices of engineering demonstrated in
discourse and artifacts, within a community of practice. A sub-research question was aligned with the entry, intermediate, and target anchor which explored and evaluated how students’ epistemic agency developed in response to engaging in the curricular activities across the learning progression.

The sub research question for the entry anchor was as follows: *How does the inclusion of learning about young African American students engaged in STEM research impact the perception of STEM and use of epistemic practices of engineering for African American student participants engaged in engineering design activities?* The entry anchor of the learning progression focused on two components: the cultivation of identity formation and self-efficacy and the demonstration of the epistemic practices of engineering. Within this anchor participants were engaged in a series of activities that positioned their identity as STEM contributors.

The sub research question for the intermediate anchor was as follows: *How do African American student participants engage in the use of epistemic practices of engineering when exploring engineering activities in collaboration with a local computer scientist and how is their sense of identity and efficacy impacted?* The intermediate anchor of the learning progression focused on the development of knowledge and practices with an expert within a community of practice. Within this anchor participants worked in a community of practice with a local computer scientist to learn disciplinary knowledge and skills for general computer programming and more specifically with EV3 robotics programming.

The sub research question for the target anchor was as follows: *What epistemic practices of engineering do African American student participants adopt when building prototypes and how can their prototypes contribute to the advancement of their community and larger society?* The target anchor of the learning progression focused on the development of epistemic agency
and creation of an engineering prototype using the epistemic practices of engineering. Within this anchor, changes in participants’ identity and self-efficacy positioned them to use the knowledge, skills, and practices that they learned and demonstrated in previous anchors for the engineering design challenge assigned to them in the target anchor. Using knowledge and skills from previous anchors, participants identified a science related issue in their local community and designed an engineering prototype to address the issue. The curricular design of each anchor is presented in detail during the discussion of data collection later in this chapter.

**Qualitative Design: Case Study**

The qualitative design of this study was a continuation of the case study for the Actualizing STEM Potential (ASP) robotics program. Robson (1993) states that case studies are “a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence” (p. 146). Robson’s statement provided a rationale for selecting a case study as a methodical approach for exploration. The first part of Robson’s statement suggests that case studies are an appropriate tool for empirical investigation of contemporary phenomenon. Currently, one of the trending topics in educational research revolves around examining factors that influence African Americans participation in STEM and STEM related fields as it relates to inequitable teaching practices, issues of representation, STEM identity transformation, and academic opportunities (Milner, 2011; Mau & Li, 2018; Colins, 2018; Young & Young, 2018). However, there were not many studies regarding African American’s development of epistemic agency within learning progressions and its influence on STEM participation and orienting students towards STEM related fields. The empirical unknowns for this research topic justify using a case study as this approach would produce thick, rich, descriptions of data (Merriam, 2002). Thus, employing a
case study methodology provided an opportunity for an in depth study and description of changes in students’ epistemic agency as STEM learners through exploring identity transformation as they engaged in engineering design activities that promote the advancement of the epistemic practices of engineering throughout the learning progression.

The second part of Robson’s (1993) statement involves conducting research within real life contexts. Real life contexts include multiple variables within a study that affect participants and all ensuing dynamics. Wang et al. (2017) note that the Mississippi Delta is characterized by economic disenfranchisement that is compounded by lack of employment opportunities. In Harvey’s (2013) study he notes that in the Mississippi Delta the “racialized social structure systematically obstructs consensus-based efforts to construct interracial and inter-institutional relations of trust and cooperation” (p.257). The educational landscape in the Mississippi Delta is constrained by racialized social structures that feed into inequality which result in a segregated system that provides a dual education system (Harris, 2020). Creating equitable academic opportunities is particularly critical to broadening STEM participation of individuals from underserved regions in the U.S. whose needs are compounded by social inequities. A case study in this region included navigating social structures that impacted student’s perception of their identity, self-efficacy, and exposure to STEM. This research was instrumental in exploring what contextual relationships influenced the epistemic agency of STEM learners for a sample of participants in the Mississippi Delta.

The third part of Robson’s (1993) statement involves conducting research with multiple sources of evidence. The selection of case studies enable researchers to conduct in depth studies that produce a wealth of data points. Within this case study, there were three major data points that provided evidence for changes in students’ epistemic agency as STEM learners. The first
data point encompassed examining discourse to explore changes related to identity formation, epistemic agency and progression of epistemic sophistication denoted by the adoption of epistemic practices of engineering. Discourse included all speech acts and interactive dialogue during learning across all three anchors within the learning progression.

The second data point was exploring how participants demonstrated and adopted the epistemic practices of engineering in their artifacts which included activity sheets, digital artifacts, engineering design models, engineering prototypes, and all student work produced during the learning progression. The third data point included data from interviews (i.e., focus groups and individual semi-structured interviews) related to participants’ perceptions of their identity, self-efficacy, and epistemic agency as they engaged in activities across the learning progression.

**Action Research.** As educational goals in K-12 engineering move toward developing students’ epistemological understandings, researchers are intently focusing on creating learning that centers the development of epistemic practices. Developing curricula that demonstrates how to progress epistemic agency through the engagement of the epistemic practices of engineering can serve as a valuable contribution to broadening the body of knowledge within the field.

Creating a learning progression that prioritizes the development of epistemological sophistication for minoritized populations that have historically experienced epistemic injustice can broaden our understanding of how to intersect equity focused initiatives within educational practices. Implementing action research for this study was critical for examining the efficacy of the curriculum and examining instructional practices that encourage epistemic development.

While there is much research devoted to enhancing students’ epistemic practices, researchers have noted that “most educational research trickles down very slowly before it
finally affects teaching practices” (Laudonia et al., 2018, p. 480). Thus, using an action research-based approach in this study was significant to addressing a gap between research and practice. Action research is typically defined as an approach of systematic inquiry that encompasses gathering, analyzing, reflecting, and revising practices to enhance the process of teaching and learning (Mills, 2011). Trist (1976) urges researchers to consider the planning process as a critical part of action research. Trist (1976) further notes that within the planning process, the researcher should consider all of the complexities, conditions, and relational aspects that form the environment that is being studied.

Efron and Ravid (2019) note that within action research, to generate a holistic understanding of the inner workings of the community, a researcher has to immerse themselves in the educational setting and conduct interviews to understand the routines and ways of being within that space. Per this recommendation, I moved into the local community for the space of four months. The first month and a half, I spent time engaging in observations, discussion, and interviews. I had meetings with the principal, vice principal, teachers, administrative personnel, and people from the local community. Through these interactions, I gained more cultural insight into the community. Although, I had written curriculum for the ASP program for the last five years, I was not known or recognized in this community. Because the teachers usually were the ones that taught the curriculum, I was an invisible contributor to the ASP program. Upon moving into the community, I occupied the position as an outsider typically referred to as “that lady from Virginia Tech.” As time progressed, I began to integrate myself into the community by attending basketball games, award ceremonies, and visiting the school on a weekly basis early in the morning to talk to and recruit participants.
Action research begins with a clear plan of inquiry. For this study, action research was used to explore the relationship between the learning activities within each anchor, cognitive development of students, and changes in their dispositions during learning. In addition, I sought to explore if there was any curricular coherence between the learning activities across all three anchors and the development of the epistemic practices of engineering. Within action research, once the teacher researcher has clarified and contextualized the inherent problem within the study, they must determine what tools would effectively address the research question. Efron and Ravid (2019) prescribe four types of teacher researcher instruments: observations, interviews, surveys, artifacts, and documents. In alignment with this recommendation for this study, I used observations, discourse, and artifacts across all three anchors of the learning progression. The collection of data and methods of analysis related to these tools are discussed later in this chapter.

Johnson (2008) positions action research as engaging in a systematic inquiry into your own instructional practice. McLean (1995) notes that reflection is a critical component to engaging in action research. Reflective practice is a very significant component in understanding and improving instructional approaches. At the conclusion of each learning activity across each anchor, I handwrote and digitally recorded a reflection. The reflection allowed me to recount what happened, examine assumptions, evaluate outcomes, and modify practices based on the data that was collected.

Klein (2012) stated, “Recent themes within action research reflect an emphasis on collaborative inquiry, with aims toward social justice…” (p. 2). Because this learning progression was designed as a sociohistoric response to a legacy of epistemic injustice, creating community engagement with the affected population was significant to the social justice
component of this research. The region where this study was conducted has limited STEM capital and very few STEM programs. Conducting STEM Night was a significant component of the target anchor because it provided an opportunity for participants to raise STEM awareness within their community. Riggs et al. (2019) noted that, “Parental involvement increases K-12 student interest in STEM careers; however, when parents lack confidence in STEM content, or language and cultural barriers exist, parental engagement decreases” (p.1). Situating the epistemic development of marginalized populations within their community not only presented opportunities to influence dissociated identities related to STEM, but it was also an opportunity to create a sustainable collaboration between the school and community for STEM exposure.

**Participant Observer.** My position in this case study was that of a participant observer. Bruyn (1963) noted that the participant observer “shares in the life activities and sentiments” of those that they observe in research (p.224). As a participant observer I have been involved with the ASP robotics program for the last four years. I designed the curriculum, attended robotics competitions, and engaged in promoting extension programs such as a countywide STEM community summer camp. Bruyn notes that the participant observer should be personally engaged and detached. While I shared in the progression of the ASP robotics program, I am an outsider from the perspective of the rich community culture in the Mississippi Delta. I am not a member of the Mississippi Delta community nor apart of the social dynamics that govern community relationships. Merton (1972) suggests that the participant observer has to consider points of access in terms of relationships with the participants in terms of insiderness. While I am not a member of the Mississippi Delta, I do share in the common experiences of an African American navigating educational inequity due to inherent racialized structures that perpetuate educational inequity. As a former educator and student of the U.S. education system I understand
firsthand the sociocultural barriers that stifle African American’s epistemic participation and agency in STEM. Having a sense of insiderness enables the researcher to have access to the hidden knowledge in the community that would not be produced without the relationship (Labaree, 2002). Bernard (1994) noted that having a familiar relationship to or with the community of study minimizes performative behaviors exhibited by participants that know they are being observed.

While DeWalt and DeWalt (2002) discuss the advantages of using the participant observer method in that quality data is produced, Johnson and Sackett (1998) note that flawed descriptions of data occur when the researcher focuses on the aspect of the phenomenon that is indicative of the researcher’s interest as opposed to examining the phenomenon in its entirety as it is. Merriam (2002) asserted that the researcher has to consider what they are to observe in the study and that what the researcher observes is in alignment with the purpose, aim, and research questions of the study. Kalwich (2005) echoed Johnson and Sackett (1998) in which they suggest that the research should have a rigorous and systematic way of observing and recording detailed observations as field notes. Per this recommendation, I kept handwritten and digital records of memos and field notes of observations for discourse, artifacts, and interviews so as to develop a holistic understanding of how students develop epistemic agency across anchors within the learning progression.

Trustworthiness. Lincoln and Guba (1985) suggest that the researcher should employ methods of trustworthiness for validity to ensure quality of research. Creswell and Miller (2000) suggest peer debriefing which includes an outside perspective to discuss what they observe in the findings. Per this recommendation, I used peer briefing as means of employing analytic triangulation. Lincoln and Guba (1985) also suggested that trustworthiness can be enhanced by
ensuring that the researcher provides thick rich descriptions so as to present the participants experiences as authentically as possible. Maxwell (2013) suggests that at the conclusion of the data analysis, the researchers should share the findings with participants as a method of member checking. Member checking is not only a way to ensure trustworthiness it is also an ethical practice. In this study, I used member checking as a means of having validity and reliability in my analysis. Marshall and Rossman (2016) urge the researchers to consider their position of power in shaping the way that a participant is represented in the world and to employ strategies of transparency and ethics to provide the most authentic representation.

**APS Program and Participant Selection**

The Actualizing STEM Potential (ASP) robotics program was open to all high school students in the Burghardt County School District. The demographics within this school district is predominantly African American; thus, the target population for this study was African American students. The student participants enrolled in the ASP program had limited science exposure. The Mississippi Department of Education (2018) only requires three credits of science to obtain a diploma. At the high school where the ASP project is housed, per state mandate, students are to take biology which fulfills the two of the three credits required to obtain a diploma. Most students at this high school take environmental science to meet the third credit requirement instituted by state. Because chemistry is not required by the state most students at this school opt out of taking chemistry. Additionally, there are no physics courses taught in the school. Thus, the majority of participants enrolled in this program have only taken biology and environmental science. This resulted in a limited range of scientific knowledge and practices during their engagement with engineering activities across the learning progression.
Participation in the ASP afterschool program was voluntary. Students that signed up for the robotics program were not required to participate in the case study. A total of twenty-three participants joined the afterschool program. Of the twenty-three students that joined the afterschool program, fourteen of the students participated in this case study. The high school in which the study was conducted consists of grades 10th-12th. Of the fourteen participants, six were female and eight were male. Of the six female participants, one of the females was in 12th grade, two of the females were in 11th grade, and two of the females were in 10th grade. Additionally, one of the female participants in this program was in 9th grade and attended a nearby junior high school and heard about the afterschool robotics program through a parent and decided to join. Of the eight male participants, five of the males were in 11th grade, and three of the males were in 10th grade. Most of the participants were honor roll students, and the majority of the participants were involved in extracurricular activities such as band, track, and softball.

While there were several time conflicts with participants’ extracurricular activities and the ASP after school pre-engineering robotics program, participants managed their schedules to make sure that they attended the afterschool program. Pseudonyms were used for participants involved in this case study.

**Sampling Strategy.** Convenience sampling or voluntary sampling was used for this study. Ishak and Bakar (2014) state, “The primary purpose of sampling for a qualitative researcher is to collect specific cases, events, or actions that can clarify or deepen the researchers understanding about the phenomenon under study” (p.29). The parents and student participants signed consent forms prior to data collection as outlined in the IRB protocol of the study. The IRB Memorandum for this study as well as the IRB consent and assent form are represented in Appendix A and B respectively.
Data Collection Methods

Several data points were collected across all three anchors spanning the six-week period that the learning progression was implemented. This study examined various data points such as discourse, artifacts, semi-structured interviews, and observations across all three anchors of the learning progression. The use of multiple data points aided in the generation of a rich description. Additionally, examining multiple pieces of data enabled me to develop a broad and in depth “understanding of social realities and to draw attention to processes, meaning, patterns and structural features” (Flick, 2009, p.1).

Discourse. Ambitious objectives established by the National Research Council (1996) require educators to assess students’ understanding of science inquiry through physical means as well as assess students’ understandings and practices through discourse which include reasoning and argumentation (Russ et al., 2008). Language is a significant cultural tool that is used to engage students in intellectual practices and content knowledge. Cohen (1994) concludes from multiple studies that if students are to advance in the knowledge of the discipline, they will have to develop skills for discourse that are in alignment with the discipline. Carlone and Johnson (2007) assert that developing skills in relation to discourse is essential to developing the identity of students. Cunningham & Kelly (2017) note communication as a significant practice of engineering due to the social engagement with the engineering community and the engagement with stakeholders. Because discourse was central to participants developing as practitioners of engineering, I examined how participants demonstrated the epistemic practices of engineering in discourse when they collaborated with each other during engineering design activities across the learning progression. Additionally, I examined how participants demonstrated the epistemic practices of engineering in discourse when they collaborated with a local expert while working in
a community of practice. Lastly, I examined how participants demonstrated the epistemic practices of engineering in discourse when they interacted with the local community during STEM Night. Field notes during the data collection process were handwritten in a notebook as well as audio recorded in an effort to capture a contextualized rich description for analysis.

**Artifacts.** The vision of the National Research Council (1996) supports students engaging in authentic experiences of inquiry that mirror the professional discipline. Gearhart et al.’s (2006) study reveals that student work is critical for exploring how they were developing in knowledge and practices during learning. Krebs’s (2005) study reveals the significance of collecting student work to examine students’ thinking and reasoning. Carlone and Johnson (2007) note student performance as an essential element for constructing identity and improving students’ perception of their abilities as practitioners. Artifacts were collected during all three anchors of the learning progression. I used the artifacts to examine what epistemic practices of engineering participants adopted as they engaged with the curriculum. Artifacts included activity sheets, digital presentations of work, engineering design models, engineering prototypes, and all other curricular materials that were produced during learning.

**Interviews.** Semi-structured interviews were used to explore students’ perceptions related to changes in their identity, efficacy, and epistemic agency. Using semi-structured interviews were critical practices for eliciting individual or group responses regarding their personal experiences and meanings within a flexible manner (Merriam, 2002). Semi-structured interviews were conducted with individual participants and with groups of participants across each anchor of the learning progression. The interviews were conducted to reflect on their experiences as they traversed the curriculum. Rubin and Rubin (2012) noted that building rapport is a necessary component for data collection as it enables the researcher to elicit depth and detail
during the interviewing process. Thus, engaging as a participant observer (wherein I shared in their experiences during the learning) was a crucial aspect of data collection related to interviews. Wilson (2016) suggested using a constructivist approach for semi-structured interviews as it positions the researcher to create open ended questions and allows for active listening of participant experiences (Creswell, 2013). Participants were asked open ended questions in regard to sharing their thoughts about various topics aligned with the study so as to not direct their answers during the interviews. Active listening when interviewing participants required a systematic method to capture the narration of their experiences. All interviews were recorded and transcribed. Field notes and memos of observations during semi-structured interviews were crucial components for data collection. Hamilton et al. (2012) asserted that member checking in which you have the participants to examine and validate their responses adds validity during the data collection process. During the interview, I repeated the participants responses back to them to ensure that I produced an accurate representation of their experiences. 

Interview questions are displayed in Appendix C.

In addition, focus groups were conducted during the data collection process to learn more about which experiences, if any, in the curriculum had impact. According to Byers and Wilcox (1991), focus groups provide data that cannot be obtained through self-report measures and observations. Participants were asked open-ended questions (Patton, 1990) and were encouraged to reflect over their curricular experiences at the end of the learning progression and discuss ideas that they believe had the greatest impact on their development and success without predetermined pointed questions, or preconceptions from the researcher. In alignment with Zeldin and Pajares’s (2000) and Brand and Wilkins’s (2007) studies, the questions were asked in a manner that allowed for a fluid discussion to emerge related to their identity, efficacy beliefs,
and epistemic agency related to their experience with the curriculum and or with other relevant experiences. Focus groups and semi-structured interviews were recorded, and the data was transcribed.

**Curricular Design and Data Collection for Entry Anchor**

The curriculum designed for this learning progression was titled, “Be the First” which centered a progression of identity development for epistemic agency through the cultivation of the epistemic practices of engineering. During the entry anchor, student participants learned about the Flint Water Crisis via a facilitated discussion and news report video clip shown on YouTube. Following the video clip, participants engaged in a WebQuest and learned about lead exposure and the dangers of lead consumption and poisoning. Proceeding the WebQuest, participants were asked to discuss their findings with the class. Next, participants were led in a discussion about how the information that they found related to their personal lives and local environment. After the discussion, participants were shown a map of drinking water violations across the U.S. and engaged in exploring the relationship between drinking water violations, poverty, and populations of color.

Next, participants read about a group of African American high school students known as the S3 group that created a water filtration system for contaminated water and as a result were placed into the National Aeronautics and Space Administration (NASA) competition. Participants read about the successes and challenges that the S3 group faced in relation to their work and their participation in the NASA competition. At the conclusion of the reading, participants were asked to share their thoughts about the reading through answering two prompts presented in the Poll Everywhere app. For prompt 1, participants were asked, “In what ways are their [referring to the S3 group of students engaged in STEM research from the reading]
contributions significant to society?” For prompt 2, participants were asked, “What tools do you need to make contributions to society and what would you contribute?” Participant responses were sent via text message to the Poll Everywhere app and were recorded. Participants' responses were then projected onto the promethean board in real time as they texted the PollEverywhere app. Prompts 1 and 2 were used for coding.

The purpose of prompt 1 and 2 was to explore participants’ thoughts and conceptions related to their personal sense of self as it relates to identity and self-efficacy in response to learning about young students engaged in STEM research making contributions. Typically, across mainstream curricula, African American students are introduced to scientists and engineers that have identities that are opposite of their race and age which could consequently reinforce dissociated identities associated with those disciplines. Thus, I sought to explore the impact of participants’ personal conceptions of STEM as a result of exploring students that were engaged in STEM research whose identities were directly aligned with their age, race, and gender. In addition, I explored participants’ perceptions of value in relation to the significance of the STEM contributions of the students engaged in STEM research in conjunction with their own aspirational STEM contributions. Centering the participants identity and perceptions of self-efficacy in relation to their STEM contributions for prompts 1 and 2 was essential to cultivating epistemic agency as STEM learners.

Next, participants were shown the inside of a Brita water filter and were asked if the order of the layers constructed in the filter mattered. The entry anchor concluded with participants engaging in an engineering design challenge titled, “The Brita Water Filter Challenge” in which they designed their own water filtration system. During this challenge, participants created their own contaminated water and then proceeded to test various materials to
find out the filtration effectiveness of each material. After testing various materials, the participants hypothesized an order of how the materials should be layered to provide the most efficient method of filtering their contaminated water. Creating the order also encompassed an iterative process of testing. The goal was to get the water as clear as possible using the available materials. This process was documented on their activity sheet, which was taken from the Teach Engineering Project titled, *Water Filtration Project: Make Your Own Water Filters* (University of Colorado Boulder, 2013).

The engineering activity, “The Brita Water Filter Challenge” was designed to teach the participants about the engineering design process and engage them in the epistemic practices of engineering. The engineering design process, displayed in Figure 2, is a series of steps that engineers use to create models or prototypes to solve a problem. The iterative steps of the engineering design process are as follows: identification of problem and constraints, research the problem, brainstorm multiple solutions, select a promising solution, create prototype, test and evaluate prototype, and improve the design.
Figure 2

The Engineering Design Process

Note. The figure reflects an adaptable process that engineers use across varied disciplines to create a solution/model or prototype that addresses a problem.

The engineering design process exemplified procedural steps necessary to create a prototype, however, this does not explicitly outline cognitive practices necessary to efficiently execute each step during the engineering design process. Therefore, I included the epistemic practices of engineering to compliment the engineering design process for the “The Brita Water Filter Challenge.” Cognitive practices facilitate exploration, reasoning, and processing; thus, the epistemic practices of engineering were significant markers for observing how participants were progressing cognitively during the engineering design process. The epistemic practices of
Table 2

<table>
<thead>
<tr>
<th>Epistemic Practices of Engineering</th>
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<tbody>
<tr>
<td>Developing processes to solve problems</td>
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<tr>
<td>Considering problems in context</td>
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<tr>
<td>Envisioning multiple solutions</td>
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<tr>
<td>Innovating, processes methods, and designs</td>
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<tr>
<td>Making trade-offs between criteria and constraints</td>
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<tr>
<td>Using systems thinking</td>
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<tr>
<td>Applying math knowledge to problem solving</td>
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<tr>
<td>Applying science knowledge to problem solving</td>
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<tr>
<td>Investigating properties and uses of materials</td>
</tr>
<tr>
<td>Constructing models and prototypes</td>
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<tr>
<td>Making evidence-based decisions</td>
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<tr>
<td>Persisting and learning from failure</td>
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<tr>
<td>Assessing implications of solutions</td>
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<tr>
<td>Working effectively in teams</td>
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<tr>
<td>Communicating effectively</td>
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<td>Seeing themselves as engineers</td>
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*Note. Source adapted from Epistemic practices of engineering for education (Cunningham & Kelly, 2017, p.492).*

The epistemic practices of engineering served as a compliment to the engineering design process. For example, step 4 of the engineering design process is *selecting a promising solution*. While this step is critical to developing a prototype, it does not outline the cognitive practices necessary for selecting a promising solution. *Selecting a promising solution* necessitates *making evidence-based decisions* which is an epistemic practice of engineering. The method of *making evidence-based decisions* hypothetically could be the derivative of other epistemic practices of engineering such as *investigating materials, assessing implications of solutions*, or *making trade-offs between criteria and constraints*. Thus, the engineering design process was paired with the epistemic practices of engineering to cultivate skills associated with problem solving, critical
thinking and reasoning which were essential cognitive practices observed and assessed during participants’ engagement with activities during this anchor.

The purpose of my observation during the “Brita Water Filter Challenge” was to evaluate how participants displayed and engaged in the epistemic practices of engineering through discourse. In addition to cultivating cognitive practices, these practices also included social dimensions of engineering which were fundamental to participants negotiating identity and expressing intrapersonal skills in tandem with the engineering design process. This activity was designed to position the participants as producers of knowledge by centering their identity and self-efficacy across the entry anchor. Centering their identity and self-efficacy during learning was significant to developing epistemic agency as STEM learners.

For prompt 3, I examined how participants were engaged in the epistemic practices of engineering per written documentation on their activity sheet titled, *Water Filtration Project: Make Your Own Water Filters* (University of Colorado Boulder, 2013) during the engineering design process. Using the epistemic practices of engineering deductively as an evaluation method aided in my reflection regarding which components of the curriculum were effective in progressing social and cognitive development as well as which components of the curriculum needed to be further enhanced for the entry anchor. Per the action research component of this study, a pedagogical reflection was conducted to assess my instructional practice as well as the curricular design for each anchor. The pedagogical reflection is shown in chapters 5, 6, and 7.

**Curricular Design and Data Collection for Intermediate Anchor**

The curriculum design for the intermediate anchor prioritized the development of identity with the development of the epistemic practices of engineering as participants advanced toward epistemic agency within a community of practice. Per the zone of proximal development of
epistemic agency for STEM learners, participants were positioned to co-construct knowledge with an expert in the field and with each other during the learning activities for the intermediate anchor. At the beginning of the intermediate anchor participants were engaged in a class discussion in which they distinguished between machines, robots, and artificial intelligence by evaluating the functions of various everyday objects. Next, participants watched three YouTube videos in which they explored how robots and artificial intelligence are combined to solve problems both nationally and globally. Participants then were led in a class discussion about the intersection of robots and society as it relates to both positive impacts and impending implications.

The next phase of the lesson entailed an activity in which participants proposed ideas about how robots sense their environment and make decisions which bridged a discussion about computer programming. Proceeding the discussion, participants explored the components of the Lego Mindstorm EV3 robots. Participants were led in an activity in which they built a basic design called a harvester robot and were introduced to the basics of EV3 computer programming. The next session was led by an expert computer scientist from a local university who provided an overview of computer programming. After the introduction on computer programming, the computer scientist provided participants with an activity sheet that displayed a checklist of tasks that their robots were to perform titled the “EV3 Programming Activity”. The tasks on the activity sheet, which prompted participants to develop their own programming applications, increased in difficulty from simple to challenging and occurred over two sessions. The discourse and observations of participants during the EV3 Programming activity was used for coding. The question guiding my observation of the participants’ discourse and behavior during the EV3
programming activity was, “What epistemic practices of engineering emerged in participant discourse, behavior, and artifacts as participants engaged in the EV3 programming activity?”

In addition to exploring what epistemic practices of engineering were demonstrated, the purpose of my observation was to explore how participants engaged in a community of practice with a computer scientist via observation and discourse. I also sought to explore how participants’ identity, sense of self-efficacy, and progression toward epistemic agency as STEM learners were influenced due to working with an expert in the field. I sought to understand how participants engaged in a community of practice with each other based on my observation during the entry anchor in which participant behaviors indicated that they were influenced and inspired by each other.

Curricular Design and Data Collection for Target Anchor

The curriculum design for the target anchor prioritized the progression of identity development for epistemic agency through the demonstration of the epistemic practices of engineering. At the beginning of the target anchor, participants were given an activity sheet titled, “STEM Night Robotics Challenge.” During this design challenge, participants identified a local or global problem and constructed an EV3 robot prototype to address the problem. This activity was designed to engage participants in the practices and processes used by engineers in real contexts. This design challenge built upon the knowledge, skill, and practices acquired from previous anchors. Participants used the “STEM Night Robotics Challenge” activity sheet to map out their ideas using the engineering design process that they were introduced to during the entry anchor. Participants also used the activity sheet to design an EV3 programming application using the programming knowledge and skill that they were introduced to during the intermediate anchor. Per the zone of proximal development for epistemic agency as STEM learners, this
activity allowed participants to exhibit the greatest amount of autonomy and epistemic agency related to regulating the knowledge building process. Participants were positioned to identify the problem, devise methods for how to solve that problem, establish parameters, as well as decide the level of difficulty for their prototype design. Additionally, this design challenge served as a summative evaluation of participants’ cognitive development related to the demonstration of the epistemic practices of engineering. The “STEM Night Robotics Challenge” activity sheet served as prompt 4 and was used for coding.

The purpose of prompt 4 was to explore how participants engaged in the epistemic practices of engineering (via artifacts) as they documented the engineering design process on their activity sheet. Exploring how participants were engaged in problem solving, critical thinking, and other cognitive practices were significant in this anchor because they were positioned to take on more independent work that was less structured. Using the epistemic practices of engineering to evaluate how participants engaged with the curriculum aided in my pedagogical reflection regarding which components of the curriculum were effective in progressing social and cognitive development as well as which components of the curriculum needed to be further enhanced for the target anchor.

The target anchor concluded with us conducting an annual community STEM Night. STEM Night encompassed a range of activities in which the participants informed their local community about engineering design and robotics. During the introductory portion of STEM Night, participants programmed the EV3 robots to verbally welcome the guests. Next, participants introduced themselves and shared their STEM interest with the community. After the introduction I highlighted participant work from the entry anchor associated with the engineering design process. The next phase of STEM Night consisted of participant led
discussions and presentations. During STEM Night, observations and dialogue were evaluated to assess how participants’ knowledge, practices, and contributions impacted their community. My observations of both the participants and their community dialogue was used for coding. The purpose of my observation was to explore how participants displayed epistemic agency related to community outreach.

**Data Analysis for Case Study**

There were multiple data points (i.e., discourse, artifacts, focus groups, and semi-structured interviews) during this study that served to answer the research questions as noted in Figure 3. The multiple data points served to provide a thick, rich, description of how participants were progressing towards epistemic agency through development of identity formation in tandem with the epistemic practices of engineering. The research questions explored the demonstration of the epistemic practices of engineering which were evidenced through artifacts and discourse that occurred during participants engagement in engineering design activities across each anchor. The research questions also explored the progression of identity and self-efficacy which were evidenced through participant discourse and semi-structured interviews. The discourse captured participants’ perception of their identity and sense of self-efficacy during their demonstration of the epistemic practices of engineering during the engineering design activities. The semi-structured interviews enabled participants to reflect on their progression of identity formation, development of self-efficacy, and progression of epistemic agency after the activity. The focus group interviews allowed participants to reflect on how they collectively developed in identity formation, development of self-efficacy, and progression of epistemic agency during the engineering design activities.
Figure 3.

Overview of How Data Points Answer Research Questions

Note. The figure provides a graphic illustration of how the analysis of all of the data points work together to answer various aspects of the research questions related to the progression of the epistemic practices of engineering, identity formation and self-efficacy, and epistemic agency.

Marshall and Rossman (2016) note that when drafting a study, it is imperative that the researcher design a systematic plan for how to “manage, analyze, and interpret the data” (p. 207). Management of data as it relates to discourse and artifacts was a combination of handwritten and digitally recorded memos and field notes. Management of data produced from interviews was
recorded and digitally stored until it was time for transcription. Marshall and Rossman (2016) caution researchers to examine the transcribed data to ensure accuracy. Researchers have a range of coding techniques that they can employ that are useful tools in constructing meaning that is aligned with the objectives of the study (Saldana, 2016). I listened to the audio recordings and video files of each anchor and transcribed the discourse for this study due to regional accents. I listened to these files repeatedly to ensure accuracy.

**Coding Discourse.** Discourse analysis was used to examine and make meaning of participant dialogue. Burck (2005) described discourse analysis as a way to “scrutinize the orderly ways of talking with which individuals account for and make sense of themselves and their social worlds” (p.248). Deductive coding was used to determine which epistemic practices of engineering were demonstrated by participants during their learning across all three anchors of the learning progression. Marshall and Rossman (2016) noted that in more objectivist proposals the researcher deductively designs and predetermined codes to guide their analysis of data. For this research, predetermined codes for the epistemic practices of engineering were used to examine which disciplinary practices for engineers were adopted by participants. The deductive coding table for the epistemic practices of engineering are displayed in Table 3 below.
Table 3.

Deductive Codes for the Epistemic Practices of Engineering

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPSP</td>
<td>Developing processes to solve problems</td>
</tr>
<tr>
<td>MTCC</td>
<td>Making trade-offs between criteria and constraints</td>
</tr>
<tr>
<td>IPUM</td>
<td>Investigating properties and uses of materials</td>
</tr>
<tr>
<td>AIOS</td>
<td>Assessing implications of solutions</td>
</tr>
<tr>
<td>CPIC</td>
<td>Considering problems in context</td>
</tr>
<tr>
<td>UGST</td>
<td>Using systems thinking</td>
</tr>
<tr>
<td>CMOP</td>
<td>Constructing models and prototypes</td>
</tr>
<tr>
<td>WEIT</td>
<td>Working effectively in teams</td>
</tr>
<tr>
<td>EMSL</td>
<td>Envisioning multiple solutions</td>
</tr>
<tr>
<td>AMTP</td>
<td>Applying math knowledge to problem solving</td>
</tr>
<tr>
<td>MEBD</td>
<td>Making evidence-based decisions</td>
</tr>
<tr>
<td>COME</td>
<td>Communicating effectively</td>
</tr>
<tr>
<td>IPMD</td>
<td>Innovating, processes methods, and designs</td>
</tr>
<tr>
<td>ASTP</td>
<td>Applying science knowledge to problem solving</td>
</tr>
<tr>
<td>PLFF</td>
<td>Persisting and learning from failure</td>
</tr>
<tr>
<td>STAE</td>
<td>Seeing themselves as engineers</td>
</tr>
</tbody>
</table>


During the deductive coding process, the participants’ statements were recorded in a table and examined. In examining the participants’ statements, a four letter code was applied when the described behavior related to the epistemic practices of engineering was exhibited. The code was then compared to the participants’ original statement to ensure that there was alignment. An example of this deductive coding process for a participant’s statement during an engineering design activity from the entry anchor is shown below in Table 4. In the example the participant stated that they were a “real scientist” during the activity which reflect the identity component of the epistemic practices of engineering thus the assigned code was seeing themselves as engineers (STAE). After the four letter code was applied, I checked to see if there was alignment between the participant’s statement and the assigned code that reflected the identity component of the epistemic practices of engineering.
Table 4.

**Deductive Coding Process of Discourse**

<table>
<thead>
<tr>
<th>Anchor</th>
<th>Entry anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants’ Statement/Discourse</td>
<td>“Because I’m a real scientist that’s how!”</td>
</tr>
<tr>
<td>Epistemic Practice of Engineering Deductive Code</td>
<td>STAE- Seeing themselves as engineers</td>
</tr>
<tr>
<td>Evaluation for Alignment</td>
<td>While the participant is speaking of a scientist. The concept of identity formation in practice is expressed, thus there is alignment.</td>
</tr>
</tbody>
</table>

*Note.* This table shows the deductive coding process that was used for discourse. The four letter code that was used in the table was taken from the table of epistemic practices of engineering.

Additionally, inductive coding of discourse was used to capture a broader context of the participants personal accounts of their experience. A constant comparative analysis consisting of ongoing, recursive, and inductive analysis (Strauss & Corbin, 1991) was used to analyze participant discourse. The inductive analysis of participants’ discourse began with line by line coding to ensure that the meaning of the statement was not lost. Next the line by line codes were collapsed into focused codes, however, they were constantly being compared to the original statement to ensure alignment. Next, axial coding was used to create categories and those categories were organized and developed into themes. At each phase of this process the codes, categories, and themes were compared to the original statement to ensure alignment. Figure 4 displays a graphical overview of the iterative process for inductive coding.
Figure 4.

*Inductive Analysis Process of Discourse*

Note. The figure depicts the iterative inductive coding process. At each level the codes, categories and themes are compared to the previous iteration and original statement.

An example of the inductive coding process is displayed below in Table 5. During anchor one, participants read about a group of African American high school students that created a water filtration system for contaminated water and as a result were placed in the NASA competition. Participants read about the successes and challenges that the African American high school students faced in relation to their work and their participation in the NASA competition. At the conclusion of the reading, participants were asked to share their thoughts about the reading through answering two prompts presented in the Poll Everywhere app. For prompt 1, participants were asked, “In what ways are their [referring to the S3 group of students engaged in STEM research from the reading] contributions significant to society?” Due to repetitive responses concerning the relationship between STEM representation and gender, participants were asked to share why they thought females were underrepresented. Table 5 displays examples of participant responses. The first iteration of the responses consisted of line by line coding, the second iteration consisted of axial coding and the proceeding iteration consisted of categories.
Table 5.

Example of Inductive Coding Analysis of Discourse

<table>
<thead>
<tr>
<th>Participant’s Statement</th>
<th>Line by Line Coding</th>
<th>Axial Codes</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>“They may have inspired other females to get involved with engineering despite their skin color”</td>
<td>Overcoming racial and gender barriers for STEM participation perceived as inspirational</td>
<td>Sociocultural identities STEM representation</td>
<td>Sociocultural identities related to race and gender impact participation and representation in STEM</td>
</tr>
<tr>
<td>“At only age 17, and black, facing verbal racism and sexism due to being black and females, they created a water purifier to decrease lead pollution in water supplies”</td>
<td>Acknowledgement of STEM contribution while addressing conflict of race and gender</td>
<td>Sociocultural identities STEM contributions</td>
<td></td>
</tr>
<tr>
<td>“Because people think it’s normal to only see male engineers.”</td>
<td>Gender biased normalized in engineering representation</td>
<td>Sociocultural identities norms of STEM representation</td>
<td></td>
</tr>
</tbody>
</table>

Note. The table displays an example of the inductive coding process for participant discourse during the entry anchor of the learning progression.

Thematic analysis was used to capture accounts of participants lived experience. Memos and field notes related to the coding process was documented were handwritten as well as digitally recorded.

**Coding Artifacts.** Saldana (2016) and Marshall and Rossman (2016) note that artifacts require careful analysis because artifacts do not have meaning without interpretation. Gibbs (2007) suggest that coding can be predetermined through deductive methods that are based on a concept or theory. The artifacts in this study were coded deductively using the predetermined codes related to the epistemic practices of engineering. The process encompassed examining the artifact, describing what was seen of the artifact, and applying a predetermined code exhibiting the epistemic practices of engineering. A combination of qualitative memos and field notes were used to determine the appropriate deductive code for artifacts. Figure 5 depicts a visual representation of this deductive coding process of artifacts. Figure 5 displays students work of
EV3 robot programming applications created by participant 1 and participant 2. In this scenario, both participants were given the same EV3 programming problem to solve during the learning activity. Both participants produced EV3 robot programming applications that were different from one another. While the EV3 robot programming applications were different, both applications solved the same problem given to both participants. The participants’ ability to discuss the differences and similarities of their applications during the learning process demonstrated their ability to envision multiple solutions which is an epistemic practice of engineering. Thus, for the artifact demonstrated in Figure 5, the code envisioning multiple solutions (EMUS) was applied during analysis. Field notes and qualitative memos were used during the analysis process to ensure that the artifact was accurately contextualized within the learning activity and to ensure accuracy during the coding process.
**Figure 5.**

*Deductive Coding of Artifacts*

![Deductive Coding of Artifacts](image)

**Qualitative Memo:**

Anchor: Intermediate Anchor

Description of Image: Two participants working next to each other developed different solutions to the same problems and discussed the differences and similarities in their design process.

Epistemic Practice of Engineering: **EMUS - Envisioning Multiple Solutions**

*Note.* The figure above shows the deductive coding process for artifacts with the corresponding digital qualitative memo.

**Coding Interviews.** Inductive analysis was used for coding of focus group interviews and semi-structure interviews. The participants’ open-ended responses were analyzed using constant comparative analysis consisting of multiple iterations of analysis. See Figure 4 for a graphical overview of this process. A constant comparative analysis consisting of ongoing, recursive, and inductive analysis (Strauss & Corbin, 1998) was used to analyze participant discourse. The inductive analysis of participants discourse began with line by line coding to ensure that the meaning of the statement was not lost. Next the line by line codes were collapsed into focused codes, however, they were constantly being compared to the original statement to ensure alignment. Next, axial coding was used to create categories and those categories were
organized and developed into themes. At each phase of this process the codes, categories, and themes were compared to the original statement to ensure alignment. Memos and field notes were reviewed to ensure accurate interpretation reflected in analysis. Using the memos and field notes as an additional datapoint during the coding process of student interviews served as a method of triangulation and greatly strengthened the validity of the data analysis process (Marshall & Rossman, 2016).

**Thematic Analysis.** Braun and Clarke (2006) state that thematic analysis “is a method for identifying, analyzing, and reporting patterns (themes) within data” (p.79). Several iterations of thematic analysis ensued to ensure coherence between all data points (discourse, artifacts, and interviews) to capture an accurate presentation of participants’ perceptions and experiences. Examining patterns across all data points (discourse, artifacts, and interviews) was a significant step in the thematic analysis as Leininger (1985) notes that fragmented data is meaningless when analyzed alone. Qualitative memos were electronically documented during this process to reflect upon and critique the analytical process. Nowell et al. (2017) state for qualitative researchers it is “imperative to conduct it in a rigorous and methodical manner” to achieve trustworthiness and value in regard to the results. Peer debriefing, which is a best practice, occurred biweekly to ensure reliability concerning the analytical approach for this study. During the process of thematic analysis, coding was examined for patterns to create categories, and then categories organized into themes. These patterns were examined and compared to original codes and statements to determine if the themes appropriately portrayed participants’ perceptions and experiences during their engagement with the learning progression. A visual representation of this process is displayed in Table 6.
Table 6.

Thematic Analysis Table

<table>
<thead>
<tr>
<th>Anchor Sub-Research Question</th>
<th>Data Point</th>
<th>Codes</th>
<th>Categories</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>How does the inclusion of learning about young African American student scientists impact the perception of STEM and use of epistemic practices of engineering for African American student participants engaged in engineering design activities?</td>
<td>Discourse</td>
<td>Sociocultural identity</td>
<td>Confronting situated norms related to race and gender for STEM participation and contributions</td>
<td>1. Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contribution (reflected in entry anchor)</td>
</tr>
<tr>
<td></td>
<td>Artifact</td>
<td>IPUM: Investigating properties and uses of material</td>
<td>Multiple cognitive problem-solving skills associated with problem solving.</td>
<td>2. Participants displayed a range of social and cognitive skills related to epistemic practices of engineering during engineering design activities (reflected in the entry anchor)</td>
</tr>
<tr>
<td></td>
<td>Interview Question: What do you think about the African American high school student scientists in relation to you?</td>
<td>MERI: Making evidence-based decisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inspired</td>
<td>Self-Efficacy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased sense of self efficacy based on identity</td>
<td>Identity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motivation to persist</td>
<td>Motivation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Desire to make a STEM contribution</td>
<td>Persistence</td>
<td></td>
</tr>
</tbody>
</table>

Note. This table displays an example of how themes were identified for the entry anchor. This table is not inclusive of all the data that was used to identify the two themes, it merely provides an abbreviated example of how some of the data contributed to the identified themes.

Table 6 displays the overarching and sub research question for the entry anchor and how the categories (that were produced during the coding process across multiple data points) were organized into two themes for the entry anchor. While Table 6 does not detail all of the data that was used to generate themes, it provides a demonstration of how coding across multiple data points was used to generate two themes for the entry anchor.

There were four themes identified using this process of thematic analysis. The four themes that were generated across the learning progression were as follows:

1. Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contribution (reflected in entry anchor)
2. Participants displayed a range of social and cognitive skills related to the epistemic practices of engineering during engineering design activities (reflected in the entry anchor)

3. Participants advanced in self-efficacy, cognitive practices, and epistemic agency as it related to computer programming in response to working with an expert in a community of practice (reflected in the intermediate anchor)

4. Participants raised STEM awareness, stimulated community engagement, demonstrated enhanced cognitive practices, and displayed epistemic agency in their showcasing of their engineering design prototypes for STEM Night (reflected in the target anchor)

The subsequent findings for the entry, intermediate, and target anchor are discussed in chapters 5, 6, and 7, respectively.

Conclusion

This research aimed to highlight and present student experiences in an effort to explore in more depth the learning processes by which African American participants develop epistemic agency as STEM learners. The methodology in this study was significant in producing data that informs the pedagogical practices of researchers and teachers as it relates to how to explicitly identify and formatively assess students’ epistemological development. This research-based methods used in this study enable me to explore participants’ development of epistemic agency as STEM learners as they engage in engineering activities across a learning progression designed to advance the epistemic practices of engineering.
Chapter 5: Findings for Entry Anchor

This chapter details the findings reflected in thematic analysis of qualitative data from discourse, artifacts, and observations during engineering activities for the entry anchor. The curricular objectives and engineering activities within the entry anchor centered the progression of identity development for epistemic agency through the cultivation of the epistemic practices of engineering.

Research Questions for Entry Anchor & Emerging Themes

The overarching research question for this study was as follows: What epistemic practices of engineering do student participants demonstrate in their artifacts and discourse when engaging in engineering activities within and across all three anchors of a learning progression designed to develop epistemic agency for STEM learners? The sub research question for the entry anchor was as follows: How does the inclusion of learning about young African American students engaged in STEM research impact the perception of STEM and use of epistemic practices of engineering for African American student participants engaged in engineering design activities?

There were two salient themes that were identified from discourse and artifacts during the activities in the entry anchor. The two emerging themes were as follows:

1. Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contributions.

2. Participants displayed a range of cognitive and social skills related to the epistemic practices of engineering during engineering design activities.
Theme 1: Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contributions

During the entry anchor, participants read about three African American high school students engaged in STEM research that created a water filter which decreased lead pollution and were placed in competition for NASA in recognition of their work. Participants were led in an activity in which they were prompted to share their thoughts about the article. The question posed to participants for prompt 1 was, “In what ways are their [referring to students engaged in STEM research] contributions significant to society?” Participant responses indicated that they equated the significance of STEM contributions with being an inspiration while confronting issues associated with race and gender regarding traditional STEM representation. One participant stated the significance of the societal contributions of the students engaged in STEM research as follows: “They gave us a way to filter dirty water and exposed racism in front of society.” Another participant stated, “They may have inspired other females to get involved with engineering despite their skin color.” Another participant stated, “They are providing a way to clean water. They are also becoming role models for other girls that might want to become engineers. They are paving a way for future African American girls and women to become successful in STEM.” Another participant stated, “At only age 17, and black, facing verbal racism and sexism due to being black and females, they created a water purifier to decrease…pollution in water supplies.” Another participant stated, “They … inspired other black girls to take on STEM projects.” Because I observed a pattern in participant responses related to race and gender in relation to the STEM contributions of the students engaged in STEM research, I asked why they thought African Americans and women were underrepresented in
STEM. Pierre responded, “Because white people think that they are smarter than us…people think it is normal to only see male engineers.” During a focus group interview conducted with seven students, I also asked participants how does seeing young students engaged in STEM research impact their conceptions of STEM. I asked this question during the focus group interview to understand the impact of learning about these young STEM researchers on participants’ identity and efficacy during the entry anchor activities. Participants indicated during the focus interview that seeing young scientist was instrumental for motivation, inspiration, and self-efficacy. Brandon stated, “I think it is motivational to see stuff like this because it motivates me to keep going in STEM.” Bernard stated, “It makes me think like if they can do it, I can do it!” The other participants in the focus group verbally agreed with their classmates.

For prompt 2, participants were asked, “What tools do you need to make contributions to society and what would you contribute?” Participants identified dispositions of persistence and diligence as critical components needed to make STEM contributions. One participant stated, “You need determination, drive, grit, and the right mentality. I could contribute a unique view on problems that could help others to figure out how to solve the part they are stuck on.” Another participant stated,

You would need to be driven towards your goal and never give up and always see through your ideas. When contributing to society, you will not always succeed the first time, so you have to keep going and have a supportive strong-minded group around you.

Participants also noted the significance of being in community in regard to making STEM contributions. One participant stated that they would need to be around “Supportive people with the same ideas.” Another participant stated that they would need, “Money support, and a team. I
would create a car that could be driven from any seat.” When I read one of the participants’ responses that stated “… I would create a car that could be driven from any seat” I asked the participant to share and explain their idea in more detail with the class. Because the responses were anonymously submitted during this activity, I did not know which ideas belonged to the participants. To my surprise a girl, Chelsea began to explain her idea about how the steering wheel in the car would be able to move electronically throughout the car. A male participant listening to Chelsea’s idea remarked aloud, “What? That’s a dumb idea!” Then I interjected and said,

Actually, that idea is very creative! That idea [pause] well a derivation of that idea already exists on a concept car. Do you all know what a concept car is? It’s pretty much a futuristic car. Next class, I am going to show you something very similar to Chelsea’s idea. This car has a moving steering wheel, so her idea is actually kind of fly! You need people like Chelsea. These types of people think outside of the box. Next semester you will have to build a whole robot for competition, and you will need to think outside of the box.

Chelsea pointed to herself, looked around the class, and remarked, “Yeah, y’all gone need me!” The male participant that called her idea dumb then stated, “Chelsea, you can be on my team!”

Following that dialogue participants continued to share their vision for their STEM contributions noting the significance of resources. One participant stated, “You would need money, but I would start a farmers market in the black neighborhood for black people’s health so that they would live longer.” Another participant stated, “I would like to contribute power savings plants in my community. I would need many solar panels and energy saving materials.” The participants brainstormed several solutions related to STEM contributions that could impact
their community. This brainstorming process encompassed verbal expressions regarding their sense of self in which they perceived themselves as capable of imagining solutions which served to affirm their identity and self-efficacy in STEM.

**Theme 2: Participants displayed a range of cognitive and social skills related to the epistemic practices of engineering during engineering design activities**

Following the discussion regarding STEM contributions, participants completed the “Brita Water Filter Challenge” in which they designed a water filter. The purpose of prompt 3 was to observe and evaluate how participants displayed and engaged in the epistemic practices of engineering through discourse during the “Brita Water Filter Challenge.” For prompt 3, participants’ discourse displayed a range of epistemic practices of engineering. Some of the practices displayed included *carrying out investigations* and *making evidence-based decisions* as a result of *investigating properties and uses of materials* through iterative testing. During my observation of participants building a water filter prototype, Melanie stated, “Oh my god! Our water! It’s coming along! It’s coming along! But it’s like…[pause] we need more cotton balls. We need to add an extra layer. We need to remove the rocks.” Jon responded and stated, “Yeah…at the bottom we tried the rocks at first, but a lot of stuff fell through.” Participants were constantly evaluating their decisions to use certain materials in response to the filtration effects of the materials on various components in the dirty water. Another epistemic practice of engineering entails *applying scientific knowledge to problem solving*. During the activity, Allen reflected on a scientific reference that influenced the construction of their prototype. Allen remarked, “Ms. Duke, let me tell you about my idea for our water filter! See I thought about ground water in the water cycle for our design. We got a good concept going.” This participant was referring to the concept of percolation of water during the water cycle similarly to how the
water was moving through the filter. Participants were actively engaged in including experiences that reflected their prior knowledge in an effort to make sense of the new experience of making a water filter.

Another epistemic practice of engineering that was demonstrated during learning entailed seeing themselves as engineers which is a critical component of the social practice of engineering. Through discourse, participants demonstrated that they personally saw themselves as valued contributors as well as seeing each other as valued contributors during the engineering design challenge. During the testing of the filters Aisha noticed Melanie’s water and asked, “How did you get your water so clear?” Melanie responded, “Because I am a real scientist that is how! Brita would be so proud!” Aisha, Melanie, and I looked at each other and smiled. At the conclusion of the activity, Aisha looked at all of the water filter prototypes and stated to me, “Oh, I am so proud of them. Wow we have some brilliant minds in here. They are really going to make some great contributions to the world!” Negotiating identity within a social context is necessary to enhance self-efficacy for participating in the knowledge building process via the epistemic practices of engineering.

While the participants were eagerly engaged in the engineering design process and were exhibiting a range of the epistemic practices of engineering in their discourse, their activity sheets did not mirror their discourse. Because participants had no pre-exposure to engineering nor the engineering design process, they demonstrated a novice level of the epistemic practices of engineering through documentation during this phase of learning. The activity sheet that was used was a seven page data collection sheet that procedurally and systematically outlined the engineering design process for iteratively testing materials, creating models, and building and modifying the water filter using evidence-based reasoning. While the activity sheet presented a
highly structured layout, none of the groups completed the sheet beyond the second or third page. Participants were highly engaged in the iterative testing of materials demonstrated in the images shown in Figure 6. In the image shown in Figure 6, participants were actively engaged in strategic testing of various materials to determine the filtration effectiveness.

**Figure 6**

*Participants Engaged in the Engineering Design Process of the Brita Water Filter Challenge*

Note. The participants were engaged in testing materials to determine the effectiveness of various materials such as small rocks, coffee filters, cotton balls, etc.

Figure 7 reflects participants testing coffee filters in combination with other materials. As participants were engaged in creating and testing their proposed designs, they were constantly comparing the color and visibility of the dirty water to determine the filtration effectiveness of their design. Participants continued to demonstrate the practice of *making evidence-based decisions* during this process.
Figure 7

Participants Engaged in The Iterative Process of Testing and Evaluating the Effectiveness of Filters

Note. The participants were examining the filtering properties of various materials and comparing water clarity to determine the effectiveness of different materials for filtering substances.

Per the directions on the activity sheet, the participants began testing and documenting their process. However, once they understood the iterative process of testing materials, they abandoned the procedural guidelines related to documenting each step of the engineering design process. While I provided procedural instructions regarding documentation during this activity, participants may have not understood the value and practice of how engineers document their process and findings. The lack of documentation on the activity sheet demonstrated that participants placed value on the process of building a prototype versus engaging in documenting practices associated with engineering. In this way, participants exhibited the epistemic practices of engineering as it pertained to carrying out an investigation, investigating properties and uses of materials, and making evidence-based decisions, however, they were not as successful in communicating the results during the documentation process.
The activity sheet provided procedural directions for engaging in the engineering design process, however, the questions on the activity sheet also engaged participants in the use of science practices. The first prompt in the activity sheet required participants to make an observation. In Figure 8, the participants drew a picture of their dirty water in the jug, however, they did not provide a qualitative description of their dirty water. The purpose of providing a qualitative description was to aid participants in making an informed based prediction through reasoning regarding which materials would be most effective at filtering particular contaminants in their dirty water.

Figure 8

Data collection Activity Sheet for the Brita Water Filter Challenge

Note. This figure shows the group work of 10th grade participants during the engineering design challenge.
The next prompt on the activity sheet in Figure 8 required participants to make a prediction about the filtration properties of the materials. Making a prediction is another science practice that complemented the engineering design process during this activity. In Figure 8, the participants made a prediction that the “cotton ball will remove most of the dirt.” This prediction is sound and encompasses reasoning based on the participant thinking about physical properties of cotton balls. On the following page the participants drew significantly more detail of their filtration system, however, they did not complete in other prompts on the activity sheet. Figure 8 displays participant work from a group of 10th graders.

The demonstration of science practices in relation to epistemic practices of engineering varied across participant groups and grade level. In Figure 9, the 11th grade participants provided a qualitative description along with their drawing of their dirty water. In addition, one the participants of that group included a description of what he saw and smelled as it related to the dirty water. Providing the qualitative detail of the water is significant to purposefully selecting and evaluating materials during the engineering design process.
Figure 9

Data Collection sheet for the Brita Water Filter Challenge

Note. This figure shows the group work of 11th grade participants during the engineering design challenge.

In Figure 9, the participant provided significantly more detail for their prediction in writing, “I predict that the assembled filter will remove the large particles, such as grass, and chunks of dirt and potentially make the water seem visible.” While the participants have significantly more detail regarding their prediction, they are making a prediction in reference to
the layered filtration system instead of the individual material. Additionally, the 11th grade participants also provided significantly more detail as it pertains to the layers of their filtration design on the next page of their activity sheet. While this group seemed to be more engaged with the written documentation of the engineering design process, they eventually stopped documenting their process in similitude to other groups.

Documenting the process is a significant practice in engineering as it relates to communicating effectively and is crucial to authentically engaging in both science practices and engineering practices. Communicating effectively not only entails exhibiting people skills within the social practice of engineering but also encompasses communicating findings across the discipline on which research (the second step in the engineering design process) is dependent.

At the close of the activity the participants exhibited success in filtering the contaminants and improving the visibility of the water. Figure 10 displays four different water filter designs for four different groups. Additionally, each groups image includes a before and after of the dirty water as compared to the filtered water. In Figure 10, the participants that experienced the most success in water clarity were the 10th graders (Group 3) despite their limited documentation. They achieved their results by adding additional layers of cotton balls throughout their design inside of the coffee filter. In summary, the activity sheets do indicate that participants were actively engaged in carrying out investigations, investing properties and uses of materials, constructing models and prototypes, working effectively in teams and a host of other performance expectations associated with the epistemic practices of engineering.
Figure 10

Participant Water Filters: Before Filtration and After Filtration

Note. This figure displays four water filters constructed by four different participant groups. Each group shows the water before filtration and after filtration.

The Brita Water Challenge enabled participants to learn about the engineering design process as well as perform the epistemic practices of engineering related to problem solving. Because the engineering design process was made explicit, in that it was shown in diagram and discussed, participants understood that the construction of a prototype occurs through a series of
steps. Because the epistemic practices of engineering were not made explicit, some participants experienced dissonance between how science practices compliment engineering processes.

During a focus interview with seven students at the conclusion of the entry anchor, I sought to understand participants personal agency around learning about STEM and more specifically engineering. I asked participants why they continued to attend the after school sessions. One of the participants commented that they “love engineering” because he loves that “you get to build stuff,” however, he indicated that he is not as enthusiastic about science. This statement indicates that participants may not understand the vital connection between the two disciplines in practice, as scientist also “build” models and models are crucial to building prototypes. I asked the participants, “How do you think what you did during the “Brita Water Filter Challenge” is similar to what actual engineers do every day…” to which Bernard responded, “It is not even close to what engineers do every day … engineers use a lot of technology to make it easier.” In one regard the participant had a point in terms of using technology, however, because the epistemic practices of engineering were not explicitly presented to participants, it may have hindered some of them from seeing the connection between their experience and engineering practices demonstrated within the profession. In contrast, Melanie stated, “I think it is like what engineers do because you had to come up with a system and a method to make it.”

During the focus interview, many of the participants overwhelmingly discussed their conception of engineering in relation to the “The Brita Water Challenge” noting that there were “so many steps!” Chloe stated, “Engineering sounds really fun, but it comes with a lot of thinking.” Chloe’s statement about engineering was significant because prior to this activity some of the participants discussed their conception of engineering as being a series of “…hands on activities” which is not a truly accurate depiction of engineering. The findings for prompt 4
provide justification for modifying instruction to facilitate the development of science practices to strengthen the understanding of the epistemic practices of engineering prior to engaging in the engineering design process. While participants had varying perceptions of what engineering was, they still displayed a desire to learn about STEM and specifically engineering.

The data from the focus group interviews reflected that participants were still developing in their understanding of engineering processes and practices. Additionally, creating a series of sub-lessons that explicitly teach the epistemic practices of engineering prior to the entry anchor would be useful for participants. In this way participants will not build a prototype without an understanding of the epistemic practices that produce the prototype. Enhancing participants understanding and mastery of the epistemic practices of engineering in which they understand the tools and ways of knowing that produce knowledge is key to participants adapting the practices for their own purposes which is vital to them exercising epistemic agency as STEM learners.

The findings from the entry anchor reflected in discourse and artifacts indicate that participants were learning about engineering and engaging in the corresponding practices as novice learners which is aligned with the first phase of the zone of proximal development. The first phase or entry phase into the zone of proximal development is a phase of learning in which knowledge, skills, and practices associated with engineering was out of reach due to limited STEM exposure. The activities were designed to pair meaningful learning as it related to engineering design with aspects of socialization whereby students’ identities and personal sense of self efficacy were enhanced through interacting with their community of practice. Participants progressed in their knowledge about engineering as well as their understanding of what processes enable engineers to build prototypes. For example, during the first lesson when I asked
participants to tell me about what they know about STEM, Keith stated, “I know the S and the T but I don’t know about the E.” By the end of the entry anchor, Keith not only engaged in the engineering design process and associated practices he was positioned to envision himself as a valuable contributor to STEM and his community early on in the lesson of the entry anchor.

**Teacher Researcher Reflection**

During instruction for the entry anchor, there were several experiences that caused me to engage in pedagogical reflection as it relates to the social and cognitive dynamics of learning. During the past four years, the instructors in the program and I would use a bottom up approach which entailed examining participant performance across the learning progression to assess what critical components would be needed to enhance participants’ engineering knowledge and practice of the engineering design process in relation to building a prototype. From a researcher standpoint, I sought to enhance their performance through positively repositioning their identity and sociocultural association with STEM in addition to introducing them to practices associated with engineering. From this context, I designed the first anchor of this learning progression to create a learning environment in which the participants could see themselves as potential engineers by showcasing young African American scientist that were of the same race and around the same age as them.

Upon the participants providing their perspectives of the young African American scientist, topics of gender repeatedly surfaced which was unexpected for me, as my sole intention was for participants to see racial representation of themselves as well as age. Their responses during instruction caused me to think about the various ways that I had overlooked my own identity at the intersection of race and gender during this process and did not consider how it could have impacted the learning environment. The class discussion with the participants, in
which they clearly referenced both race and gender in terms of STEM participation, caused me to question whether or not my identity had any impact on the enrollment of female participants this year, as previously the instructors were male. The role of identity continued to be salient as participants engaged in the engineering design activity. Once more, the curricular design was structured to influence their sense of self through showcasing representations of African American scientist, however, what I observed was how impactful their sense of self was influenced by each other. This phenomenon not only caused me to reflect upon how knowledge is constructed within a learning environment but how identities both in terms of individual identity and group identities are also co-constructed during the learning process. Repositioning their identity not only entailed focusing on how they saw themselves as producers of knowledge, but also entailed how they saw each other as producers of knowledge during the learning process. Instructionally, this caused me to reflect upon the significance of fostering a learning environment in which each participant has epistemic credibility during the learning process in addition to displaying racial and gendered representation in STEM. As a result of my observations of the social dynamics of learning during the entry anchor, I expanded my instruction to prioritize greater collaborative learning during the intermediate anchor. This instructional practice of prioritizing more collaborative engagement of participants was directly aligned with my desire to research and explore the community of practice within the curricular design of the intermediate anchor.

While the social dynamics of learning provided many facets on which to reflect upon, the experiences during instruction related to cognitive development provided immense pedagogical insight. Instructionally, I assumed that because I made the engineering design process explicit that participants would be able to understand how their practices were aligned with what
engineers did, however, a better pedagogical strategy would have been to have them identify which practices they used during the engineering design activity that is like the practices that engineers do every day. Additionally, upon examining the data from this anchor my instructional recommendations for myself are to revise and expand this lesson over the course of several days with added components to enhance science practices in addition to introducing the epistemic practices of engineering. If the goal is to truly reposition them cognitively to become producers of knowledge, I think it is vital for participants to understand the nature of engineering in relation to how knowledge is produced through the epistemic practices of engineering in the same way that they come to understand the nature of science by exploring practices that enable scientists to engage in inquiry.
Chapter 6: Findings for the Intermediate Anchor

This chapter details the findings reflected in thematic analysis of qualitative data from discourse and observations during engineering activities across the intermediate anchor. The curricular objectives and engineering activities within this anchor centered the development of knowledge, skills, and epistemic practices of engineering through working in a community of practice with a local computer scientist. This anchor within the learning progression was designed to progress participants into the second phase of the zone of proximal development in which they worked with a more knowledgeable other or expert (computer scientist). Working with a more knowledgeable other was key to cultivating the enculturation of participants into a community of practice for computer programming for EV3 robots. This chapter provides an overview of thematic findings. Following the presentation of results, a pedagogical reflection for action research is presented.

Research Questions for Intermediate Anchor & Emerging Themes

The overarching research question for this study was as follows: What epistemic practices of engineering do student participants demonstrate in their artifacts and discourse when engaging in engineering activities within and across all three anchors of a learning progression designed to develop epistemic agency for STEM learners? The sub research question for the intermediate anchor was as follows: How do African American students engage in the use of epistemic practices of engineering when exploring engineering activities in collaboration with a local computer scientist and how is their sense of identity and efficacy impacted during the intermediate anchor? There was one salient theme that was identified from observations, discourse, and artifacts during the activities in the intermediate anchor. This theme was as follows: Participants advanced in self-efficacy, cognitive practices, and epistemic agency as it
related to computer programming in response to working with an expert in a community of practice. The next section will discuss the findings in detail as it relates to the theme.

**Theme 3: Participants advanced in self-efficacy, cognitive practices, and epistemic agency as it related to computer programming in response to working with an expert in a community of practice**

At the onset of the activity, Mr. Davis continually positioned the participants’ identities as programmers with the ability to produce unique contributions via programming applications. Mr. Davis stated the following,

So, in programming, all of you are programmers, a programmer writes algorithms. Here is an algorithm that I want. Then it is converted into a program, and then the program is run on a computer. The most important concept of that is the algorithm. It is your solution. If I told everyone in here right now to write out the steps in order to brush your teeth everybody would say do this first, do this second, do this third. Now, I can guarantee you that no one will have the same algorithm. They would be similar, but I may do one step before you do another step. Does it make my algorithm wrong? No. It is just my algorithm. The beauty of programming is most of the time your algorithms are unique. So, in my class when students copy, I know that they copied because you don’t think like that person. We don’t think alike. We may think similarly, but we don’t think alike or identical.

As Mr. Davis explained introductory knowledge related to programming applications, explanation of algorithms, and the role of computers, he also set a tone for the learning environment that positioned the participants as present and future contributors. The participants
were extremely engaged and intently listening. Mr. Davis continued to position them as programmers during instruction in stating,

> So as a computer scientist, I’m doing a little bit of recruitment. I focus on critical thinking and problem solving. You can apply critical thinking and problem solving in anyone of your classes. That is what people are looking for. They are looking for people who have solutions to problems. You can find any person on the street and say hey I need you to go and do this. But they are looking for the individual that they can say here is the situation; can you give me a solution that I can use to help in this situation. That means that you are thinking! They are looking for those. So, we want to be a creator instead of a worker. Workers are good too, but we want to be the ones that are creating the actual applications as opposed to the one who is actually using it.

Referring to the participants as programmers during instruction projected a social and cultural context of learning that positioned the participants to see themselves as capable of achieving cognitive development related to computer programming. For participants their identity and ability to fulfill robot programming tasks was affirmed by an expert in the field. Mr. Davis stated, “Once you learn the basics and learn how to develop your own solutions, you will be able to make these robots climb the walls. I really believe that!” Mr. Davis proceeded to give participants verbal instructions that were simple computer programming task for the EV3 robot. The first task that Mr. Davis requested was to program the robot to display “good afternoon across the screen” and also to make the robot verbally say “hello!” The participants began to work on designing solutions for the programming task. As the participants heard their robot say hello in response to their programming application, they all were smiling and laughing. The
verbal instructions allowed the participants to become familiarized with the software. Starting
with simple tasks allowed the participants to have positive experiences with achievable task
which was key to sustaining participants persistence and motivation during learning.

Mr. Davis explained to them that their robot’s performance will only be as good as the
computer programmer. Mr. Davis’s statement regarding the connection between computational
input and output resonated with many participants. As participants began completing verbal
computer programming task, some of them expressed frustration during this problem solving
activity. One participant, when the robot did not do what he expected, shouted, “Man, what is
wrong with this thing [referring to the robot]!” Denise a few seats over looked at him and stated,
“Remember, it’s not the robot’s fault, it’s you! You got to program it right.” As the evening
continued, participants viewed the robot’s performance as an assessment of their programming.
As the participants continued to work, Mr. Davis later provided the participants with an activity
sheet that had a list of robot tasks. Figure 11 displays the activity sheet with programming tasks
that participants checked as complete once their robot performed the scripted tasks.
Figure 11

*EV3 Robotics Programming Activity*

Note. This figure shows the programming task for the EV3 programming activity. This figure shows the participants progress in completing the programming task indicated by checkmarks.

As participants engaged in completing the tasks, a series of cognitive practices associated with problem solving and persistence during learning emerged.

As previously discussed, the question guiding my observation of participants’ discourse and behavior during the EV3 programming activity was, “What epistemic practices of engineering emerged in participant discourse and behavior as participants engage in the EV3 Programming Activity?” The guiding question for my observation enabled me to assess if the curriculum produced learning experiences that were in alignment with practices that engineers demonstrate in authentic contexts. While the EV3 computer programming design activity in the intermediate anchor was different from constructing a water filter during the entry anchor, the application of iterative testing as a means of developing an efficient prototype was the same. In this case the engineering prototype was the programming application. Thus, the epistemic practices of engineering associated with *envisioning multiple solutions, persisting and learning*
from failure, and working effectively in teams surfaced during the learning process. Many of the epistemic practices of engineering were expressed in discourse during their engagement with the programming design activities.

Participants experienced a learning curve in developing their fundamental understanding of EV3 programming. When participants were challenged with completing a particular task, they did not resort to copying each other’s application to bypass the challenge. Devonte shouted, “Man, I don’t know what I’m doing wrong. I don’t know…” to which Brandon responded, “Hold on, start your robot and let me see. I’ll help you figure it out.” The process of “figuring it out” included a series of iterative steps which entailed participants examining the robot’s execution of the task, discussing what the robot was supposed to do, skimming the programming application for errors, and redesigning the program in response of the identified errors. After examining the robot’s execution of the task and skimming the programming application, Brandon proceeded to ask him questions and suggest different ways to think about how to make the robot complete the desired task. All of the participants were programming their robots to complete the same task via the same activity sheet, so Brandon could have simply looked at his computer screen and explained to Devonte how he programmed his robot and instructed him to copy his codes. Instead, he looked at Devonte’s solution and assisted him with his idea reflecting their understanding that the programming task can have multiple solutions.

Participants occasionally walked over to other groups during this process and conversed about how they programmed their robot to complete task associated with getting the robot to turn in opposite directions or make 90 degree turns along with other series of tasks. Through their conversations they discussed multiple ways to get the robot to do the same things with different solutions. On the activity sheet, task 10 states, “Wait for the center button is pressed on the EV3
brick, then move forward until the robot is within 15 cm of an obstacle, then move backwards until the robot is 30 cm from an obstacle.” While participants had the same command or tasks, the solutions that participants created were different. Figure 12 compares two images of two different programming solutions created by different participants.

**Figure 12**

*Participants Demonstrate Multiple Programming Solutions*

Note. The figure displays programming solutions for task number 10 shown in Figure 10. Participant 1 created a different solution from Participant 2.

In Figure 12, participant 1 designed a linear step by step process in terms of moving the robot forward and sensing the environment separately, whereas Participant 2 added a “repeat until” command that loops the robot’s forward movement with sensing the environment. Additionally, Participant 1 programmed the robot to move forward for 60 seconds, whereas Participant 2 commands the robot to move at 20 at 20% speed. Participants were able to reflect upon what Mr. Davis stated during their introduction to programming when he said, “The beauty of programming is most of the time your algorithms are unique…. We may think similarly, but we don’t think alike…” This statement positioned participants to demonstrate the epistemic practice of engineering related to *envisioning multiple solutions*. The multiple solutions also served as an
expression of their unique contribution that affirmed both their identity and personal sense of efficacy during this learning process.

As participants engaged in envisioning multiple solutions related to their programming applications, they also grew in their understanding of developing processes to solve problems which is another epistemic practice of engineering. As I walked around monitoring the participants’ progress, I noticed Kia staring at her screen intently. I asked her what was going on and she stated, “What did I do? I cannot remember the programming that I did to make it turn around in the opposite direction.” I proceeded to look over her programming application. I had very limited knowledge because I did not have any experience with EV3 programming prior to this experience, so I asked Mr. Davis to assist Kia. Mr. Davis said to her, “Sometimes you have to break up the problem into parts to come up with a solution.” Kia began thinking about what the robot was tasked to do per the instructions on the activity sheet. She started breaking the task down into steps on her paper and designed a program in accordance with what she had written on her paper. She continued working until she programmed the robot to complete the task that was required on the activity sheet which was different from the solution that she had before. In addition to completing the tasks on the activity sheet, Kia began to come up with programming tasks outside of what was required on the activity sheet and then she devised steps to solve the problem. This activity positioned her to express autonomy and advance her sense of self-efficacy during the knowledge building process.

During the learning process, participants personal identity was influenced during the programming session. At the conclusion of the first night of programming, Keith walked up to Mr. Davis and asked, “So, what would I need to do to get into programming?” Although Keith and Devonte had experienced challenges that evening while programming the robot, Keith’s
sense of identity and sense of self-efficacy was enhanced enough for him to see himself as being capable of majoring in computer programming. Mr. Davis began explaining what type of courses he would need to take and what it was like to be a computer programmer. Keith’s behavior was aligned with the epistemic practice of engineering that indicates the significance of identity construction noted as seeing themselves as engineers (in this seeing themselves as a case computer programmer).

Another epistemic practice of engineering that was observed in the student participants’ discourse was persisting and learning from failure. All participants were significantly challenged during the second session of the EV3 programming activity; however, they were extremely engaged despite their frustration. Devonte and Keith called me over to demonstrate their robot. During the demonstration, the robot did something unexpected and Keith threw up his hands and stated, “It didn’t turn. It won’t turn. It turned but it didn’t turn back this way.” Keith and Devonte proceeded to look over the programming for about ten minutes or so and located and fixed the error. They called me over to demonstrate their robot. When they demonstrated their robot again it worked, they gave each other a high five and smiled. Engineering solutions in authentic contexts are typically the result of collaborative effort. Positioning participants to co-construct knowledge is significant to participants negotiating their identity as problem solvers and valuable contributors both collectively and individually.

As participants worked on the tasks, they expressed frustration yet demonstrated persistence. One of the participants, Aaron remarked, “I give up! I quit!” and walked away from his computer. Later, he returned to his computer and continued working. Once he completed the programming task, he called Mr. Davis over to demo his robot. I walked over with a smile and said to Aaron, “I thought you quit, what happened?” He responded, “This is hard, but I had to
figure it out.” Aaron’s frustration and desire to quit indicated that the task encompassed a range of difficulty that was beyond current knowledge and skills. However, Aaron’s personal desire for mastery of the task motivated him to persist during this learning process.

During a semi-structured interview, I asked Aaron about how he navigated the complexities of learning EV3 programming to gauge his sense of self-efficacy. I asked Aaron, “What did you think the very first day when you saw me lugging all those robots into the room?” He stated, “I thought to myself [pause] I’m going to be struggling. But I’m learning. It’s not that bad!” Aaron demonstrated a cyclical phase of learning in which he perceived that he could not complete the task to persevering in completing the task while acquiring new knowledge and skills.

As participants demonstrated persistence and learning from failure, they were also growing in their personal sense of self-efficacy. I wanted to understand how students were evolving in their perception of self during learning. During a semi-structured interview at the end of the night I asked Aisha, “Well what do you think so far? How do you think you did tonight?” She replied,

I think I did pretty good tonight! I wish the computers wouldn’t keep freezing up because it kind of discouraged me. I was really getting it and then it stopped. But I don’t blame that on the programming, it really was the computer. I feel really good though! It was fun to actually see what I did. I don’t know how to explain it. It was crazy to see how I could put out some commands on this computer and then it works all the way over there [pointing to the robot].

I also interviewed Bernard in order to understand how his perception of self was impacted during learning. I asked Bernard what he thought about the computer programming session, and he
stated, “This is showing me that I can do anything that I try.” Participants’ responses indicate that they were growing in their perception of their ability to complete the programming tasks.

The social dynamic and epistemic practices of engineering related to working effectively in teams was a significant finding during all computer programming sessions. During the learning process, the more difficult the challenges became the more the participants began to rely on each other as a community of practice. During my observation, I noticed that the participants rarely asked for assistance from Mr. Davis nor me. Instead, they assisted each other and were invested in each other success. Keith and Devonte called me over to demonstrate their robot. Aisha was working with them although she was in another group. When Devonte and Keith demoed their robot again, it did not perform the task as expected. Aisha stated, “What why? I can’t understand why their robot did that? They had it right. It was working right. I just want to know why.” She stayed around that group until they fixed the programming issue. She was invested in their mastery of the task. I went back to check on Aaron who was assigned to work with Brandon and found him sitting and working with Bernard. Figure 13 shows Aaron sitting between Brandon (his assigned group partner) on the left and Bernard on the right. Figure 13 also displays Aaron migrating over to Bernard to talk through Bernard’s EV3 programming application. Aaron had gone from stating that he was going to “quit” to persisting and learning from failure as well as assisting others reflecting the epistemic practices of engineering associated with communication and working effectively in teams.
Although I placed participants in groups of two, they adapted their own fluid model of group learning. Because of my observations and reflection during the entry anchor concerning how participants perceived each other as contributors, I allowed them to continue to submerge themselves in peer instruction. Mr. Davis noticed that many of the participants were working across groups, and he told them to go back and work with their assigned partner. I walked over to Mr. Davis and asked him to allow the participants to support each other as they go through the learning process. Mr. Davis later spoke with me about how I provided instruction to the participants. He stated, “You are so positive with them, and you are always telling them that they did a great job. At times I wondered, should I be like that with them?” I explained my perspective to Mr. Davis. I believed that having a positive and affirming environment was crucial for participants because they were encountering a new challenge. Participants were also
developing in range of skills and knowledge as a result of peer instruction. They were becoming the more knowledgeable other for each other across their zone of proximal development.

As the participants were advancing in knowledge and skill in EV3 programming, in preparation for the target anchor, I made the announcement that we would be conducting our annual STEM Night and that they would be making presentations to the local community. Denise shouted, “We have to present this to our parents and teachers? Oh my gosh, I can’t do this!” I then explained to participants that not only would their parents be there, but I invited the superintendent, principal, and instructors in addition to people in the community that may not know about the robotics program. Denise was nervous, however, during the following session she came to me and stated, “Okay, I want to be the class representative for STEM Night!” I said, “Well you can welcome all of the parents and guests. And you know what? You can actually lead the parents in an activity!” I then began explaining that she would have to teach the parents the difference between machines, robots, and artificial intelligence. Denise said, “Okay, I’ll be ready!”

The positive experiences that Denise experienced were critical to her identity, self-efficacy, and personal agency. As Denise continued programming that evening, she began to experience challenges to which she looked at me and stated, “I don’t want to be the class representative anymore.” However, as she persisted beyond the programming challenges and experienced success with completing the tasks on the activity sheet, she came back to me and said, “Okay, I’m still the class representative!”

A new girl who was in ninth grade entered into the classroom during this session. I introduced her to the class collectively, however, Denise quickly walked over to her and introduced herself and stated, “Hey, I am the class representative! If you need anything you can
come to me, and I will help you.” When the new girl came into the class, she was extremely shy and did not want to program by herself. I told her that she and I could go to a computer, and I would show her how to program by herself so that she could have enough skill to join other groups after learning the basics. I asked her if she wanted to learn programming with me, and she told me that she just wanted to watch. I said, “Okay but eventually you will have to learn how to program.” Before the evening was over, Denise helped her to acclimate to the classroom learning environment and she started to participate in the programming activities. Denise's personal sense of identity was critical to her sense of agency in enculturating the new participant into the community of practice.

The intermediate anchor evoked the use of various cognitive practices as it related to the epistemic practices of engineering such as envisioning multiple solutions as well as persistence and learning from failure. The findings from this anchor not only depicted how participants engaged in problem solving but this anchor also depicted how their cognitive development included the transformation of their identity and self-efficacy as they engaged in a community of practice. Thus, participants saw themselves as capable contributors and displayed a range of the epistemic practices of engineering such as working effectively in teams as well as seeing themselves as engineers. During this anchor, the demonstration of epistemic agency (in which participants took control of the knowledge building process) was mediated through their community of practice. Participants were introduced to programming by Mr. Davis and myself, however, they relied on each other to build knowledge and skill. The participants’ display of community of practice is aligned with the second phase of the zone of proximal development in which people develop individually in identity and personally as it relates to self-efficacy in response to social interactions that occur with each other and the expert in the field.
Teacher Researcher Reflection

The intermediate anchor encompassed a variety of instructional insights concerning how learning occurs within a community of practice. Perhaps one of the most striking discoveries during the entry anchor was the social impact and influence that participants had on each other during the learning process. While I designed the entry anchor to cultivate identity and efficacy through introducing them to young African American students engaged in STEM research, there greatest source of motivation was each other. Thus, during the intermediate anchor I allowed for less structure for how participants interacted within and across their groups during the learning process. I also structured continual dialogue and class discussions across each phase of the lesson so that participants could be attuned to the voices and views of each other in the classroom.

Participants mediated much of their learning within their community of practice which caused me to profoundly reflect on participants statements made in the previous anchor. During the entry anchor participants noted the significance of persistence and being in community when asked about what components were needed for them to make STEM contributions. The implication of their idealized statements from the entry anchor were actualized during the intermediate anchor. During the entry anchor one participant stated, “You would need to be driven towards your goal and never give up and always see through your ideas. When contributing to society, you will not always succeed the first time, so you have to keep going and have a supportive strong-minded group around you.” Embedded within this statement are ideas about persistence and being in community with resolute individuals which were reflected in the intermediate anchor through their community of practice. Another participant stated during the entry anchor that in order for them to make a STEM contribution they would need to be around “Supportive people with the same ideas” while another participant stated that they would need...
“…support and a team.” While I theoretically understood the significance of the social constructivist approach to learning, it was fascinating to observe this phenomenon in practice in the classroom.

Pedagogically, I recognized that participants ebbed and flowed across the zone of proximal development. It was evident that participants persisted during the EV3 robot programming activity. Participants expressed frustration and motivation during the learning process. Aaron in one moment professed that he would quit while in another moment achieved success in relation to acquiring skill and knowledge. There were moments during the activity when participants worked unassisted during the learning process and other moments when participants required assistance or scaffolding from Mr. Davis or their peers. The intermediate anchor demonstrated that learning does not occur in a linear path rather participants ebbed and flowed cognitively across the zones of proximal development as they progressed to more independent learning. Their discourse and behavior indicated that their sense of self-efficacy was enhanced and were demonstrating more independence and epistemic agency as they engaged in a community of practice. This anchor also caused me to think about how engineers authentically create solutions in tandem with increasing their disciplinary knowledge and skills across collaborative social contexts. In a sense, engineers within the fields experience their own zones of proximal development as they encounter various engineering processes.
Chapter 7: Findings for the Target Anchor

This chapter details the findings reflected in thematic analysis of qualitative data from discourse, artifacts, and observations during engineering design activities across the target anchor. The curricular objectives and engineering activities within the target anchor focused on participants exercising epistemic agency through the construction of robot prototypes in response to science related issues in their local or global community. The learning experience in the target anchor was structured so that participants could exhibit the most autonomy during the knowledge building process. This chapter provides an overview of thematic findings and offers a pedagogical reflection for action research.

Research Questions for Intermediate Anchor & Emerging Themes

The overarching research question for this study was as follows: What epistemic practices of engineering do student participants demonstrate in their artifacts and discourse when engaging in engineering activities across all three anchors of the learning progression designed to develop epistemic agency for STEM learners? The sub research question for the target anchor was as follows: What epistemic practices of engineering do African American student participants adopt when building prototypes and how can their prototypes contribute to the advancement of their community and larger society? There was one salient theme that was identified from observations, discourse, and artifacts during the activities in the target anchor. The theme was as follows:

4. Participants raised STEM awareness, stimulated community engagement, demonstrated enhanced cognitive practices, and displayed epistemic agency in their showcasing of their engineering design prototypes for STEM Night
At the conclusion of the second session of programming, I provided participants with a “STEM Night Robotics Challenge” activity sheet and explained the logistics of the assignment. I explained that the STEM Night Robotics Challenge activity sheet would aid in transforming their thoughts and ideas into a tangible robot with programming applications. I encouraged them to work with their group and complete the activity sheet. The activity sheet served to address prompt 4 which was designed to assess how participants progressed in their documentation of the engineering design process and to assess what epistemic practices of engineering participants adopted when engaged in problem solving.

**Theme 4: Participants raised STEM awareness, stimulated community engagement, demonstrated enhanced cognitive practices, and displayed epistemic agency in their showcasing of their engineering design prototypes for STEM Night**

Initially, participants were significantly challenged by experiencing such an open ended problem. Darius stated, “I don’t even know what to do. I can’t think of anything.” Another participant echoed in the background, “Me either. This is hard.” Some of the participants began to disengage and play with their phones instead. I encouraged them to continue brainstorming ideas with their groups and to call me over if they required further assistance. For the first portion of this session, participants seemed to have regressed in their perception of self-efficacy related to completing this particular task. Because this open ended problem solving activity lacked structure, participants experienced an element of discomfort during the learning process. I provided participants with a previous example of how past participants in this program created agricultural drones in response to the agricultural industry in the local community. I provided a brief summation of how previous participants used the engineering design process to create their prototypes. Participants began to have discussions in their group in relation to problems in their
community that could be addressed by their EV3 robot prototype. As participants engaged in discourse during learning, I would join their discussions and ask questions.

As participants engaged in problem solving, they exhibited several epistemic practices of engineering such as developing processes to solve problems. Dashawn’s group stated, “We thought about doing an autonomous vehicle because they are the future. Our robot will detect red, green, and yellow like a stop light. During the previous anchors, we had several discussions about autonomous vehicles in relation to how they sense their environment. Participants found these discussions to be engaging and as a result began to envision what programming an autonomous vehicle would be like. As participants discussed ideas in their group, they settled on what they wanted their robot to be able to do. On their activity sheet they wrote “Our robot will proceed to go at green, slow down on yellow, and stop at the color red.” The group wrote very clear instructions. The clear instructions enabled them to brainstorm various programming solutions for their robot to achieve these tasks. Other groups in the class documented their process, but it was a general summary of what their robot was going to do. However, this group developed a process of writing out very clear tasks always considering the programming applications for their vehicle. Additionally, participants exhibited working effectively in teams and communicating effectively in that they were able to think, communicate, and modify their ideas through meaningful discussion.

As participants were engaged in the problem solving process, they continued to demonstrate a range of epistemic practices of engineering. Two of the groups in the class were discussing weathering and erosion. At the conclusion of the discussion, the first group, Denise and Bernard, decided to create what they called a “Weather/Erosion Simulator” whereas the second group Pierre and Chelsea decided to create a robot that removed sediments and large
rocks that block water ways and documented their ideas on the activity sheet. The first question on the activity sheet displayed in Figure 14 was, “What is the local or global problem that you would like to solve? Why is this problem meaningful to you?” In response to the activity sheet prompting participants to identify a problem, Pierre and Chelsea stated, “Sediments block a pathway for water to flow. This is meaningful because the sediments can damage water and cause back up.”

Figure 14
Participant Sediment Removal Robot Prototype

Note. This figure displays participants’ ideas for the design of their EV3 robot prototype design.

I assumed that participants across the two groups were learning about sediments, weather, and erosion in their science class and desired to connect the content to their robot design. This discussion of sediments, weathering, and erosion reflected their effort to apply science knowledge to problem solving. Additionally, Pierre and Chelsea had assessed the implications of
the solution as it relates to the environment. They explained to me the importance of streams and rivers being able to flow and how their robot will ensure that the water is not blocked.

When I asked Denise and Bernard about their “Weather/Erosion Simulator” their ideas were intriguing but underdeveloped. Additionally, they had not established programmable tasks for the design of their robot. I kept asking questions to determine what they were trying to achieve for the design of their EV3 robot and while they had good intentions, they could not provide a clear explanation. Denise and Bernard continued to work on their ideas. Later, Bernard asked me, “Can we use the ultrasonic sensor?” I replied, “Sure! But tell me why.” Bernard replied, “We want our robot to see obstacles and then go in another direction.” I replied, “What problem does that solve? Why does your robot need to avoid obstacles?” Bernard and Denise had become excited about their programming idea but had not considered the problem in context. I told them to think about different events that have happened in the news recently. We began discussing the tornado that just occurred in Kentucky. I asked them how their robot could solve a problem in Kentucky. Bernard and Denise began talking about how their robot could help locate people lost in the rubble but would need to avoid all the debris in the streets. Denise and Bernard looked at me and stated, “Okay we got it now” and began constructing a field with obstacles. Their obstacles in their practice field consisted of cups taped to construction paper. They discussed how to program the ultrasonic sensors in relation to the distance of the cups because the cups in their model represented buildings and they wanted to position their cups in context. Denise and Bernard continued to refine and measure components in their field.

Some of the other groups easily adopted the concept of considering the problem in context. Keith’s group decided to address the issue of pollution in their community. The first question on the activity sheet displayed in Figure 14 was, “What is the local or global problem
that you would like to solve? Why is this problem meaningful to you?” Keith’s group stated, “The problem is meaningful because our environment is polluted, and the community won’t do it so we as a group decide to help pick up… land trash.” Keith’s group named their robot in association with their community and mapped out the sensors that they needed as well as their programming applications in steps reflected on page 2 in Figure 15.

Figure 15
Keith’s Group Work for the STEM Robotics Challenge

Note. This figure displays participants’ work as it relates to the engineering design process. Engaging in the engineering design process was crucial for the ideation phase of creating a EV3 robotic prototype for STEM Night. In addition, to coming up with an idea, Keith’s group mapped out programming tasks related to how their robot would recognize and pick up the pollutants in their community.

During this phase of learning, participants had progressed in documenting how they intended to solve problems using the engineering design process as compared to their work
during the entry anchor. Kia’s group decided to create an autonomous bike that functioned like an autonomous vehicle. Their group discussed that when people are riding their bikes in company, they are engrossed in conversing with each other and are not paying attention and are in jeopardy of “...bumping into something or running over something,” thus they opted to use an “ultrasonic sensor because it senses if something is in the robot’s path.” On page 2 of their group’s activity sheet, Kia wrote out the programming application for their robot. Kia’s group went through several iterations of envisioning multiple solutions as well as several iterations of testing during this learning process. On her activity sheet, she documented specific programming instructions reflected in Figure 16. Figure 16 also depicts a drawing done by Kia’s partner Chris. Both the programming and drawing serve as models that explain and display their programming application and structural build of the robot. Creating models is a critical science practice which is essential to building prototypes in engineering. The epistemic practices of engineering related to creating models and building prototypes is significant to the ideation phase for the engineering design process.
Figure 16

Kia and Chris’s STEM Night Robotic Challenge Activity Sheet

Note. This figure displays participants’ work as it relates to how they used the engineering design process to design a EV3 robotic prototype for STEM Night.

Across all of the groups the participants completed the “STEM Night Robotics Challenge” activity sheet with drawings. While the level of detail varied across groups, they all used documentation of the engineering design process to engage in the problem solving process which indicated significant growth from the entry anchor. This activity evoked the use of various epistemic practices of engineering such as developing processes to solve problems, assessing implications of solutions, considering the problems in context, and constructing models and prototypes. Participants also demonstrated social practices such as working effectively in teams and communicating effectively which is critical when engaged in collaborative problem solving. The demonstration of the epistemic practices of engineering was crucial to participants being able to design and program their robots in preparation of STEM Night. Although participants
Initially were challenged by the open ended structure of this activity, they persisted and showed diligence and personal agency in completing the STEM Night Robotics Challenge.

The participants’ commitment towards learning robotics served as a catalyst for STEM engagement in their school. The participants arrived an hour and half early before STEM Night to work on last minute details on their robot. As I was setting up refreshments, a student that I had never met came to me and asked, “Are you the teacher that is over robotics? I would like to join but I don’t know if it is too late. My friend told me about it, and I want to join.” I responded, “Sure you can join! We could use your help building our competition robot next semester.” I began to explain STEM Night and through conversation he informed me that Bernard told him about robotics. Another student, Camille, came into the room and introduced herself to me and said, “Are you the teacher that teaches robotics? I want to sign up for robotics today!” I responded, “Of course you can sign up.” I explained what participants were doing with their robots and she told me that she was going to stay for STEM Night. She walked over to one of the groups that was working on programming their robot and started trying to learn. I found out later that the ninth grade participant told her what she had learned in robotics class, and it motivated Camille to join. Participants acted as influential agents in their community and raised STEM awareness.

Some of the participants’ younger siblings came into the room before STEM Night and saw their siblings programming and testing their robots. One of the participants’ siblings (an elementary aged student) walked over to me and said, “I want to do robotics too! Can you show me how to do it?” I told him, “Yes! And your brother can teach you too!” As parents entered the room, they came to me and shared how happy they were to have a robotics program in the school. Another parent came to me and said, “I am so surprised that my daughter signed up for
this. She never signs up for anything except band because she is really shy. I didn’t even know she was interested in this!” One of Denise’s parents came to me and remarked, “You know it's great that they have this class, so our kids won’t be behind in technology.” He then started telling me about his profession and how it intersects with engineering and technology. Discussions with the parents highlighted that they had their own perspectives about how access to STEM impacts their community.

Participants’ robot prototypes served as a tool to inspire, motivate, and educate the community about engineering and innovative technology. STEM Night opened up with a greeting from Kia’s robot which audibly remarked, “Hello! Welcome to STEM Night!” The audience smiled, laughed, and recorded the greeting from Kia’s robot on their phones. Next the participants all introduced themselves and explained why they signed up for the robotics program. The new girl, Camille, who had come to sign up an hour before STEM Night also introduced herself as being a part of the robotics program. During Camille’s introduction to the audience she stated, “I joined to learn about robotics and STEM.” Following the introductions, I discussed and showcased what participants learned and created during the entry anchor as it related to the water filters and the engineering design process. Next, Denise, the self-appointed class representative, led the parents in an activity in which they deciphered between machines, robots, and artificial intelligence. Denise asked the audience, “Can you guess which one is a robot?” One of the parents raised her hands and pointed to the image of the drone and said, “I think that is a robot.” Denise responded, “Why do you think that [pointing to the drone] is a robot?” The parent responded, “Because it…well maybe it isn’t a robot because you have to operate it.” Denise said, “Okay. Does anyone else want to guess?” One of the parents said, “I don’t want to say the wrong answer.” After a long pause of silence, I interjected and said, “Well
can anyone state which items on the screen are not robots?” One of the parents shouted, “I think the Tesla car is a robot!” Another parent said, “I don’t think the printer is a robot.” Another parent said, “That round vacuum at the corner of the screen is definitely a robot!” As the parents began sharing their ideas, the participants, myself, and Mr. Davis began to use parent responses to define what a robot is. We then led the parents in a discussion about artificial intelligence and how it is used with robots. This activity not only showcased what participants learned about robotics and STEM it provided a way for participants to take an active role in transferring their knowledge into their community.

Next, each of the participant groups came forward to demonstrate their robots. The majority of the parents had their phones out and were recording the presentations. The participants impressed the audience with their innovative designs and programming applications. Denise and Bernard’s robot navigated a field of objects and made various turns to avoid collision with the objects. Keith, Charles, and Jahir’s pollution detection robot used a light and touch sensor to dispose of litter. When I called Dashawn’s group to come forward to demonstrate their robot, he expressed enthusiasm about explaining their robot design. He looked at me and said, “Can I explain our design to them? I want to explain it to them first!” Previously, for the other groups I announced the name of their robot and made a few statements prior to their demonstration, however, Dashawn wanted to be the person to introduce his robot to the audience. He explained that his robot was a model of an autonomous vehicle and explained how his robot was designed to obey different colors associated with traffic signals using a light sensor. Their robot navigated the field that they created and when the robot sensed the color green it increased speed, when it sensed the color yellow it decreased speed, and when it sensed the color red the robot stopped. One of the teachers in the audience spoke out and said, “How
long did they have to really learn this?” I responded, “they learned this over the course of a week and a half”. The teacher responded,

> What I am seeing tonight is just amazing! I remember the first day that I dropped by to visit one of the classes [referring to one of the EV3 programming classes] I saw the kids over there programming and when the robot did something that they programmed it to do, I saw the look on their faces, and it did something for them to see that the robot did what they asked it to do. So, everything that you see them doing tonight they learned in less than ten days. In less time than that! They only had three classes! So, what they are doing tonight is amazing!

As the participants presented their robots to the audience, they were solidifying their identity as valuable and capable STEM contributors within their community.

The community affirmed the participants identity and sense of self efficacy. Kia came to the front of the room to present her group’s design (Chris was unable to attend). She told the audience that their robot design was an autonomous bike. She talked about how cars have sensors that allow them to detect other cars around them (e.g., blind spot sensors, back up cameras, etc.). She then explained that “bikes do not have sensors that detect objects or cars” and because there are no sensors on bikes people are more inclined to have an accident. She showed the audience their robot and explained that she used the ultrasonic sensor on their autonomous bike design to sense and avoid obstacles. Kia demoed the robot and it performed obstacle avoidance in a linear path. However, Kia went a step further and designed the robot to follow a line about a circular path using a light sensor. Figure 17 displays an image of her groups’ robot following a circular path similar to lane detection performed by cars.
Figure 17

*Kia Programmed the EV3 Robot to Follow a Path*

*Note.* This image displays Kia and Chris’ robot prototype moving along the path using the light sensor.

When Mr. Davis saw her robot following the line, he stated to the audience,

This is a big deal! I have college students now and it takes them forever to figure out this whole process. Most people just want to put the robot on the black line and just go forward and then once it gets off that black line, they have to find the black line again. So, most of the time they end up programming the robot to circle around to find the black line. But for her to just program the robot to stay on the black line all the time is really good on her part. It is really good for her to have figured that out on her own!

The audience clapped for Kia! The assistant superintendent was recording the presentations on his phone and spoke very highly of the participants and STEM Night.
After STEM Night was over, many of the parents expressed pride in the participants. A participant’s younger sister (elementary age) came and hugged me and asked me to teach her about robots. After everyone began to leave, Kia went over to the computer with her robot and continued programming her robot. Mr. Davis went over to her and started to converse with her about programming and how well her presentation was. About 5 minutes later, Kia’s mother walked into the room. Kia’s mother had gotten off work late because she had to work out of town that day. Kia began to show her mother all the different tasks that she had programmed her robot to do, which were beyond what the curriculum required. Her mother took out her phone and recorded Kia’s robot. Kia’s mom said to her, “If you can do all of this, why would you want to major in business? You should consider majoring in computer programming!” Kia’s demonstration of epistemic agency was the result of Kia’s enhanced sense of self related to programming. Additionally, as a result of Kia’s epistemic agency, Kia’s mother had a transformed perception of Kia’s identity and self-efficacy related to computer programming. Overall, each of the participants’ contributions not only educated their community about STEM but impacted the communities’ STEM identity and cultivated STEM participation.

**Teacher Researcher Reflection**

The instructional outcomes of the target anchor provided me with a myriad of pedagogical implications. Using the epistemic practices of engineering to evaluate the structural components of the curriculum related to teaching and learning were instrumental in broadening my understanding of engineering education. As I deductively evaluated my curriculum and learning outcomes, I have come to understand that there is a difference between having participants to complete activities associated with engineering and cultivating the habits of mind in participants that enable them to think like engineers. While my instruction and curriculum
certainly did not make the epistemic practices of engineering explicit to participants nor did it aid in their understanding of these practices, it did provide them with an engineering process to build prototypes. The epistemic practices of engineering during this study provided instructional clarity regarding what concepts were missing and needed to be developed related to engineering. For example, some of the participants in their prototype designs assessed the implications of their solutions, however, all students did not. Assessing the implication of solutions is not a part of the engineering design process but it is a critical component of the epistemic practices of engineering. Engineers in authentic contexts have to consider the impending impact of their prototype on the environment both locally and globally. Engineers also have to consider the social and ethical implications of their designs. Assessing the environmental, social, and ethical implications of the design solution are the result of making evidence based decisions. Effectively engaging in assessing the implications of the solutions also necessitates practices such as making tradeoffs between criteria and constraints. Assessing the implications of the solutions was not a question nor a prompt on the “STEM Night Robotics Challenge” activity sheet nor had I made this instructionally explicit. I asked the participants to identify a problem and consider the problem in contexts for their robot design, but I did not ask them to assess the impending implications of their design. I would not have reflected on this if I did not evaluate the curriculum and instruction using the epistemic practices of engineering.

Additionally, I realized during the target anchor that the learning progression was very practice oriented and not content driven. Typically, at the end of a learning progression, learners would have a deeper understanding of content as well as practices. The learning progressions within the Next Generation Science Standards are heavily content driven thus the learning outcomes of the target anchor result in a well-developed understanding of a topic. The learning
outcomes of the target anchor for this study were heavily associated with performance expectations associated with practices. Participants learning outcomes for the target anchor reflected a broad range of topics related to content (lead poisoning, drinking water violations, engineering design, water filters, computer programming related to EV3 robots, etc.); however, they did not learn deeply nor linearly about one topic. While this learning progression provided a six week crash course on engineering, in the future I would structure the curriculum to provide a deeper understand of content in tandem with the epistemic practices of engineering.

The learning outcomes of the target anchor also displayed the significance of how the social dynamics of learning influence the cognitive practices of learning. Within the community of practice that was constructed in the classroom, participants positioned themselves as contributors as a result of their identity and personal sense of self-efficacy. However, I learned that identity and self-efficacy sometimes is in flux during the learning process. When the participants were given the “STEM Night Robotics Challenge,” they disengaged the learning process because they seemingly encountered a task that was out of reach per their capabilities. Internally, I was concerned that I may have pushed them too fast, however, I was confident that they could achieve the task, but I wanted them to be confident in themselves so that they could regulate their own learning. With a little bit of scaffolding the participants were able to re-engage during this phase of learning. Participants were positioned to have full autonomy during the knowledge building process which was significant to them enacting epistemic agency. I thought that this part of the curriculum was the most powerful.

While participants expressed agency in learning, they also expressed agency in cultivating STEM awareness. I had no idea that they were talking to a lot of students in their school and the neighboring junior high school about joining the robotics program. At the end of
the target anchor, I thought about how the participants had become just like the students engaged in STEM research that they learned about in the first anchor. They had become a source of motivation to their community.
Chapter 8: Discussion of Findings

The visible integration of engineering as a discipline in science classrooms is becoming apparent for states that have formally adopted the Next Generation Science Standards (NGSS) framework and for states that are remodeling state curriculum to instructionally align with the NGSS framework (NGSS Lead States 2013, Antink-Meyer & Meyer, 2016). Exploring instructional approaches for engineering content and practices is pertinent to students engaging authentically with engineering as active learners. Active learning entails performing the engineering design process while engaging in the social practices of engineering that enables knowledge production. Acquiring the epistemic practices of engineering is fundamental to progressing epistemic agency whereby students take ownership of the knowledge building process. The knowledge building process is social in nature and occurs within a community of practice in which students develop identity and self-efficacy. Science and engineering curricula and progressions of learning continue to prioritize cultivating students’ epistemological development within a community of practice in a way that simulates authentic engineering contexts. However, it is important to note that the social engagement within the classroom community of practice is often influenced by sociocultural and sociohistorical narratives that project deficit credibility to students that do not embody mainstream representations of STEM. Additionally, mediating identity and self-efficacy within a community of practice is of particular importance for demographics that have been epistemologically estranged from STEM communities such as African Americans. Thus, for this study a curricular learning progression was designed to explore how African American students progress toward epistemic agency as a result of engaging in the epistemic practices of engineering in tandem with identity transformation.
The purpose of this study was to explore participants’ development of epistemic agency as STEM learners as they engaged in engineering activities across a learning progression designed to advance epistemic practices of engineering. Each anchor within the learning progression was designed to progress the epistemic practices of engineering in relation to identity transformation for the entry anchor, learning within a community of practice for the intermediate anchor, and cultivating epistemic agency within the context of community outreach for the target anchor. Using qualitative methods for this study enabled me to generate data from a myriad of sources such as observations of discourse, interviews, and artifacts across all three anchors of the learning progression. Analyzing multiple sources for this study provided greater insight in understanding the participants experiences related to identity transformation, demonstration of the epistemic practices of engineering, and progression toward epistemic agency as they engaged in the activities across the learning progression. Four themes were identified from thematic analysis of the qualitative data that provided insight related to how the development of cognitive practices is impacted by social dynamics of learning. The following four themes are as follows:

1. Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contribution (Reflected in entry anchor)

2. Participants displayed a range of social and cognitive skills related to the epistemic practices of engineering during engineering design activities (Reflected in the entry anchor)
3. Participants advanced in self-efficacy, cognitive practices, and epistemic agency as it related to computer programming in response to working with an expert in a community of practice (Reflected in the intermediate anchor)

4. Participants raised STEM awareness, stimulated community engagement, demonstrated enhanced cognitive practices, and displayed epistemic agency in their showcasing of their engineering design prototypes for STEM Night (Reflected in the target anchor)

The following section will include a discussion of each theme. The findings from this study indicate that a community of practice is essential to negotiating and progressing identity, self-efficacy, and epistemic agency as STEM learners. The findings of the study also indicate that a community of practice in which participants have epistemic credibility is significant in transcending racialized and gendered conceptions of STEM. What follows is a discussion of each theme within the conceptual framing of Cunningham and Kelly’s (2017) epistemic practices of engineering as well as the theoretical framing of Holland et al.’s (1998) concept of figured worlds and Wenger’s (2004) concept of community of practice.

**Theme 1: Participants examined and critiqued STEM representation with respect to race and gender and identified dispositions and resources needed to fulfill their desired STEM contribution**

This study sought to explore how students progressed towards epistemic agency as STEM learners through examining changes in identity and self-efficacy which were mediated through the engagement of the epistemic practices of engineering. Engaging in an epistemic culture as it relates to practices is fundamental to students authoring themselves as knowledge builders within epistemic communities (Carlone et al., 2021). Authoring oneself as a knowledge builder within an epistemic community is the product of identity transformation and an enhanced
sense of self-efficacy. Cunningham and Kelly (2017) note that one of the significant epistemic practices of engineering is *seeing themselves as an engineer*. Thus, the entry anchor focused on positioning participants to envision themselves as potential knowledge builders in STEM and more specifically in engineering by having them to read about students participating in STEM that have closely aligned demographic identities. Additionally, Cunningham and Kelly (2017) posit that as actors engage in the collective social and cultural practices reflected in the epistemic community, their position as a member of the community is legitimized and recognized. In response, the entry anchor was also designed to engage participants in engineering design activities collaboratively to demonstrate the epistemic practices of engineering. Cunningham and Kelly’s (2017) research on the epistemic practices of engineering discuss how these practices demonstrated across the engineering community lead to the production of knowledge and identity formation. However, current research related to the epistemic practices of engineering understate how the actor’s sociocultural positioning which is structured by hierarchy and power influence the social and cultural production of knowledge in epistemic spaces. Nasir and Victoria (2006) note that social processes “have different implications for groups of students …because they are inherently situated in broader contexts of power and access within society” (p.468).

The epistemic practices of engineering related to identity formation are presented as neutral and universal, however, the findings from this study indicate that the sociocultural positioning related to the identity of the participants had influence within knowledge building spaces related to STEM. During the entry anchor, participants read about three teenage African American female students engaged in STEM research that worked together to create a water filter that decreased lead exposure in tap water. When participants were asked to reflect upon the
societal contributions of the students engaged in STEM research, their responses did not separate the epistemic tool (contribution) from the students engaged in STEM research sociocultural positioning. Participants statements such as “They may have inspired other females to get involved with engineering despite their skin color” is an indication that the participant perceived skin color and gender as sociocultural barriers to participating in STEM. In addition, another participant also acknowledged both the epistemic tool and sociocultural positioning of the students engaged in STEM research in stating, “They are providing a way to clean water. They are also becoming role models for other girls that might want to become engineers. They are paving a way for future African American girls and women to become successful in STEM.” During this phase of learning in the entry anchor, participant responses were replete with ideas that indicated that they perceived STEM as racialized and gendered and that for African American women to engage in STEM was inspirational. Participants’ responses were aligned with Carlone et al. (2021) perspective in which they note that epistemic communities presented in classrooms are “heavily tied to larger social structures of race, class, and gender” (p.173). These findings in which participants perceived STEM (and associated STEM disciplines) as racialized is consistent across the literature. In a study conducted by Lee et al. (2020), African American and Hispanic students discussed how only certain races were recognized as legitimate actors in epistemic communities of STEM and more specifically engineering.

While participants in my study perceived race and gender as cultural barriers, their statements did not reflect an internalized deficit credibility related to their intellectual capacity to engage in STEM. When I asked participants to share their thoughts about why African American women are underrepresented in STEM, a participant responded, “Because white people think that they are smarter than us…people think it is normal to only see male engineers.” The
participant’s response suggests that his perception was that white people in actuality are not “smarter” rather that they simply perceive themselves to be. This response aligns with Sheth’s (2019) research in which he notes that students of color are constantly negotiating their identity as they navigate negative characterizations stemming from stereotypes and “cultural dissonance from dominant conceptions of who is capable of science and who belongs in science” (p. 38). Participants acknowledged the cultural norms in STEM; however, they also rejected cultural norms that would dissociate their identities in relation to STEM participation. Instead, participants refigured for themselves a world that countered dominant narratives in relation to STEM participation. In this study, I use the conceptual framing of figured worlds to show how participants managed the sociocultural dissonance between embodying identities that are epistemologically estranged from epistemic communities in STEM and seeing themselves as potential contributors in STEM.

Holland et al.’s (1998) concept of figured worlds, which is a derivative of sociocultural learning theory, is defined as a “socially and culturally constructed realm [s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others” (Holland et al., 1998, p. 52). Urrieta (2007) notes that figured worlds are often organized by narratives, storylines, and other cultural means that establish a cultural order within the socially constructed realm. He elaborates on this idea in stating that the cultural means by which a figured world is organized could be constituted by power, hierarchy, and privilege. From the participants perspective, the reality of the figured world (in which they currently exist) has socially constructed situated norms regarding STEM participation and representation that are dissociated from their identities. Additionally, from the participants’ perspective the situated norms related to STEM participation and representation are
organized by constructs of racism and sexism that are confronted when creating epistemic tools in STEM. One participant demonstrates this ideology in stating, “At only age 17, and black, facing verbal racism and sexism due to being black and females, they created a water purifier to decrease…pollution in water supplies.” Alternatively, within the concept of figured worlds actors can construct and reconstruct their own sociocultural realms and determine what and who has value. While the students engaged in STEM research in one realm were challenged by society because of their sociocultural identities, in the participants’ refigured realm they were evaluated differently. In participants’ refigured world these African American female students STEM researchers were a valued source of inspiration. One participant stated when he sees “stuff like that” he thinks, “If they can do it, I can do it.” Another participant noted that the students engaged in STEM research served as a significant source of encouragement in his pursuit of STEM.

Zuckerman and Lo (2021) note that “situated norms” in figured worlds can reinforce existing implicit hierarchies which are not inclusive within cultural spaces. Thus, actors create sociocultural dimensions or refigured worlds for improvisation and imagination across cultural contexts. This refigured world is significant in that it enables the actor to engage in identity work that runs counter to situated norms that exists in other socially constructed realms. Although participants critiqued the cultural norms as it related to their perception of a racialized and gendered STEM in the figured world, it did not prevent them from envisioning themselves as potential STEM contributors in their refigured world. In their refigured world they defined the cultural behaviors, values, and resources necessary to create epistemic tools. Participants stated that, “You need determination, drive, grit, and the right mentality. I could contribute a unique view on problems that could help others to figure out how to solve the part they are stuck on.”
Another participant stated, “You would need to be driven towards your goal and never give up and always see through your ideas. When contributing to society, you will not always succeed the first time, so you have to keep going and have a supportive strong-minded group around you.” Notions of diligence and persistence were constituted behaviors defined in their refigured world. Other participants established that being in community in which epistemic tools were culturally constructed were valuable. One participant stated they would need “Supportive people with the same ideas” while another participant stated they “would need a team.” Additionally, value was also placed on how the epistemic tool impacted the community. Participants discussed building a farmer’s market to address public health disparities of African American people in their community while another participant talked about constructing a power savings plant with solar panels for energy savings. Through improvisation in this refigured world, participants were able to counter perceived deficit narratives related to their sociocultural positioning and figure their identity as capable STEM contributors. Through improvisation and imaginations, they were able to constitute social attributes needed to create epistemic tools within an epistemic community.

The findings in this anchor are consistent with research that discusses how marginalized populations often create counter spaces in educational spaces to counter deficit narratives that are assigned to their sociocultural identities. For example, Ong, Smith, & Ko (2018) note in their study that,

Counterspaces are made necessary by, and are partially defined by, STEM’s culture and its structural manifestations and behaviors that have historically privileged norms of success that favor competitive, individualistic, and solitary practices—norms that are associated with White male scientists.
One of the key findings in Ong and colleagues’ (2018) study was that counterspaces were key to marginalized populations persisting in STEM. Thus, the concept of figured worlds for this study served as a spatially suspended counterspace in which participants can establish their own cultural norms and values in relation to their sociocultural identities.

**Theme 2: Participants displayed a range of social and cognitive skills related to epistemic practices of engineering during engineering design activities**

Cunningham and Kelly (2017) discuss the social nature of engaging in the epistemic practices of engineering. In their work they discuss that in authentic contexts, engineers socially engage in epistemic practices to achieve a common goal as well as work across social contexts with clients and other entities. The social practices that engineers engage in across social contexts is vital for identity formation. This concept is aligned with Holland et al.’s (1998) concept of ‘identity in practice’ that posits that as the actor performs the cultural activities in their figured world their identity is formed or figured. Urrieta (2007) asserts that because Holland et al.’s (1998) concept of figured worlds centers the cultivation of identity, activity, and positioning in relation to concepts of power, this figured world becomes a realm of possibility for enacting agency. As participants engaged in the epistemic practices of engineering they negotiated and figured their identities along with their sense of self-efficacy. As participants experienced identity formation within their refigured world, they began to see each other not only as valuable contributors but as agents capable of impacting the world.

The engineering activity, “The Brita Water Filter Challenge,” was in and of itself an invitation for ‘identity in practice’ aligned with the concept of figured worlds. Urrieta (2007) highlights a defining characteristic of figured worlds in stating, “Figured worlds are cultural phenomenon to which people are recruited, or into which people enter, and that develop through
the work of their participants” (p. 108). During the challenge participants were recruited and invited to pretend that they were engineers working for Brita. Assigning participants improvisational identities for a real company that they are familiar with blurred the line between real and purely imaginary. Creating actual clients within design activities was significant for helping participants understand how engineers create epistemic tools in authentic contexts. Cunningham and Kelly (2007) state, “These epistemic practices of engineering are evident in the social contexts set by the problem space of the clients and conditions.” Thus, the practices which are real are performed in a refigured world but still maintain relevance in the real world.

As participants engaged in the “Brita Water Filter Challenge” the water filter served as a meaningful artifact that motivated participants to engage in the cultural practices of engineering. Holland et al. (1998) refers to this phenomenon as semiotic mediation in which actors ascribe meaning to artifacts that are culturally produced and the ascribed meaning of the artifact in turn influences behaviors and action in relation to it. During the Brita Water Challenge, participants were only exposed to the engineering design process. However, participants performed a series of cultural practices within their refigured world which were in reality the epistemic practices of engineering. Participants were collaboratively engaged in the acts of carrying out investigations, making evidence-based decisions as a result of investigating properties and uses of materials through cycles of iterative testing. As participants engaged in the cultural production of knowledge, they expressed excitement which was tied to the enhancement of self-efficacy. During my observation of the design challenge Melanie stated, “Oh my god! Our water! It’s coming along! It’s coming along! But it’s like…[pause] we need more cotton balls. We need to add an extra layer. We need to remove the rocks.” The practices and construction of the water
filter gave them an opportunity to explore their identity and personal sense of self-efficacy as a result of performing the epistemic practices of engineering.

As Melanie and her groups continued to experience success another participant inquired about how she was able to achieve clear water of which Melanie responded, “Because I’m a real scientist that is how!” Melanie’s response was a reflection of ‘identity in practice.’ As she engaged in the epistemic practices, she figured herself as a scientist. Her statement of being a “real scientist” demonstrates that there is a certain amount of dissonance between a professional scientist and herself. However, her response embodies the notion that because she was engaging in the practices in similitude to professional scientist in the figured world that she could refigure herself as both real and a scientist in the refigured world. In this experience, the practices and the water filter were the source of semiotic mediation. Thus, the epistemic practices of engineering served as a way for her to perform her identity and the water filter was an epistemic tool that validated the realness of how she figured herself. Additionally, Melanie’s experience of identity formation which was formed in her refigured world ran counter to the dominant narratives of “…people think it is normal to only see male engineers.” While Melanie may have perceived STEM as being racialized and gendered, she refigured a world in which she could see herself as a “…real scientist!

As participants engaged in the epistemic practice of engineering, they used prior experiences to inform their process. Within the concept of figured worlds, actors can engage multiple voices, experiences, and contexts for evaluation whereby they are compared and contrasted. Actors in the figured world are positioned to make meaning of their experiences and assign value to them. During the activity, Allen performed actions of exploration, interaction, and play with ideas from prior science experiences to make meaning in the refigured world.
During the activity, Allen reflects on a scientific reference that influenced the construction of their prototype. Allen remarked, “Ms. Duke, let me tell you about my idea for our water filter! See I thought about ground water in the water cycle for our design. We got a good concept going.” This participant was referring to the concept of percolation of water similarly to how the water was moving through the filter. This exploration, interaction, and play of integrating science concepts from past experiences is aligned with the epistemic practices of engineering defined as applying scientific knowledge to problem solving. Perhaps performing the improvisational identity of an engineer also allowed Allen to explore, imagine, and improvise what it was like to act as a scientist.

The concept of play is another feature of figured worlds. Holland et al. (1998) notes play as the “the medium of mastery, indeed of creation of ourselves as human actors…” (p.236). In figured worlds, the actor is able to engage in the performance of activities that figure the identity. Play is the product of revealing the imaginations associated with the perceived identity. As actors engage with the acts of improvisation they interact with or create tools and then ascribe meaning to it. While the participants ascribed meaning and value to the construction of the water filter, the participants did not assign meaning and value to the Data Collection Sheet for the “Brita Water Filter Challenge” which organized their design process. Perhaps the paper in their meaning making did not perform their ideas, nor did it validate their identity in the same way that the water filter did. In their world they could not see that the activity sheet was also a performance of their ideas and provided opportunity to play with ideas through making predictions. Perhaps they could not see that the activity sheet was also an opportunity to play with ideas as it related to creating models through sketches, or creating and analyzing data, or other science practices that ‘real scientist’ do which would have allowed them to explore their imaginations.
The findings in this anchor are consistent with the concept of identity formation being a salient factor in students engaging in the epistemic practices of engineering. Additionally, while there is a very small body of literature that discusses the connection between science practices and the epistemic practices of engineering, the findings of this study highlight that the sophistication of demonstrating the epistemic practices of engineering is connected to proficiently demonstrating scientific practices. For example, Isaac (2021) found that science practices associated with creating models was essential to participants ‘thinking like an engineer’ and demonstrating epistemic sophistication during problem solving activities.

**Theme 3: Participants advanced in self-efficacy, cognitive practices, and epistemic agency as it related to computer programming in response to working with an expert in a community of practice**

The concept of ‘identity in practice’ was a critical component of progressing epistemic agency. Within figured worlds, the actors are positioned with power and can figure and refigure their identities and roles as well as reorganize the cultural rules and norms within this suspended dimension. During the intermediate anchor, participants were invited to refigure themselves from acting as engineers that work for Brita to acting as computer scientist. The intermediate anchor was designed to have participants work with an actual expert in the field in an effort to cultivate and validate their identities in computer programming. Interacting with an expert during the intermediate anchor was significant to enculturating participants into a community of practice for computer programming. During instruction within the refigured word, the local computer scientist repositioned the identities of the participants in stating, “So in programming, all of you are programmers, programmers write algorithms.” In another statement the computer scientist invited participants to envision themselves as potential creators, “So we want to be a creator
instead of a worker. Workers are good too, but we want to be the ones that are creating the actual applications as opposed to the one who is actually using it.” The term “invite” is used to recognize the participant’s power in this figured world. Participants had to choose and agree to the identity that they would perform within this space. In addition, Urrieta (2007) notes that in figured worlds, identity and the self-concept transcend constituted labels. Furthermore, identity is about how the actor comes to derive meaning of who they are or who they could be within and outside of these worlds. Although, participants were engaged in the improvisation of acting as a computer scientist in the refigured world, at the conclusion of the first programming session one of the participants approached Mr. Davis to discuss what he would need to do to major in computer programming. While Keith was actively engaged in performing the activities of a computer scientist as it related to problem solving, his sense of identity and personal self-efficacy was influenced and enhanced. Somewhere in the midst of Keith performing the identity and practices of a computer scientist, he began to envision the potential reality of becoming a real computer scientist.

The intermediate anchor facilitated identity transformation for individual participants, however, another significant finding was the social transformation of the collective identities of participants through the construction of a community of practice. The construction and inner workings of a community of practice has its own forms of engagement that complement the concept of ‘identity in practice’ within figured worlds. Weinberg et al. (2021) note that figured worlds are dependent upon the social interactions that occur across members and communities and that the interactions that occur are fundamental to creating shared understandings and values that are reflected in the outcomes. Wenger and colleagues shed insight on the functionality of how members within a community of practice engage across social contexts. Wenger et al.
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(2011) state that a community of practice is a “learning partnership among people who find it useful to learn from and with each other about a particular domain. They use each other’s experience of practice as a learning resource” (p. 9). Wenger (2004) defines the community of practice of having three critical components. The first component is a domain which constitutes an area of knowledge or shared interest that gives a set people and identity. The second component is a community which is a set of people that are delineated by their relationship and interest relevant to the domain (Smith et al., 2017). The last component is practice which includes the body of knowledge and epistemic tools that are co-constructed by members of the community (Smith et al., 2017). The EV3 programming challenge served as the domain of interest. The community was the participants who were performing the identity of computer scientist while engaging in a range of epistemic practices of engineering. Merging conceptual ideas about community of practice into the concept of figured worlds is pertinent to expounding on how assemblages within socially constructed realms offer opportunities for actors to exhibit individual and collective agency in practice.

While participants enjoyed learning about the foundational aspects of EV3 computer programming from Mr. Davis, participants mediated much of their learning through their community of practice. Because participants were the main characters within the socially constructed world, they had the power to organize themselves into an epistemic community. Urrieta (2007) emphasizes that “figured worlds are socially organized and reproduced, which means that in them people are sorted and learn to relate to each other in different ways” (p. 109). Participants organized their community of practice to provide peer instructional support and feedback which in turn fostered both individual and group directed learning. As participants were individually engaged in problem solving activities associated with developing EV3 programming
applications, they would often come together to compare and contrast the design of their program. Participants congealed around knowledge construction related to the multiple solutions that they created to solve the problem. Discussing multiple solutions reflected innovation and creativity across participants’ EV3 programming applications. As participants exchanged ideas within their epistemic community, they were demonstrating the epistemic practices of engineering related to communicating effectively and working well in teams. Additionally, forming an epistemic community in which identity formation occurred, served as a social intervention that positioned their identities in spite of their perceptions of STEM representation being dissociated from their sociocultural identities.

At the onset of the activity Mr. Davis assured them that no one programming application would be identical because each individual thinks differently, so their programming solutions would be different. The difference of ideas stemming from participants’ programming solutions were significant in broadening the knowledge base within their epistemic community. During the EV3 programming activity, participants shifted their improvisational roles within the community of practice from computer scientist to instructor in an effort to support collective learning. During the programming activity, Devonte vocally expressed challenges to which Brandon responded, “Hold on, start your robot and let me see. I’ll help you figure it out.” All of the participants were programming their robots to complete the same task via the same activity sheet, so Brandon could have simply looked at his computer screen and explained to Devonte how he programmed his robot and instructed him to copy his codes. Instead, he looked at Devonte’s solution and assisted him with his idea. Brandon individually was engaged in the knowledge building process. Additionally, in assisting Devonte, Brandon positioned himself as a legitimate member in the epistemic community. Brandon affirmed Devonte’s identity as a
legitimate member by positioning Devonte to make a unique contribution to the solutions presented in their epistemic community. Brandon and Devonte displayed the epistemic practices of engineering associated with *developing multiple solutions, working effectively in teams* and *communicating effectively*. Additionally, both participants demonstrated epistemic agency in that they took ownership of the learning process and added to the body of knowledge within their learning community.

The interaction between Brandon and Devonte also reflected Lave and Wenger’s (1991) concept of legitimate peripheral participation. Within this concept, members within a community of practice occupy the identity of an expert, practitioner, or apprentice. The apprentice is the novel learner whereas the practitioner has progressed from a novel learner through the acquiring of more experienced knowledge and skill. The expert within the community of practice is positioned as an authority with respect to knowledge. Within the legitimate peripheral participation, the apprentice may engage in learning with the expert, however, in many cases within the community of practice the apprentice engages in learning with the practitioner. Additionally, the acquisition of the cultural practices within the community of practice is significant to legitimizing the identity of the apprentice and the practitioner within the community of practice. Devonte could have requested assistance form Mr. Davis since he was the expert within the community of practice and could provide the most knowledge related to the cultural practices of problem solving in computer programming, however, Devonte allowed Brandon, the practitioner, to engage him in the cultural practices of problem solving. Through this social interaction between Devonte and Brandon both participants advanced in the epistemic practices of engineering and through this social interaction both identities were legitimized within the community of practice.
The findings from this study are congruent with studies that posit that learning communities are essential for cultivating epistemic agency. In a study, Stroupe et al. (2018) established four critical components necessary for developing epistemic agency within classrooms. The first component is creating opportunities to solicit and build on student knowledge as a resource for learning. During the programming activity, actors served as a type of living curriculum for one another during the knowledge building process. This phenomenon was observed when Aaron decided to quit temporarily due to his frustration during the programming activity, but then pivoted his role to that of an instructor for Bernard in which both participants were able to progress toward mastery of knowledge and skill. The second component was creating *opportunities to build knowledge through participation in practices*. This phenomenon was observed as participants displayed a myriad of epistemic practices of engineering related to *developing processes to solve problems, designing multiple solutions, working effectively in teams, communicating effectively, and considering the problem in context*. The third component was creating *opportunities to build a knowledge product that is useful to students*. Each participant during the EV3 programming activity exemplified persistence from failure. While participants were met with frustration and challenges during the programming activity they were motivated to progress to mastery. One participant named Kia began to create programming challenges for herself which were outside of the scope of the assignment. Thus, the EV3 programming activity enabled participants to experience identity transformation and enhance their personal sense of self-efficacy which appeared useful and valuable to participants. When I asked Bernard what he thought about the programming activity, he stated, “This is showing me that I can do anything that I try”. The fourth component was creating *opportunities to change structures that constrain and support action*. This last component pertains to how
participants created change within their local environment and will be discussed within the context of STEM Night in the next section. Participants’ behaviors within their community of practice allowed them to engage in improvisational acts that displayed identity transformation both individually and collectively.

**Theme 4: Participants raised STEM awareness, stimulated community engagement, demonstrated enhanced cognitive practices, and displayed epistemic agency in their showcasing of their engineering design prototypes for STEM Night**

The target anchor examined how participants progressed towards epistemic agency as STEM learners. Epistemic agency is developed within the context of prior knowledge, skill, and dispositions related to identity and self-efficacy (Taylor & Brand, 2021). The activities within the target anchor enabled participants to use epistemic tools to create knowledge and decide how such knowledge would be used. This anchor positioned participants to have the most autonomy during the knowledge building process in that they identified the problem, devised the methods, designed their process, and created solutions. In addition to the knowledge and skills gained in previous anchors, the target anchor hinged on participants development of identity in practice through the engagement of the epistemic practices of engineering in their refigured worlds. The target anchor also hinged on the community of practice that was developed in which their identity was negotiated and legitimized. Across each of the previous anchors, the locus of control continued to shift toward participants, however, within the target anchor the participants were positioned with the most power associated with the knowledge building process.

Participants were given instructions in regard to designing a robot prototype for STEM Night and initially began to disengage once they recognized that they had full epistemic autonomy. It appeared that participants regressed from their improvisational identities as
problem solvers. However, their reaction of disengagement was consistent with other studies. Stroupe, Caballero, & White (2018) note that cultivating epistemic agency is challenging because students are scripted with the idea that “teachers deliver the correct canonical information to students, who subsequently reproduce information and methods privileged by the teacher or other instructional authority, such as a visiting scientist” (p.1177). Spence (2020) notes that participants tend to disengage through various modes of procrastination when the task at hand seems to align with their perception of their own competence or when they have low regulation in learning (Grunschel, Patrzek, & Fries, 2013). Furthermore, Spence (2020) indicated that in her study, which was designed to cultivate epistemic agency, that students were impatient with the problem exploration phase and required scaffolding using additional epistemic oriented activities. As I used techniques of scaffolding that broke up the problem exploration phase into chunks, participants began to explore issues in their community. Participants again entered their refigured world in which they identified themselves as potential STEM contributors. This phase of the learning experience was aligned with Vygotsky’s (1978) ideas in which he noted that learning does not occur in a linear path nor distinct and set phases. Learning then occurs across messy processes of progression, regression, progression with reflection sprinkled through as learners move toward mastery of knowledge, skill, identity, and self-efficacy.

The open ended nature of this activity required a more developed demonstration of the concept of ‘identity in practice’ thus participants had to engage in the epistemic practices of engineering with a more advanced approach. In prior anchors, participants were given identities to perform within the refigured worlds. During the entry anchor they were invited to act as engineers working for Brita. During the intermediate anchor they were invited to act as computer scientists. During the target anchor participants had the autonomy to author their identities within
their refigured world. Participants used the activity sheet to document their ideas about the problem that they wanted to address as well as they type of prototype that would be designed to address the issue. They provided significantly more ideas than they had in the entry anchor. Across all groups participants used drawings to explain their ideas. For example, the activity sheet for Kia’s had a sketch of the programming application as well as the robot design provided by her team member Chris. These sketches served as a model which explained how the prototype would be designed to address the problem. Isaac’s (2021) study indicates that incorporating models and tools for representation are significant in progressing students along a trajectory of developing sophistication as it relates to epistemic practices of engineering. The specificity of the processes across both groups required cyclical phases of discussion of ideas and iterative testing of those ideas within their group. Participants exhibited communicating effectively, but additionally their conversations reflected more depth. Isaac (2021) study also indicated that think aloud methods in which participants methodically discussed processes during the engineering design process was significant to progressing students’ epistemic sophistication related to engineering practices. These findings were significant in depicting how ‘identity and practice’ was demonstrated in the target anchor. Possessing the ability to see oneself as an engineer cannot be excluded from the epistemic practices of engineering that cultivate the habits of mind in engineers. Holland et al. (1998) notes that the realm of figured worlds enables actors to perform out who or what they claim to be (Günter et. al., 2021).

Participants demonstrated the concept of ‘identity in practice’ across learning activities. Participants also positioned themselves as agents of change within their local community. As participants were engaged in designing their robots in class, they were discussing their STEM experiences with students in their school outside of class. This discussion served as recruitment
tools that raised STEM awareness. As a result of the ongoing conversation, a ninth grader, Aaliyah, from a nearby junior high school joined the after school program. Denise, the self-appointed class representative, integrated Aaliyah into the community of practice. I suggested to Aaliyah that I could quickly teach her the basics of EV3 programming so that she could start working with the other groups with some programming experience. She informed me that she wanted to watch the other participants. Denise’s dialogue with Aaliyah was effective in that by the end of the night Aaliyah was programming with the other participants and she became a legitimate member in the community of practice. Lave and Wenger (1991) refers to this phenomenon as legitimate peripheral participation in the community of practice. Lave and Wenger (1991) note that as a newcomer crosses boundaries into a community of practice they are offered a peripheral position in which they are not part of the in group nor part of the out group rather they occupy a unique space in the peripheral region. Through active engagement with the community of practice they are repositioned in the community as a legitimate actor (Lave & Wegner, 1991).

STEM Night started off with students who were not a part of the robotics program signing up to be a part of the program. While some participants positioned themselves within the periphery, Camille, did not. Camille was a friend of Aaliyah who decided on STEM Night that she was ready to be a part of the program. When participants introduced themselves to the audience, Camille introduced herself as being part of the team. Camille entered the community of practice with a high sense of self-efficacy on the strength of the participants’ experiences in the program. Bandura (1977) posits that when people observe other people with similar identities to them achieve success, it raises their belief and expectation that they will also succeed prior to engaging in the actual experience. When the participants’ younger siblings saw
their robot prototypes being presented to the local community they were also inspired to learn about robotics. Participants expressed enthusiasm when engaging their parents in the STEM oriented activities and presenting their robot prototypes to the community. Participants had legitimized their identities within their community of practice in the classroom. Additionally, participants extended their identity to assume the role of experts. Participants were introducing their epistemic tools and changing their community’s perception of what they were capable of. When Kia’s mother’s saw her robot prototype, she asked her why she wasn’t majoring in programming. Prior to this program, Kia’s mother had not considered programming as a possibility for her daughter; however, Kia’s robot prototype was an invitation to her mother to reimagine possibilities.

The findings in this anchor were interesting because the participants’ statements from the entry anchor were actualized in the target anchor which reflected a progression toward epistemic agency. During the entry anchor, when I asked the participants to share their thoughts related to the significance of the contributions from the students engaged in STEM to society one participant stated,

They are providing a way to clean water. They are also becoming role models for other girls that might want to become engineers. They are paving a way for future African American girls and women to become successful in STEM.

Participants engaged in a series of engineering activities in which they designed prototypes. The showcasing of their EV3 robot prototypes raised STEM awareness and served as a physical representation of the possibilities with STEM for African American students in their community in similitude to the water filter of the students engaged in STEM research that they read about. Another, participant stated, “They … inspired other black girls to take on STEM projects.”
While participants perceived STEM to be racialized and gendered, they figured a world in which Denise could serve as the class representative, Kia could design challenges in programming beyond the curricular requirements, and Camille could position herself as part of the team. Participants also figured a world in which they could discuss how they perceive their sociocultural identities as barriers to STEM, yet they did not internalize these deficits instead they inspired their community to “take on more STEM projects”. Participants were bringing the community into their refigured world and engaging the community in identity transformation with an enhanced sense of self-efficacy.

During the entry anchor, participants were asked what they would need to make STEM contributions, one participant stated, “Supportive people with the same ideas.” Other participants also noted the importance of being in community. These statements aligned with their behaviors. During the intermediate anchor as well as the target anchor, participants mediated both identity formation and learning through their community of practice. Another participant stated, “You need determination, drive, grit, and the right mentality. I could contribute a unique view on problems that could help others to figure out how to solve the part they are stuck on.” Participants demonstrated the epistemic practices of engineering that is associated with persistence and learning from failure across all three anchors. In addition, participants shifted roles from being a co-creator of knowledge to performing the role of a teacher in support of their peers’ progression toward mastery of knowledge and skill.

Lastly, participants discussed how they would make a STEM contribution to their community during the entry anchor. One participant stated, “I would like to contribute power savings plants in my community. I would need many solar panels and energy saving materials.” The sentiment behind this idea was actualized in the target anchor. Participants not only directed
the knowledge building process by using the epistemic practices of engineering to construct knowledge, but they also chose to use their knowledge and epistemic tools to empower their community.

**Limitations**

There were three distinct limitations related to this study. The first limitation was that the engineering design curriculum originally designed for the study was intended to span the course of three and a half months. However, due to the COVID-19 pandemic and other administrative issues beyond my control the curriculum was shortened to six weeks. Thus, the engineering design curriculum did not provide participants with the full scope of the engineering design process along with the epistemic practices of engineering. Participants did not fully understand the connection between the epistemic practices of engineering and the practices that they were demonstrating.

The second limitation was that although this study was about the epistemic practices of engineering and epistemic agency, the curriculum did not develop participants epistemological understandings because we did not explicitly touch on how knowledge is created nor how practices generate knowledge. Participants did not have to legitimize knowledge claims or perform other interrogation epistemic practices related to knowledge building. Rather the curriculum focused on the emerging practices and processes related to building prototypes in engineering. Additionally, a learning module should have been created to teach participants about the epistemic practices of engineering prior to engaging in engineering design challenges.

The third limitation was that although the learning progression was designed to engage participants in the epistemic practices of engineering it was not anchored in content. Learning progressions are designed to progress content knowledge. While many learning progressions are
heavily content focused at the expense of practices, the learning progression designed for this study was heavily focused on practices at the expense of cultivating depth of content knowledge. Thus, at the end of the target anchor participants experienced breadth of topics as opposed to growing an in depth understanding of a topic. Orienting the learning around specific content would have allowed participants to understand and interrogate the construction of knowledge using the epistemic practices of engineering.

Implications

The learning progressions designed for this study focused on how to cultivate identity and self-efficacy through the engagement of the epistemic practices of engineering in an effort to move participants toward epistemic agency. The learning progression for this study prioritized equity and was presented as an example of a sociohistorical response for African American populations that endured a legacy of epistemological estrangement from STEM related communities. Using qualitative methods to explore participants’ experiences as they traversed the learning progression allowed for a rich description of findings. This study provides several implications for educational practices related to epistemic practices of engineering, epistemic agency, and action research in engineering education. What follows is a discussion of the implications of this study.

Implications for Learning Progressions

Within the last decade, engineering education in K-12 has received significant attention by policy makers, stakeholders, researchers, and educators. Simarro and Couso (2021) state that “the role of engineering education has been modified, gaining more prominence and centrality in pre-college education” (p. 1). In response to the prominent interest of engineering education much research is being conducted to create an engineering education framework for K-12.
Research has indicated the effectiveness of learning progressions in their ability to organize curriculum, assessments, and instruction (Corcoran et al., 2009). In an effort to create a research informed approach, the Engineering Learning Progression Framework was recently created and encompasses three main components which are the engineering habits of mind, the engineering design process, and curriculum that focuses on designing technology (American Society for Engineering Education, 2020).

Within the last decade, in conjunction with education reform initiatives, learning progressions are being oriented towards equity. In addition, engineering within the National Research Council has also adopted an equity focus reflected in their education-for-all approach (Simarro & Couso, 2021; NRC, 2012). In the Engineering Learning Progression Framework document, they state the goal of engineering literacy for all is to “ensure that every student, regardless of race, gender, ability, socioeconomic status, or career interests, has the opportunity” to engage in, adapt to, and thrive in engineering related environments whether in the workplace or in society in general (American Society for Engineering Education, 2020, p. 4-5). While these efforts have been expressed goals for some time reflected in the science for all mission, the needle of progress has not yielded noticeable results especially related to science, STEM, or engineering participation for African American students.

Engineering Learning Progression initiatives have the potential to enhance the educational experience for all; however, there is small body of research being conducted with minority populations that need equity within the educational system. Participants in this study, are African American, and had very limited STEM capital prior to starting this STEM program in their school. Many of the participants have aspirations of majoring in engineering, yet they have very little background knowledge about STEM. Additionally, due to the socioeconomic
positioning of many schools that have high populations of African American students there is a severe lack of resources which impede the goals of authentically exploring engineering. Thus, conducting research with minoritized populations is crucial for providing STEM resources. Additionally, assessing the effectiveness of equity-oriented learning progressions for engineering begins with conducting research with populations that need access to STEM especially related to engineering.

One of the major shifts in learning progression research related to engineering is enhancing students’ epistemological understanding beyond simply engaging students in the engineering design process. Engineering learning progressions are shifting to engage students in the habits of mind of engineers. Science teachers are typically tasked with teaching the habits of mind associated with science and engineering within the Next Generation Science Standards Framework (NGSS) or within modified versions of NGSS that are being adopted nationally. Typically, science teachers do not have an engineering background which may be challenging when attempting to design curricular learning progressions or learning objectives for engineering education. In response to these challenges Cunningham and Kelly (2017) derived sixteen epistemic practices of engineering that are critical for developing the habits of mind of engineers in students in K-12. In this study, the epistemic practices of engineering were used as an evaluation tool for examining the curriculum, learning objectives, and student engagement during engineering design activities. Evaluating the curriculum using the epistemic practices of engineering was critical in identifying the strengths and weaknesses in the curriculum design for this study. In addition, implementing the epistemic practices of engineering within a learning progression enables instructors to set clear learning goals that are critical for developing epistemic sophistication over time. Deductively coding the curriculum, student behaviors, and
student work using the epistemic practices of engineering provided structure for pedagogical reflection and served as a tool to enhance instructional practices related to engineering education.

**Implications for Epistemic Practices of Engineering**

The epistemic practices of engineering are a significant contribution to the body of research for engineering education. While the Next Generation Science Standards (NGSS) Framework introduces practices associated with engineering in tandem with science practices, they do not explicitly focus on the social nature and social processes associated with engineering. Cunningham and Kelly (2017) broadened research discussions in engineering education by including the social dimensions of engineering such as communicating effectively, working well in teams, and seeing themselves as an engineer. The epistemic practices of engineering are framed within Vygotsky’s (1978) concept of sociocultural learning theory and zone of proximal development. Cunningham and Kelly (2017) state, “Learning often occurs through engagement with more knowing others and draws from the historical knowledge of a culture” (p. 501).

Cunningham and Kelly (2017) situate the epistemic practices as social and cultural. The social component of the epistemic practices of engineering refers to the fact that knowledge is co-constructed within a community, and cultural in that they bear social and historical influence. The epistemic practices of engineering are also aligned with the concept of identity-in-practice which posits that as an actor enacts the epistemic practices of engineering, they are recognized as legitimate participants within the epistemic community.

Although Cunningham and Kelly (2017) noted identity formation in their research related to the epistemic practices of engineering for K-12, their research does not address sociocultural influences that impact the socialization process into the epistemic community. *Seeing themselves as an engineer* is quite different from *being seen as an engineer*. The African American
participants in this study have a perspective that STEM is racialized and gendered; nevertheless, their perspective is congruent with the literature. Lee et al. (2020) conducted a mixed method survey at the university level. Lee et al. (2020) discovered that marginalized students that were STEM majors were not accepted into STEM communities and more specifically engineering communities despite their engagement in the social practices assigned to the discipline. STEM majors from minoritized populations such as African Americans and Hispanic communities reported having their contributions minimized or ignored, having to deal with stereotype threat, and not being taken seriously. Additionally, minoritized populations in that study reported that ‘the more knowledgeable others’ in the epistemic community discouraged them from pursuing their academic goals. Research is replete with studies that discuss the displacement that minoritized students experience in relation to STEM communities with dominant populations. These accounts are reflective of deficit credibility that is projected onto minoritized communities that have endured a legacy of epistemic injustice. This legacy of epistemic injustice has resulted in minoritized populations being epistemologically estranged from STEM communities. For example, African Americans have had their intellectual capacity questioned since slavery, the Jim Crow Era, and beyond. Unfortunately, these tropes continue to persist even when engaging in the social dimensions of the epistemic practices of engineering.

Much research has been conducted to understand the initiatives that need to be instituted to help minoritized populations see themselves as engineers. These initiatives often focus on addressing internalized deficits that interfere with the concept of identity formation in STEM so that they can persist. While this work has been groundbreaking in creating research-based approaches to increase the STEM participation of underrepresented groups, the research trends tend to reflect a pathologizing narrative that insinuates that minoritized populations are all
burdened with the myth of inferiority. The participants in this study understood that others (dominant populations) perceived them as inferior, but they did not internalize this narrative in relation to their identity. It is also important to represent minoritized populations that have a strong sense of self in the literature. The myopic focus on identifying methods to ‘fix’ the perceptions of minoritized populations creates a blind spot in research in which there is minimal research being conducted with dominant populations related to helping them to see ‘others’ as engineers. The lack of research regarding the perspectives of dominant populations related to how they perceive the ‘other’ in STEM leads to the formation of epistemic communities that continue to perpetuate epistemic injustice in K-12, higher education, and industry. Thus, the research related to the social dimensions of the epistemic practices of engineering should consider how the sociocultural positioning of the actors are legitimized or delegitimized in epistemic spaces. Broadening the discussion to include the sociocultural influences on knowledge building spaces is one way to bring discussions of equity as well as social justice into educational research for the epistemic practices of engineering.

**Implications for Epistemic Agency**

Developing students’ epistemic practices is key to developing their epistemic agency. Within the NGSS framework the science and engineering practices are designed to aid students in constructing knowledge (Miller et al., 2018). The epistemic practices of engineering provide a more comprehensive catalog of practices that engineers use to construct knowledge. Epistemic agency encompasses students directing the knowledge building process. Additionally, in directing this process students are able to determine why and how the knowledge will be constructed, as well as determine how the knowledge will be used. Another significant aspect of epistemic agency is being positioned to interrogate the legitimacy or validity of the knowledge
constructed through analysis, argumentation, and evidence. While research has shifted to emphasize the development of epistemic agency in classrooms, the framework for epistemic agency is still undergoing refinement.

While varying definitions of epistemic agency in STEM have congealed around the importance of knowledge building practices, the intriguing discussions that researchers are engaging in relates to answering the question of “knowledge construction for what purpose?” Lakin, Mastrogiovanni et al. (2021) note that “Stereotypically, engineering is seen as affording only the pursuit of status values, such as high pay, independence, or respect from others, which may be inconsistent with the values of some students…” (p.42). The high status that is often socially ascribed to engineering also bears cultural elitism that may stratify populations based on sociocultural ranking. Research has indicated that people are more inclined to pursue a career that is congruent with their values and the “perception of the values that the career meets” (Lakin et al., 2021; Diekman & Steinberg, 2013; Merolla & Serpe, 2013). In this study, participants were given an opportunity to explore what they perceived as valuable STEM contributions and then were positioned to devise the methods to create knowledge in the form of an engineering prototype. Positioning students to construct knowledge and determine how that knowledge will be used enables students to not view engineering as “a step by step approach” to solving problems instead it allows them to “participate in a complex and rich cultural practice” (Simarro & Couso, 2021).

For this study, the conceptual definition of epistemic agency for STEM learners drew from the work of many researchers in the field that are doing significant work. In this study, the conceptual definition for epistemic agency for STEM learners encompassed three components: identity formation, community of practice, and community engagement. These conceptual
components are exhibited in the field; additionally, these components are also designed from a lens of social justice. The components are designed to cultivate mastery of practices related to the knowledge building process and agency to use the knowledge to impact their community. Additionally, the identity formation component in the conceptual definition of epistemic agency as STEM learners was designed to position participants as experts which is a sociohistorical response to a legacy of epistemic injustice.

**Practical Implications for Afterschool Programs**

The findings from this study provide many practical implications for educational researchers and educators. Young and Young (2018) note that schools that serve a large demographic of African American students of low socioeconomic status have limited opportunities to explore STEM interests. The lack of STEM access is not simply a missed opportunity it is an act of epistemic injustice. The findings from this study indicate that when participants were given access both structurally and pedagogically, they were able to actualize their STEM potential. Thus, educational researchers and educators in those schools may consider how to create more out of school and or afterschool opportunities for students to offset educational inequities associated with STEM participation. Structural access is fundamentally significant when providing STEM opportunities. For this study, having access to resources for engineering design activities, EV3 robots, and computers were critical components for engaging participants in authentic STEM experiences, however, instructional design and pedagogical practices provided a different type of access.

The Next Generation Science Standards (NGSS) presents teachers with a framework to explore various topics in science and engineering. However, the NGSS framework overlooks dispositional factors that are key to creating sustained engagement during learning. The findings
from this study indicate the significance of progressing identity formation with cognitive practices displayed as the epistemic practices of engineering during learning through instructional design. Within each anchor of the learning progression, participants were solicited to enter into an imaginary space or a figured world in which they could engage in identity transformation during learning. Additionally, this figured world which was an afterschool program served as a counterspace to confront situated norms related to race and gender that dissociated their identities as valuable STEM contributors. Participants were asked to take on the role of scientists, engineers, and computer programmers and were given problems to solve while occupying these imaginary roles. Additionally, participants were taught the practices associated with the profession which served to engage them in using the habits of mind associated with each role as well as introduce them to a STEM profession. Lastly, participants worked with local experts in the field within a community of practice which legitimized their identity during their learning experience. Educators in afterschool spaces may want to consider how to create learning opportunities through curriculum that positions students to assume various professional roles, engage in authentic problem solving while improvising in that role, and collaborate with actual experts in a community of practice to legitimize their identities while improvising in that role.

The improvisation of identities in this imaginary world solicits deeper engagement during learning while positioning students to see themselves as STEM professionals. Additionally, this level of engagement contextualizes their learning in real and authentic scenarios within a legitimate community of practice.

The equity initiative within educational frameworks such as NGSS is aimed toward closing achievement gaps through equitable instruction that promotes equality of outcomes. Closing achievement gaps is a lofty goal for African American students, however, performing
proficiently on standardized test does not do much for meeting the needs of disenfranchised communities. Afterschool STEM projects and opportunities for historically excluded groups should not only consider how to create educational capital for the student, but it should also consider how such educational capital can be situated to serve the needs of the community. Establishing the development of epistemic agency as a learning goal enabled participants to reimagine themselves as agents of change by creating tools to solve science related issues in their local community. If social justice is to be achieved in education through pedagogical approaches, then such approaches must merge educational transformation with social transformation. Such transformation can be achieved when educators and researchers design curriculum in which the student is positioned to use the knowledge, skills, and practices to create solutions to problems that exists within their own community.

The findings from this study indicate the effectiveness of the program in orienting participants toward engineering and computer programming. Future research would consider how to recreate this program for other STEM professions such as the medical field in which African Americans have been historically excluded from. Creating a program that is modeled after the structure of the Actualizing STEM Potential project would be a useful tool in starting a pipeline of African American students into the medical fields through early exposure. An after school project would unmask the many students that possess hidden medical solutions for their local community. There are a multitude of African American students, like the participants in this afterschool program, that are waiting to experience a transformational change that leads to epistemic agency.

**Implications for Future Research**
Given the findings of this study, there are several strands of research that could be conducted to advance our understanding of implementing equity oriented learning progressions. The learning progression for developing participants’ epistemic agency as STEM learners encompassed three main components. The first component for the entry anchor focused on identity formation which entailed the concept of identity in practice through engaging in the epistemic practices of engineering. The second component for the intermediate anchor entailed working within a community of practice with an expert in effort to build an epistemic community in which they can progress toward becoming age appropriate experts. The third component for the target anchor entailed using the epistemic practices of engineering to construct knowledge for the purposes of addressing STEM related issues that are valued by the participants. This process takes time, so the first strand of future research could extend the research time for implementing a learning progression. Additionally, participants should be introduced to the epistemic practices at the beginning of the learning progression so that they can monitor their development in tandem with the instructor.

The second strand of future work could entail reconceptualizing epistemic activities across all three anchors so that participants could develop a greater range of epistemic cognition and epistemic sophistication. The learning objectives would need to explicitly design activities in relation to developing and evaluating particular epistemic practices. Epistemic activities could entail developing science practices in tandem with epistemic practices of engineering so that when participants engage in engineering design activities, they approach it with greater epistemic sophistication.

The third strand of future work should focus on integrating science content within this learning progression. In this way participants will understand how epistemic practices create
knowledge in science and inform engineering. Additionally, participants would gain a broader understanding of how science practices are used to inform engineering practices. This would also enable participants to grow in depth of knowledge which is one of the main objectives of learning progressions.

The fourth strand could explore broader community partnerships within a future study. Future studies should imagine opportunities with the community to address local or global science related issues for the target anchor of the learning progression. As participants develop in their level of expertise, they can extend their community of practice to their local community to facilitate shared knowledge creation. Researchers could work with communities to rebrand themselves as STEM hubs that foster community activism related to STEM issues in their communities.

Conclusion

The purpose of the study was to qualitatively explore participants’ development of epistemic agency as STEM learners as they engaged in activities across a learning progression designed to advance the epistemic practices of engineering. Within the learning progression, participants created a spatial dimension represented as a refigured world to manage the dissonance between their perceptions of epistemic exclusion from STEM and their perception of themselves as being capable contributors in STEM. This refigured world enable participants to situate identity formation and self-efficacy development through the engagement of epistemic practices of engineering in relation to engineering design activities. Additionally, identity formation and self-efficacy development was mediated through a community of practice. This community of practice allowed participants to refigure themselves as agents of change that raised STEM awareness within their community.
The data and analysis in this study provided a way to capture how participants saw themselves and each other as they grew in their demonstration of cognitive practices related to problem solving. Using the epistemic practices of engineering as a focal point enabled me to assess the curriculum design and assessed instructional practices in my pedagogical reflection. The findings in the study contribute to a broader understanding of how equity oriented learning progressions can be designed to promote epistemic justice, how sociocultural positionings influence epistemic communities, and how epistemic agents can use their epistemic tools to raise STEM awareness within their local community. Advancing students epistemic practices of engineering and epistemic agency as STEM learners is key to creating meaningful pathways into STEM for historically underrepresented students in K-12.
Epilogue

The participants in this study for the Actualizing STEM Potential program recently competed in the FIRST Robotics Bayou Regional in New Orleans, Louisiana. For this group of participants, it was there first time building a competition robot and their first time competing. Additionally, when I saw the participants at competition, I noticed that they had recruited more students into the program. During the build season of their robot, the participants experienced a myriad of challenges related to weather, school incidents, and technical difficulties. These challenges significantly impacted their ability to gain experience with operating the robot prior to competition. Despite these challenges, they ranked as high as 11th place out of 41 teams. Additionally, they were selected to compete in the qualifying rounds for the national competition.

Because this was their first competition, I was constantly interviewing them to understand their state of mind in relation to interacting with this new epistemic community at the robotics competition. I asked, Bernard, who was selected to be the main driver of the robot, if he was at all nervous because this was his first time. Bernard stated, “No, I’m not nervous! I’m just ready to get the robot on the floor.” When the robot was put on the floor for the practice rounds prior to competition, it experienced a plethora of technical challenges which caused the robot to not even move. Bernard and Aaron who were the drivers for the robot remained calm. The participants ran to the back where the robot was housed and fixed the technical issues and soon after the robot began working.

When I spoke to the participants about the design of the robot, they made sure to inform me of the work that they put in to design it. I said to Kia, “This is perhaps one of the most streamlined and simple robot designs that I have seen within the last 4 years of competition”. Kia
responded, “Just because it is a simple design does not mean that it was simple to build!” She and I immediately started laughing. I told her about how one of the robotics instructors contacted me and told me how instrumental Kia was during build season.

The participants showed enthusiasm in participating in the social dynamics of the robotics competition. Because of Denise’s leadership upon arriving to the FIRST Robotics Competition, she was selected to be on the publicity and press committee. She was so excited; she ran to me to show me her press badge! Kia told me about how excited she was to see that there were all girls’ robotics teams at the competition. She said to me, “They have all girls’ teams! I had to go and make friends with all of them”. While participants were very social with the other teams during competition, they preserved their tightly knit community of practice. After the participants lost the qualifying match, I went back to congratulate them on all they accomplished. I was so proud of them! When I saw them huddled with each other they expressed their disappointment. I said, “You all it was your first time, and you all did amazing!” To which Bernard responded, “These people haven’t seen anything yet, just wait until next year!”
References


the equity agenda forward: Equity research, practice, and policy in science education (pp. 5–20). Springer.


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https://doi.org/10.1007/s13524-018-0666-7


https://doi.org/10.1186/s40594-021-00274-3


Appendix A: IRB Memorandum

MEMORANDUM

DATE: April 23, 2021

TO: Brenda R Brand, Lezly M Taylor, Anza Laqueta Mitchell

FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Actualizing STEM Potential in the Mississippi Delta

IRB NUMBER: 15-417

Effective April 23, 2021, the Virginia Tech Institution Review Board (IRB) approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at: https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 6,7
Protocol Approval Date: April 25, 2021
Protocol Expiration Date: April 24, 2022
Continuing Review Due Date*: April 3, 2022

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.
**SPECIAL INSTRUCTIONS:**

***Please note that your study has NOT yet received permission to resume in-person human subjects research (HSR) activities. When you are ready to resume, please submit a plan to resume by accessing the Virginia Tech IRB Protocol Management online system, select the protocol you want to resume, and select the option "Submit Plan to Resume In-Person HSR Activities" from the summary page. Do not resume in-person HSR activities until you receive notification from the HRPP that you may implement your plan.

An amendment will be needed if you plan to move activities online.

<table>
<thead>
<tr>
<th>Date*</th>
<th>OSP Number</th>
<th>Sponsor</th>
<th>Grant Comparison Conducted?</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/14/2015</td>
<td>15103211</td>
<td>National Science Foundation (Title: SPrEaD: Actualizing STEM Potential in the Mississippi Delta)</td>
<td>Compared on 04/17/2015</td>
</tr>
</tbody>
</table>

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.
Appendix B: IRB Permission Slip

Research Participant Information and Parental Permission Form

Project Title: Actualizing STEM Potential in the Mississippi Delta

The purpose of this study is to invite your child to participate in pre-engineering robotics based project. The goal of the study is to investigate factors that influence your child’s learning in STEM and their decisions to major in STEM careers. The goal is to increase access to science learning and engineering design opportunities so that youth will be better prepared to pursue STEM (science, technology, engineering, and math) aspirations. You child will engage in pre-engineering course at the high school and participate as a robotics team member after school. Your child will also have an opportunity to work with mentor scientists and engineers from Mississippi Valley State University and Virginia Tech. By working together with the mentors, your child and the youth participants will gain STEM content, science and engineering practices, robotics, and teamwork. The goal is for youth to have access and opportunities designed to support students’ academic success and preparation for college and careers in STEM fields. Your child will have a unique opportunity to learn engineering design skills, engage in robotics competitions, and meet mentor scientists and engineers.

This study is open to high school students (in grades 9-12) enrolled in pre-engineering classes. The goal is to provide enriching STEM opportunities across the high school experience. Therefore, students are invited to participate starting freshman year and remain in the program throughout their high school career. Students that join should be interested in learning about robotics, using engineering design skills, interested in learning about STEM fields, and working in a team.

Voluntary Participation:
Participation in this study is voluntary. Your child may leave the study at any time.

Procedures of the Study:
Your child will be asked to do the following:
- Enroll in pre-engineering courses as part of a high school program of study.
- Attend robotics sessions after school.
- Participate in sessions and group interviews may involve audio and/or video recording.
- Complete periodic electronic surveys.
- Complete course evaluations.
- Attend at least one regional robotics competition each year.
In addition, the researchers will observe the classroom interactions, and take notes on the events as they occur naturally during the learning process.

Potential benefits & potential risks:
The potential benefits include:
1. Access to enriching STEM and robotics learning opportunities.
2. Support for increasing science achievement in school.
3. Opportunities to develop science practices and engineering design skills.
4. Mentorship from scientists and engineers.

Participant risks are minimal and limited to potential anxiety of participation.

Questions:
If you have concerns or questions about this study, please contact the researcher (Brenda R. Brand, Professor of Science Education, Public Safety Building 330 Sterrett Drive, Blacksburg, VA, bbrand@vt.edu, 540-231-8334).

Virginia Tech Institutional Review Board Protocol No. 15-417
Approved April 25, 2021 to April 24, 2022
**Participants Rights:**
Your child may withdraw from the study at anytime. Should you have any questions or concerns about the study’s conduct or your rights as a research participant, or need to report a research-related injury or event, you may contact the Virginia Tech Institutional Review Board at irb@vt.edu or (540) 231-3732.

**Audio/Video Recordings:**
During the study, there are times were audio and video recordings will be used to document activities of participants. Participants are free to ask for the recording to be stopped at any time and may request to have those records destroyed. You and your child must be comfortable with recordings at all times.

**Confidentiality of Participants:**
1. Your child’s identity will be protected. Data will be maintained using non-identifiable information and the use of pseudonyms.
   Regarding audio and video recordings:
   1. All recordings will be stored digitally on password protected hard drives.
   2. Only the primary researcher will have access to the data including recordings. Only the primary researcher will transcribe recordings.
   3. Data sources including recordings will be erased/destroyed after five years following the termination of this study.
   4. The recordings may be used in presentations and publications.

**DOCUMENTATION OF INFORMED CONSENT.**

*For Youth Participant:*
Your signature below means that you voluntarily agree to participate in this research study.

<table>
<thead>
<tr>
<th>Participant Signature</th>
<th>Date</th>
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<table>
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<tr>
<th>Participant Name (Printed)</th>
<th>Age</th>
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*For Parents/Guardians:*
I voluntarily agree to allow my child to participate in this study. Your consent below shows that you have had the opportunity to read about and ask questions about the purposes and procedures of this study.

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<th>Parental/Guardian signature</th>
<th>Date</th>
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<table>
<thead>
<tr>
<th>Parental/Guardian Name (Printed)</th>
<th>Relationship to child</th>
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Choose one:

- [x] I agree to allow my child to be audio or video recorded during this project.
- [ ] I do not agree to have my child be audio or video recorded during this project.

Initials
### Appendix C: Student Participant Interview Questions

<table>
<thead>
<tr>
<th>Phase of learning progression</th>
<th>Semi-structure interview questions</th>
<th>Focus group questions at the conclusion of learning progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor 1</td>
<td>▪ What type of skills did you use to create your models during the engineering design activities? How did those skills impact the design of your solution?</td>
<td>▪ Why did you join the ASP robotics program?</td>
</tr>
<tr>
<td></td>
<td>▪ Reflecting on the performance of your model which skills could you have to improve the design?</td>
<td>▪ What has caused you to remain in the program?</td>
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<tr>
<td></td>
<td>▪ In regard to the African American scientist and engineers that you explored, which scientists/engineers’ contributions resonated with you and why?</td>
<td>▪ What are activities and experiences you found beneficial?</td>
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<tr>
<td></td>
<td></td>
<td>▪ Has the program caused you to look at yourself differently? If so, how?</td>
</tr>
<tr>
<td>Anchor 2</td>
<td>▪ How did it feel to work with local scientist and engineers? Describe your progress from your initial experiences of working with local scientist and engineers to now.</td>
<td>▪ What activities did you find to be beneficial?</td>
</tr>
<tr>
<td></td>
<td>▪ What knowledge and skills did you learn that will be useful for your engineering design project?</td>
<td>▪ What activities did you find challenging?</td>
</tr>
<tr>
<td></td>
<td>▪ What are some ways that you would like to science be used? What science related issues are important to you?</td>
<td>▪ What knowledge and or skill did you develop that you found to be impactful? Why did you find that to be impactful?</td>
</tr>
<tr>
<td></td>
<td>▪ What skills would you like to develop to your goals associated with how you would like to science to be used?</td>
<td>▪ Has this program caused you to consider a STEM career? What would you like to do in STEM?</td>
</tr>
<tr>
<td>Anchor 3</td>
<td>▪ What is the reason behind the engineering challenge that you selected for this project?</td>
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