Second Edition

Culturally Specific Pedagogy in the Mathematics Classroom

Strategies for Teachers and Students

Jacqueline Leonard

CULTURALLY SPECIFIC PEDAGOGY IN THE MATHEMATICS CLASSROOM

Advocating for the use of culturally specific pedagogy to enhance the mathematics instruction of diverse students, this revised second edition offers a wide variety of conceptual and curricular resources for teaching mathematics in a way that combats and confronts the forms of oppression that students face today. Addressing stratification based on race, class, and gender, Leonard offers lesson templates that teachers can use with ethnically and culturally diverse students and makes the link between research and practice. Connecting cutting-edge and emerging technologies to culturally specific pedagogy, the second edition features new chapters on mathematics and social justice, robotics, and spatial visualization. Applying a more expansive focus, the new edition discusses current movements such as Black Lives Matter and incorporates examples of rural and tribal students to paint a broader picture of what culturally rich mathematics classrooms actually look like. The text builds on sociocultural theory and research on culture and mathematics cognition to extend the literature and better understand minority students' goals and learning needs. Including new discussion questions and new examples, lessons, and vignettes of integrating culture in the mathematics classroom, this book employs pedagogical research to field-test new instructional methods for culturally diverse and female students.

Jacqueline Leonard is a professor of mathematics education and former director of the Science and Mathematics Teaching Center (2012–2016) at the University of Wyoming, USA.

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Strategies for Teachers and Students

Second Edition

Jacqueline Leonard

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IN MEMORY OF
My brother:
Frederick Terence Leonard Sr.
(1955–2005)
My uncle:
Odell Quinn
(1935–2000)
&
My grandmother:
Louvenia Campbell
(1918–2010)

THIS BOOK IS DEDICATED TO
My mother: Julia B. Leonard
My daughters:
Victoria Bloom
Cara M. Djonko-Moore
&
My grandchildren:
Christopher L. Cloud Jr.
Quiana R. Cloud
Aaron T. Djonko

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FOREWORD

Mathematics educators, mathematics teachers, and teachers of mathematics (K–16) have always known that there is a prescribed mathematics curriculum to be taught and have always been challenged to find creative ways to unpack and restructure the curriculum in ways to help students engage and, consequently, learn the mathematics. Mathematics educators have studied the cognitive state of students, the curriculum, and the methodologies of teachers in a search to find effective and efficient teaching and learning strategies. New ideas and strategies have been proposed through various “reform” movements, but, yet, many students, including large numbers of minority students, are still failing to achieve at acceptable levels and continue to find mathematics to be a mystery. This new edition of *Culturally Specific Pedagogy in the Mathematics Classroom: Strategies for Teachers and Students* offers hope that “culture-based” teaching strategies may address this achievement issue.

For more than three decades, researchers and practitioners have studied and researched the relationship of cognition and culture. Progress has been made in understanding this relationship as reported through theories, positions, and opinions using a variety of descriptions, including culturally relevant pedagogy, culturally responsive pedagogy, culturally congruent pedagogy, culturally sustaining pedagogy, culturally specific pedagogy, culturally responsive teaching, and culturally responsive instruction. Research linking students’ background knowledge (“funds of knowledge”) to achievement, and other

culturally based education curricula and instruction has also been proposed. While some of the basic tenets differ, each position adds to our overall knowledge base and has potential for changing the way we teach mathematics.

One first contribution of this new edition by Dr. Leonard is a clear description of each of the above theories and positions that will be invaluable to readers of the book. Her analyses include defining the tenets of each position and also the nuanced differences and similarities of each position. The result of her analyses allows the reader to see that the one thing all of the positions have in common is a call for teachers to consider that students' culture is an important factor in designing mathematics instruction. The research she presents supports the conclusion that "culture-based instruction" improves student achievement, develops strong mathematics identities, sustains Indigenous language, and offers respect for the background knowledge a student brings from his or her culture and community.

A second powerful contribution of this new edition is a dispelling of the notion held by some teachers (and others) that mathematics is "culture-free." Vignettes from her classrooms reveal how the prevalence of this notion continues after more than 30 years of culture-based education and research. But teaching from a cultural perspective often requires insights and skills not available to many teachers. Helping teachers to teach from a cultural lens places much responsibility on our teacher education programs. Teacher educators and preservice teachers must be willing to take on the subjects of race, equity, and social justice in teacher education programs. In my 30-plus years of teaching in teacher education programs, teaching mathematics from a cultural perspective was not a common methodological practice, and when it was practiced it was met with indifference because it went beyond the proposed mathematics curriculum. Leonard has shown throughout this book how teacher education programs and pedagogical practices can change to prepare teachers to teach differently.

This new edition by Leonard will certainly be welcomed by those mathematics educators, mathematics teachers, and teachers of mathematics who seek new ways of reaching students in their classrooms. Leonard's concept of culturally specific pedagogy is based on the foundations of critical race theory and Black feminist thought. In the first three chapters, she explains how culturally specific pedagogy is similar to and different from the myriad of other theories and positions. A main tenet is that all students should know that mathematics is a part of their history. According to Leonard, "teachers can help students to develop mathematics identity and participate in the mathematics socialization process by embracing historical figures that used mathematics and by helping students to understand how they can use mathematics in their everyday lives" (this volume, p. 20). Furthermore, the role and impact of poverty, racism, environmental situations, and gender discrimination on mathematics achievement are discussed in depth. Attention is also given to social justice issues and ways to teach mathematics from a social justice perspective.

In the first edition of *Culturally Specific Pedagogy in the Mathematics Classroom: Strategies for Teachers and Students*, Leonard used many "real-life" examples from history and other academic areas to tie mathematics to its applications. Throughout this new edition, she continues and expands on this approach by reaching into her experiences to provide insightful examples through topics filled with strong mathematics. A major focus is given to mathematics within robotics, computer programming, and aviation and aerospace. These areas are rich with important mathematics, and her presentations clearly show how the current curriculum can be extended to include applications from these areas. Further, she carefully describes the lives and outstanding careers of African-American women who pioneered in STEM fields. The point she makes is that, by showing how mathematics is applied to fields such as these, students will be encouraged to learn and the mathematics they learn will be more meaningful. Powerful examples are given to encourage

females to study the lives and achievements of other brilliant females. Finding such nontrivial mathematical contexts has always been a challenge for mathematics teachers, and this is where this book has great value.

This book brings together many topics that bear on mathematics teaching and learning. There is information here that will be helpful to all teachers (and students), from preservice to those who are experienced and enrolled in graduate study. The book is powerful in its discussion of challenging topics and opens the door for many questions that must be researched further. This book does not, in my opinion, solve all of the issues related to mathematics achievement, but it does identify many of the underlying factors that impact students' mathematics achievement and provides helpful strategies for those who wish to accept the challenge of expanding the mathematics curriculum by including cultural contexts for K–16 mathematics.

Martin L. Johnson, Professor Emeritus
Mathematics Education
University of Maryland
July 8, 2018

PREFACE

A great deal of attention has been given to what has been called the achievement gap (Ladson-Billings, 2006). The gap is defined as differences in performance outcomes among Black and White students on standardized tests. Trends show, despite efforts to reform education with state and national standards, White and Asian students continue to outperform African-American and Latinx students on these measures (Martin, 2003; Tate, 1997). Yet, very little attention has been given to differential educational opportunity (Kozol, 1991, 2005; Ladson-Billings, 2006, 2017). Instead, public schools are experiencing resegregation along the lines of race, ethnicity, and socioeconomic status (Lee & Orfield, as cited in Ladson-Billings, 2006; Leonard, Walker, Cloud, & Joseph, 2017). Given that urban school districts have largely abandoned desegregation efforts and parents of students of color have limited educational choice, the variable that continues to make a difference is teachers. However, teachers of underrepresented students are more likely to be culturally and economically different from the students they serve (Gay, 2000). Thus, there is a need to prepare teachers who possess appropriate dispositions and willingness to engage in culturally responsive pedagogy to motivate, engage, and inspire underserved students (Delpit, 1995; Gay, 2000; Martin, 2003; Nieto, 2002; Sheets, 2005).

The purpose of this text is to encourage the use of culturally specific pedagogy to enhance the mathematics instruction of students of color by making the link between research and

practice clear. The primary objective is to provide prospective and practicing teachers with ideas to develop their own culturally based lessons that can be used with ethnically and linguistically diverse students and females. Specifically, I use critical race theory and mathematics cognition to focus on three goals: (a) qualitative research to extend the literature on culturally based education to African-American and Latinx children in their development of mathematical knowledge and skills, (b) cognition research as it applies to better understanding of underrepresented students' goals, cognitive forms, and the interplay or transfer of out-of-school and in-school practices (Saxe, 1991), and (c) mixed methods to create pathways in STEM education for African-American, Latinx, Native American, rural, and female students. However, these strategies are not a panacea and should not be viewed as a recipe to undo centuries of inadequate schooling in America.

The chapters in this book provide examples from some of the research studies I have conducted, as well as my teaching experiences (K–20) in different contexts to help teachers visualize what culturally specific pedagogy is and how to use it with culturally and linguistically diverse students. Case studies, vignettes, and specific examples of culturally relevant and culturally specific teaching strategies are interwoven throughout the text to provide context and to convey meaning. Chapter 1 describes the need for culturally specific pedagogy and the rationale for using critical race theory and Black feminist thought as theoretical frameworks. Chapter 2 outlines the development of culturally based education and includes a discussion of the link between cognition and culture and how culture can be used to help students learn mathematics. From culturally responsive pedagogy to funds of knowledge, Chapter 3 outlines the development of cultural pedagogy. Chapters 4 and 5 report the results of a research study on robotics and game design that was supported by the National Science Foundation. Data were collected in both rural and urban contexts on students' development of computational thinking and

spatial ability. In Chapter 6, lessons and activities that examine the histories of women aviators and astronauts are presented alongside research findings obtained from a space science study to advance gender equity. Chapter 7 outlines culturally based strategies to enhance the mathematics education of linguistically and culturally diverse students. Multicultural literature is used to make connections to African-American, Hispanic,¹ and Asian culture. Chapter 8 provides a discussion on Black Lives Matter. Given the persistence of state violence toward African-Americans, this topic connects current issues in the African-American community to teaching mathematics for social justice. Finally, in Chapter 9, issues related to mathematics achievement among African-American students within the context of *Brown v. Board of Education* (1954) are discussed.

Since legal remedies in *Brown v. Board* and desegregation efforts have not resulted in equitable education for all students, underachievement in mathematics among African-American and other underrepresented populations must be addressed on moral and ethical grounds. A nation that is founded on principles of democracy and equality must show the world that it embraces its own diversity and provides high-quality education for all children. Teaching mathematics for social justice is one strategy to help marginalized students to understand and critically evaluate real-world problems, such as racial profiling and unfair lending practices (Gutstein, 2003; Joseph, Jett, & Leonard, 2018). “Eliminating inequities in access, achievement, and persistence in mathematics” cannot be divorced from the broader contexts in which schools exist and students live (Martin, 2003, p. 17). Students must be able to “use mathematics in the out-of-school contexts that define their lives” (Martin, 2003, p. 17) if mathematics achievement and persistence are to have meaning. Moses and Cobb (2001) contended that schools and the educational community at large must commit to everyone gaining math–science literacy just as they have been committed to reading–writing literacy. If policymakers and society at large adhere to the call for mathematics equity on moral and

ethical grounds and reward mathematics achievement with genuine economic opportunity, then students of color will strive to achieve and persist in mathematics education because economic parity has become a reality (Martin, 2000).

Note

1. U.S. Census designation for descendants from Spanish-speaking countries.

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No one accomplishes a task without the assistance of significant others in her life. The second edition of this book is no exception. I am indebted to the individuals and funding agencies mentioned in the following paragraphs.

First and foremost, I express sincerest thanks to Dr. Martin L. Johnson, emeritus faculty, University of Maryland at College Park, for serving as my dissertation chair and mentor. His leadership and teaching at Maryland helped to shape my career and direction in academia. I will always be deeply grateful to him for writing the foreword to this edition and enabling me to become a preeminent scholar in mathematics education.

Moreover, I am indebted to Dr. William F. Tate, dean of the Graduate School, vice provost for graduate education, and Edward Mallinckrodt Distinguished University Professor in Arts and Sciences at Washington University in St. Louis, for his nurturing and affable character. I am most appreciative of his mentorship throughout the years.

Furthermore, I express gratitude to Dr. Dorothy Y. White, University of Georgia, and Dr. Joy Barnes-Johnson, Princeton High School (New Jersey) for reading and offering feedback on the Black Lives Matter chapter in this text. Their advice and insight enriched the quality of this chapter. I also wish to acknowledge Dr. Monica Mitchell and Dr. Toks Fashola for collecting and analyzing data on the Visualization Basics (uGame-iCompute) project. These incredible women are genuine friends and colleagues.

Other colleagues who have been instrumental in helping me to obtain the 2018–2019 Fulbright Canada Research Chair in STEM Education Award at the University of Calgary, Alberta, to expand my research include Dr. Beverly Lindsay, University of California (multi-campus), for inspiration; Dr. Anne Alexander and Dr. Richard Kitchen, University of Wyoming, for writing letters of recommendation; and Dr. Claude Louishomme, University of Nebraska Kearney, for sharing his portfolio as a former Fulbright scholar.

Furthermore, I am beholden to Dean Kay Persichitte, who appointed and supported me as the first African-American director of the Science and Mathematics Teaching Center at the University of Wyoming. I also wish to thank Dean Douglas Ray Reutzel and Associate Dean Leslie Rush for their support of my research and scholarship during my tenure in the College of Education and for supporting me during the Fulbright Award.

Additionally, I appreciate the continuous encouragement and friendship of my former high school English teacher, Mrs. Sher Breaux Daniel. She instilled my love of writing and storytelling. Furthermore, I appreciate Mrs. Marzetta Alexander for editing and providing thoughtful input, Francine Still Hicks for contributing some of the artwork, and Peter A. C. Hill and Tonya Busse for developing lesson templates included in this edition. I also credit Rev. Dr. Zan W. Holmes, pastor emeritus of St. Luke “Community” United Methodist Church in Dallas, Texas, for seeing my spiritual gifts and encouraging me to pursue a master’s degree in theological studies. I am also indebted to my students, Melissa Coffin, Theresa Graves, Kimberly Burkhart, Kristy Palmer, Theresa Produit, and Dewayne Tillman for allowing me to tell their stories. Finally, I thank God for sustaining me throughout my graduate studies and academic career.

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Jacqueline Leonard
Professor (University of Wyoming) and Fulbright Canada
Research Chair in STEM Education (University of Calgary)

BIOGRAPHICAL NOTE

Dr. Jacqueline Leonard hails from St. Louis, Missouri. A product of the St. Louis public schools, Jacqueline received the Bachelor of Arts from Saint Louis University in 1981; Master of Arts in Teaching in Mathematical Sciences from the University of Texas at Dallas in 1991; Master of Theological Studies from Southern Methodist University in 1994; and PhD in Curriculum and Instruction from the University of Maryland at College Park in 1997.

Dr. Leonard was promoted to professor of mathematics education in the College of Education at Temple University in July 2010. She is currently appointed as professor at the University of Wyoming. Dr. Leonard has made 85 conference presentations and authored 60 articles and 12 book chapters. Prior to her appointment at Temple, she was a middle school science teacher in University City, Missouri, from 1981 to 1983, and a kindergarten and intermediate mathematics teacher in Dallas, Texas, from 1984 to 1993. While working on her doctorate at the University of Maryland, Dr. Leonard also taught sixth grade in Bowie, Maryland, from 1994 to 1997.

Dr. Leonard's awards include: Outstanding New Scholar Award (University of Maryland at College Park, 2004); Inspirational Instruction (University of Wyoming 2015); Fabulous Fieldwork (University of Wyoming, 2017), and Outstanding Research (University of Wyoming, 2018).

Dr. Jacqueline Leonard has two daughters: Victoria Bloom (MPT) and Cara Djonko-Moore (PhD); two sons-in-law, Ron Bloom and Armand Djonko-Tatou; two grandsons, Christopher L. Cloud, Jr. and Aaron T. Djonko; and one granddaughter, Quiana R. Cloud.

CULTURE, IDENTITY, AND MATHEMATICS ACHIEVEMENT

Introduction

In August 2015, I attended a gala at the Wings Over the Rockies Air and Space Museum in Denver, Colorado. The gala was held to raise funds for Shades of Blue, a nonprofit organization founded by Captain Willie Daniels. At this gala, I had the pleasure of meeting Nichelle Nichols, co-star of the original *Star Trek* television series that aired from 1966 to 1969, who was the keynote speaker. Becoming a spokesperson for the National Aeronautics and Space Administration (NASA) in the 1970s, Ms. Nichols helped to recruit women and Black astronauts for the space program, including Sally Ride, who in 1983 was the first American woman in space, and Frederick Gregory, who in 1989 was the first African-American to pilot the Space Shuttle Discovery. Other notable engineers and astronauts at the gala were Ed Dwight, who in 1961 was the first African-American astronaut candidate, Dr. Guion Bluford, who in 1983 was the first African-American in space on the Space Shuttle Challenger, and Joan Higginbotham, who flew on the Space Shuttle Discovery in 2007. The aforementioned astronauts are true heroes of science and related disciplines. They are STEM role models and an inspiration for this text, along with the women in Margot Shetterly's (2016) book—*Hidden Figures*.

Despite a myriad of accomplishments in STEM domains by women and people of color, mathematics remains the gatekeeper to STEM pathways and careers (Martin, Gholson, &

Leonard, 2010). This is important to note because myths about who can and cannot do mathematics continue to influence some teachers' beliefs about specific cultural groups (Joseph, Jett, & Leonard, 2018). If teachers judge their students' success in mathematics by socioeconomic status (SES) classifications alone, deficit ideologies may perpetuate low expectations of children from African-American and Hispanic communities (Gorski, 2008). Thus, there is a need for a new edition of *Culturally Specific Pedagogy in the Mathematics Classroom*. This edition challenges myths about mathematics ambivalence among students of color with narratives and case studies about teaching and learning that exemplify excellence in mathematics, specifically, and STEM in general.

Drawing on culturally relevant pedagogy (CRP) as the overarching theory, culturally specific pedagogy (CSP) supports the following goals for students: (a) student learning, (b) cultural competence, and (c) sociopolitical consciousness. CRP describes these goals as tenets, which are defined as follows: student learning (i.e., demonstrable growth in requisite subject areas), cultural competence (i.e., firm grounding in one's culture of origin while acquiring fluency in at least one more culture), and sociopolitical consciousness (i.e., use of school knowledge to solve relevant social, cultural, civic, environmental, and political problems) (Ladson-Billings, 2017). CRP empowers students "intellectually, socially, emotionally, and politically by using cultural referents to impart knowledge, skills, and attitudes" (Ladson-Billings, 2009, p. 20). However, learning tasks that not only have cultural significance but also expose unjust practices and empower students to challenge the status quo are the hallmark of teaching for social justice (Gutstein, 2006). CSP goes further to help students to develop their identity (e.g., racial, ethnic, gender, etc.) within the learning community. In order to understand the construct of CSP from a social justice standpoint (Leonard, Brooks, Barnes-Johnson, & Berry, 2010), the theoretical frameworks that support it must be understood.

Theoretical Frameworks

The theoretical frameworks that undergird the research reported in this text are critical race theory (CRT) and Black feminist thought (BFT). Both of these frameworks are needed to understand the context in which underrepresented students and females of color learn mathematics.

Critical Race Theory

CRT in education was first proposed by Gloria Ladson-Billings and William Tate as “a framework developed by legal scholars [that] could be employed to examine the role of race and racism in education” (Dixson & Rousseau, 2005, p. 8). CRT challenges the colorblind approach of a traditional, liberal, civil rights stance and can be traced to the legal work of Derrick Bell and Alan Freeman in the mid-1970s (Delgado, 1995). CRT begins with the premise that racism is the norm in the U.S. (Dixson & Rousseau, 2005; Ladson-Billings, 1998). The theory suggests that coded language has become a way of “referring to and disguising forces, events, classes, and expressions of social decay and economic division” (Morrison, 1992, p. 63). For example, the term *urban* has been used to describe schools that serve predominantly Black and Brown students regardless of whether the schools are located in large cities or not (Anderson & Dixson, 2016).

CRT examines how citizenship and race interact (Ladson-Billings, 1998). Based on the construct of “whiteness as property” (Dixson & Rousseau, 2005, p. 5), “whiteness as an explicit cultural product [takes] on a life of its own” (Apple, 2003, p. 113). CRT acknowledges the relationship between skin color and access to power, privilege, and status in society along with access to property and material goods. Conversely, there are systemic and institutional forces at work that continue to oppress people of color. CRT gives voice to people of color as they tell their stories and experiences within a context where the method of analysis is the narrative (Brayboy, 2005; Duncan, 2005; Solorzano & Yosso, 2002). Thus, CRT “is an especially

useful tool for examining how socio-temporal notions of race inform the naturalization of oppression and the normalization of racial inequality in public schools and society” (Duncan, 2005, p. 94). In other words, as beliefs about race become entrenched in society over time, systems of privilege and marginalization become institutionalized (Han & Leonard, 2017).

CRT is characterized by six themes that help to define the framework:

- Recognition that racism is endemic to American life;
- Expression of skepticism toward dominant legal claims of neutrality, objectivity, colorblindness and meritocracy;
- Challenges to ahistoricism and insistence on a contextual/historical analysis of the law.... Critical race theorists ... adopt a stance that presumes that racism has contributed to all contemporary manifestations of group advantage and disadvantage;
- Insistence on recognition of the experiential knowledge of people of color and our communities of origins in analyzing law and society;
- Interdisciplinary nature; and
- An end goal of eliminating racial oppression as part of the broader goal of ending all forms of oppression.

(Matsuda, as cited in Dixon & Rousseau, 2005, p. 9)

CRT has been adapted and used by scholars from other minority groups as well. Latina/o critical race theory (LatCrit), Asian critical race theory (AsianCrit), and tribal critical race theory (TribCrit) all emerged from CRT. There are nine tenets of TribCrit; however, the following three tenets help to illuminate the issues that are common in all of these theories: (a) colonization is endemic to society, (b) U.S. policies toward Indigenous people are rooted in imperialism, White supremacy, and a desire for material gain, and (c) Indigenous people occupy a transitional space that accounts for both the political and racialized natures of their identities (Brayboy, 2005, p. 429).

CRT suggests that European domination, whether it is imperial or colonial, leads to oppression. In this system, “Whiteness” is legitimized as the culture of power and becomes normalized (Matias, 2013). This norm is characterized by labeling all people of color as “non-White.” Racism is the exercise of prejudice and power to institutionalize “White privilege” and support that privilege with laws and police power. Such a system empowers Whites and disenfranchises people of color. For example, Native Americans were deprived of land under laws such as manifest destiny and the Norman yoke (Brayboy, 2005), and African-Americans were prevented from voting and deprived of land under Jim Crow (Apple, 2003; Duncan, 2005). Though the Civil Rights Act was signed into law in 1964 to reverse discriminatory practices, it has done little to protect persons of color from failing schools (Leonard, McKee, & Williams, 2013), unfair housing practices (Gutstein, 2013), gentrification of historically minority neighborhoods (Schrader, 2017), and racial profiling by police (Dyson, 2017; Hill, 2016; Himmelstein, 2013). Thus, the common thread in CRT is giving voice to those who are marginalized while working to promote antiracist practices in our communities and institutions (Han & Leonard, 2017).

CRT validates the voices of those who are marginalized and is a framework that may be used to examine both moral and social justice issues in education. Critics of CRT claim, however, that a single voice, abstract idea, or thought cannot explain the experiences of an entire group of people or community (Duncan, 2005). This criticism has merit. Thus, the voices of women (e.g., BFT), LGBTQ persons, and marginalized youth must also be heard. While no theory is perfect, complete, and without limitations, collective voices, stories, and other narratives are needed to resist oppression and persist in the struggle for civil rights (Brayboy, 2005; Duncan, 2005). However, as Dixson and Rousseau (2005) pointed out, one of the core values of the CRT movement that has been largely unrealized is an “active struggle” (p. 22). More than 60 years post-*Brown v. Board of Education*, African-Americans, as a demographic

group, are still attending separate and unequal schools. Despite the incredibility of our stories, “it is essential to resist the depiction of history as the work of heroic individuals in order for people today to recognize their potential agency as a part of an ever-expanding community of struggle” (Davis, 2016, p. 2).

Black Feminist Thought

In addition to CRT, another theoretical framework is functional in capturing women’s voices. However, rather than simply drawing on feminist frameworks in general, BFT is used to examine the experiences of Black females¹ in this text (Collins, 2009). The rationale for using such a framework is twofold. First, much of the gender-based literature on mathematics omits race, focusing primarily on White women’s attitudes and performance in mathematics (Leonard, Walker, Cloud, & Joseph, 2017; Walker, 2014). More recent literature on intersectionality (e.g., race, gender, class, religion, sexual orientation) reveals a broader view of students’ identities (Cho, Crenshaw, & McCall, 2013). Second, Black females have highly positive attitudes toward mathematics and are just as likely as White males to persist in advanced mathematics courses at the high school level (Walker, 2014). “The societal meme that women are not good in mathematics or are not confident in mathematics largely does not apply to Black women” (Leonard, Walker, Cloud, & Joseph, 2017, p. 101).

BFT is a critical social theory that seeks to “empower African-American women within the context of social injustice sustained by intersecting oppressions,” such as race, gender, class, sexuality, and citizenship (Collins, 2009, p. 26). Black women in the U.S. have a distinct set of challenges as a demographic group, but they do not all have the same kind of experiences (Collins, 2009). Black women “struggle to survive in two contradictory worlds, simultaneously, one white, privileged, and oppressive, the other black, exploited, and oppressed” (Cannon, as cited in Collins, 2009, p. 29). In this text, Black

females' experiences (including my own) in mathematics will be viewed through the lens of BFT because the theory is applicable to the intersectionality of their experience in public institutions.

Culturally Specific Pedagogy

Culturally specific pedagogy (CSP) provides the context for CRT and BFT to function as means to empower students of color and females to overcome the oppression of Euro-American mathematics (Aikenhead, 2017). American classrooms are microcosms of a larger society in which racism, power, and privilege converge to empower some students and disenfranchise others. Teachers who are cognizant of CRT and BFT can change classroom dynamics by using cultural and social justice pedagogy not only to teach mathematics but also to challenge hegemonic structures that oppress women and people of color (Han & Leonard, 2017; Leonard, Walker, Cloud & Joseph, 2017). CSP is a construct that explicitly links culture with content to help students engage in social action and identity development (Gutstein, 2006; Leonard, 2009).

Furthermore, Gutstein, Lipman, Hernández, and de los Reyes (1997), borrowing from Ladson-Billings, contend that engaging in CRP is like trying to catch "lightning in a bottle" (p. 733). In other words, how does a teacher engage a classroom of multicultural students in CRP? What aspects of students' culture should be used to engage students in authentic mathematics activities? And how do we know CRP when we see it?

While there are common characteristics and traits among people who share the same race or ethnicity, no culture is monolithic. Within cultural groups are many subcultures. Individuals have multiple layers of identity and belong to more than one subgroup simultaneously. For example, I am an African-American female born during the baby boom, who is currently working at a land-grant university in a small town in the Rocky Mountain West and a member of the African Methodist

Episcopal (AME) Church. Thus, I have a racial, gendered, generational, geographic, and religious identity. What is culturally relevant to my life and lived experiences may not be culturally relevant to a 25-year-old African-American woman who lives in the rural South. Thus, the culturally relevant construct can be broadened by defining CSP as follows: intentional behavior by a teacher to use gestures, language, history, literature, traditions, and other cultural aspects of a particular race or ethnic or gender group to engage students belonging to that group in authentic student-centered learning.

CSP in the context of learning mathematics empowers under-represented students to develop a mathematics identity and socializes them as they learn to use mathematics for their own purposes (Martin, 2000). For example, studies in Brazil (Carraher, Carraher, & Schliemann, 1987), Papua New Guinea (Saxe, 1991), and Nigeria (Oloko, 1994) show students engaged in informal mathematical activities with fluency when they conducted exchanges in the marketplace. These students were able to perform “street” mathematics with adequate success (Carraher, Carraher, & Schliemann, 1987). If students can perform mathematical calculations when they engage in real-world activities, surely they can do mathematics in the classroom if links are made from what they know to what is being taught (Taylor, 2013). Teachers must learn to scaffold children’s informal school knowledge by using cultural referents that go beyond memorization and decontextualized problems to those that draw on students’ culture and mainstream culture in a manner that values knowledge in both worlds (Aikenhead, 2017; Collins, 2009). We know that CSP is at work when students use mathematics to develop agency, sociopolitical conscientiousness, and positive sociocultural identities (Gutstein, 2006).

Prior Research on Culturally Based Education

Culturally based education has been used with American Indian/Alaska Native students for a number of years, but there is a dearth of experimental, quasi-experimental, and comparative

nonexperimental research studies that examine the links between culture, teaching, and mathematics achievement among African-American and Latinx² K–12 students. Moreover, differences among research paradigms, such as the ethnographic research tradition and the mathematics education research tradition, have limited substantive research in culturally relevant mathematics instruction (Brenner, 1998). In other words, adhering to evidence-based standards of research, fewer qualitative than quantitative studies that focus on cultural relevance in mathematics education have been funded. While ethnographic research has focused on culture, mathematics education research has focused on cognition (e.g., cognitively guided instruction and QUASAR). Thus, there is a lack of research that uses mixed methodology to examine both culture and mathematics cognition simultaneously (Brenner, 1998). Because of limited research on culturally based education, few evidence-based claims have been made to link culturally based education to improved student outcomes.

Early Culturally Based Studies

Culturally based education emerged as a means to influence the school performance of American Indian/Alaska Native (AI/AN) and Native Hawaiian children in the 1980s (Bishop, 1988; Erickson & Mohatt, 1982; Tharp, 1982). The following six elements operationally define culturally based programs:

- Recognition and use of American Indian/Alaska Native (AI/AN) and Native Hawaiian languages;
- Pedagogy that stresses traditional (Indigenous) cultural characteristics and adult-child interactions as a starting place for one's education;
- Pedagogy in which teaching strategies are congruent with the traditional (Indigenous) culture as well as contemporary (European) ways of knowing and learning;
- Curriculum based on traditional (Indigenous) culture that recognizes the importance of Native spirituality and

places the education of young children in a contemporary context;

- Strong Native community participation (including parents, elders, and other community resources) in educating children and in the planning and operation of school activities; and
- Knowledge and use of the social and political mores of the community.

(Demmert & Towner, 2003, pp. 9–10)

While there is a lack of research studies that examine culture as a basis for learning mathematics, Demmert and Towner's (2003) meta-analysis highlights several research studies that show promising results. Nonexperimental comparative studies in mathematics included the Alaska Native Knowledge Network (as cited in Demmert & Towner, 2003), which was developed and implemented to examine pedagogical practices in science and mathematics that utilized Indigenous knowledge and ways of knowing. For example, Brayboy and Maughan (2009) stressed the significance of making connections to Indigenous culture in science education by using lima beans to illustrate Indigenous systems of knowing, being, valuing, doing, teaching, and learning. Demmert and Towner found the inclusion of Indigenous ways of knowing fostered mathematics achievement, and Brayboy and Maughan found that cultural practices enhanced Native American students' science content knowledge.

In one nonexperimental study, Brenner (1998) investigated the influence of cognition and culture on the development of pedagogical practices in the mathematics education of young Native Hawaiian children in the Kamehameha Early Education Project (KEEP). In this study, Brenner (1998) described how educational materials and teacher practices reflected three aspects of cultural relevance: cultural content, social content, and cognition. Two different comparative studies were conducted: one with kindergarteners and one with second-graders.

In kindergarten, students in rural areas who spoke Hawaiian Creole English (HCE) were compared with urban students who were more proficient in English. Children were given paper-and-pencil tests in HCE and Standard English. Results revealed no difference in how urban children performed on each form of the test. However, rural children performed significantly better on the HCE form of the test than the English version (chi-square=8.612; $p=0.013$). Second-graders differed at the classroom level as one teacher in the treatment group used a school store throughout the school year to emphasize the kind of mathematics that took place in Hawaiian communities. Second-graders improved their knowledge about money and their use of calculator skills. Moreover, their standardized scores in mathematics (83rd percentile) surpassed those of other second-graders (76th percentile) in KEEP schools.

Quasi-experimental studies on the use of culturally based education in mathematics classrooms, however, have been more difficult to conduct. This type of research presents a number of challenges for those who wish to conduct culturally based research projects. Researchers simply do not have control over the research setting necessitated by experimental or quasi-experimental designs (Demmert & Towner, 2003). Time is also a major consideration that limits the number of culturally based, quasi-experimental studies. While lengthy time periods for implementation of an intervention are desirable, teacher turnover and student attrition may present a problem if the timeframe is too long. Ethics is also an issue as researchers may have to decide to exclude particular students on the basis of race, ethnicity, language, and disabilities to establish control groups. Finally, there are issues of statistical power when researchers attempt to measure student achievement or other quantitative variables while simultaneously attempting to collect rich qualitative data in school settings where the sample is too small. Yet, case studies on students of color may be more informative than quantitative data to understand their mathematics identity, socialization, and achievement (Martin, 2000).

One of the few quasi-experimental studies that examined culturally based pedagogy in mathematics was conducted by Lipka et al. (2005). The aim of the study was to ascertain the effectiveness of culturally based perimeter and area lessons in a mathematics unit. The unit was taught to urban and rural sixth-graders. Two independent variables were examined in the study by randomly assigning teachers with intact classes to one of four subgroups: urban-treatment, urban-control, rural-treatment, and rural-control. The mathematics unit for the treatment groups was infused with cultural artifacts that were representative of Native Eskimo culture. A pre-post assessment that consisted of 17 multiple-choice or constructive response items about perimeter and area was designed and administered to the students. After a series of *t*-tests were performed, the researchers found significant differences between urban-control and -treatment groups and rural-control and -treatment groups. Gain scores for the urban-treatment group exceeded those of the urban-control group, gain scores for the rural-treatment group exceeded those of the rural-control group, and gain scores for the urban-treatment group exceeded those of the rural-treatment group. The strengths of the research design in this study were the use of comparison groups, consistency of mathematics concepts taught in treatment and control groups, and valid and reliable outcome measures. The results of this study revealed culturally based approaches improved student performance in the treatment groups compared to the control groups regardless of locale.

Teachers' Beliefs about Culture and Learning Mathematics

As frequently observed in American classrooms, institutional culture can be a barrier to social change. Discussions about culture, race, and ethnicity are often absent from the discourse in teacher education classrooms primarily because the instructors themselves are "overwhelmingly White, monocultural, and culturally insular" (Price & Valli, 1998, p. 115). Yet, preparing teachers who are sensitive to diverse learners requires much

more than offering a single course or applying a single rubric (Bollin & Finkel, 1995; Phuntsog, 1995; Powell, Cantrell, Malo-Juvera, & Correll, 2016; Price & Valli, 1998). “All courses need to be infused with content related to diversity” (Nieto, 2000, p. 183). Further, in order to influence positive beliefs and attitudes among preservice teachers about cultural pedagogy, teacher educators must be proactive. Emphasis on CSP is especially needed to encourage appropriate practices among prospective teachers of predominantly African-American, Latinx, and Indigenous students, who are more likely to benefit from these practices.

Scholars and researchers of color have stressed the importance of culture and language in the education of underrepresented students for more than three decades (Berry, 2008; Boykin & Toms, 1985; Gutiérrez, 2002; Ladson-Billings, 2009; Leonard, Buss, et al., 2016; Lucas & Villegas, 2011; Malloy & Malloy, 1998; Moschkovich, 2007). Regardless of teaching philosophy (e.g., inquiry versus guided instruction; small-group vs. whole-group instruction), it is imperative that teachers commit themselves to teaching every student meaningful and relevant mathematics (Lemons-Smith, 2013; Leonard, Napp, & Adeleke, 2009; Walker, 2012). Yet, researchers who connect culture to mathematics in authentic ways remain sparse (Berry & Thomas, 2017; Powell et al., 2016). While teaching from cultural perspectives has become more acceptable, especially in urban settings where students remain segregated by race, ethnicity or economic status, teachers are asked to teach in ways they have not experienced as students nor have been prepared to teach (Leonard et al., 2018; Rodriguez & Kitchen, 2005). Thus, mathematics educators in teacher preparation programs play a critical role in helping preservice teachers to make cultural connections to mathematics.

As a professor at the University of Wyoming, I have focused on the importance of culture while teaching graduate-level mathematics education courses for in-service teachers seeking a middle-level endorsement in mathematics. In the mathematics

methods course that I taught in spring 2013, students kept journals throughout the course. Materials included the first edition of this book and *Teaching Mathematics for Social Justice: Conversations with Educators* (Wager & Stinson, 2012). Thus, in addition to best practices for teaching mathematics, critical pedagogies—specifically culturally based education and teaching mathematics for social justice—were embedded in the course. The teachers’ journals provided a running record of their beliefs and practices throughout the course.

Four out of 12 teachers’ journals were randomly selected and read for themes and patterns. Three of the four journals had substantive content that showed changes in the teachers’ thinking and learning about culture and social justice across time. The journals are presented in chronological order, as vignettes indicated their thinking in the beginning (Vignettes 1.1–1.3), in the middle (Vignettes 1.4–1.6), and at the end (Vignettes 1.7–1.9) of the course:

Vignette 1.1

In Thursday’s class, I realized that I was probably inspired by the Swanson (2010) article as I was helping [a student]. Since reading Swanson, I have been telling students to “draw a picture” more [often]. I think this helps all learners, and it might especially help learners who are learning English. (White female teacher #1)

Vignette 1.2

I have witnessed many children operating at below average performance in my 12 years of teaching at the elementary school. There are many factors that feed into the circumstances of a particular child, and each case is unique. Many times, it is lack of a proper support system within the home that contributes significantly to a child’s current performance level. Even more troubling, it can be what is happening within the home that is preventing the child from functioning at an average level in the classroom. (White female teacher #2)

Vignette 1.3

I have learned about some new philosophies of education that I have not had much exposure to, and I like to learn new ideas. I learned in the past few classes that elementary and secondary mathematics education was influenced by Marxism and postmodern thought. However, I did not anticipate their influence on the way we teach the language of the universe. I always considered mathematics the last bastion of purity and truth. I do not consider mathematics a human invention open to interpretation. Instead it was always above us and discovered by us, not made by us. (White male teacher)

The foregoing journal entries are as unique as the individual teachers who wrote them. The first teacher, a White female, focused on the content presented in the class through the assigned reading. She mentioned trying the strategy with her middle school students. She believed the technique would help all students, but she also acknowledged the strategy of drawing a picture to solve a mathematics problem would be helpful to English language learners (ELLs), which is supported in the literature (Bishop, 1988; Malloy & Jones, 1998; Van de Walle, Karp, & Bay-Williams, 2016). While teachers' self-efficacy and outcome beliefs about CRP are malleable in specific academic contexts (Leonard et al., 2018), research is limited in terms of studying teachers' equitable mathematics teaching practices and their influence on ELLs and other underrepresented students in mathematics classrooms (Goffney, 2010; Moschkovich, 2013). Moschkovich (2013) defined equitable mathematics teaching for ELLs as "(a) support[ing] mathematical reasoning, conceptual understanding, and discourse" and "(b) broadening participation for students who are learning English" (pp. 45–46).

On the contrary, a second White female blamed the students and their families for lack of success in the mathematics classroom, rather than examining the quality of the curriculum or her teaching. However, the White male student, while learning about the influence of Marxism and postmodernism on mathematics education, held a functionalist view of mathematics. He implied

that mathematics is immutable truth that exists outside of human endeavor. These entries informed me of the work I needed to do to help the teachers in the course to understand alternative views about the nature of mathematics and how mathematics might be used to empower all students in their classrooms.

Vignette 1.4

Story Corps featured a story of Hispanic siblings going to school in Lincoln, Nebraska (Hernandez, 2013). The sisters had to sit in the back of the classroom and clean the erasers after school. Their teacher told them they could not take the SAT; she said Hispanic women were just supposed to have babies. The older brother told the counselor his sisters would take the test. They had to look for pop bottles so they could buy number two pencils to take the test. The sisters scored really high. One of the sisters got into medical school. I would like to be able to share stories like this with my students. But, I don't know if I would get in trouble because it is not in line with our curriculum. At least I know the stories, and perhaps just knowing the stories of different people will make me a better teacher. (White female teacher #1)

Vignette 1.5

"Being a teacher is a political act." That is precisely the statement that I have been needing these past couple of years. I had never really thought about our profession in that light before; however, that is exactly what it is. I have recognized my part in the lives of children and families that I serve. I saw the importance of the life lessons that are painful learning, be the student, the family, or myself. (White female teacher #2)

Vignette 1.6

Another thing I learned was place-based pedagogy in the mathematics classroom. This and culturally relevant pedagogy are ideas that I can get behind, but probably not for the same reasons as some of the authors of these ideas. In fact, I have already been using some of these concepts in my teaching without realizing that there were names for them. One semester, I organized a field trip to several local businesses and had my students interview the owners for the purpose of understanding what it takes to start your own small business or the financial investment, the budgeting, the planning, and the vision. The hook was their interest in starting a small business and their connection to this place.... (White male teacher)

The second set of journal entries indicate some movement toward understanding mathematics in terms of culture and place. Place is defined as “local heritage, cultures, landscapes, opportunities, and experiences.”³ The first female teacher was confronted with overt racism and sexism in the story by Hernandez (2013). However, she was candid in describing her fear of introducing topics that were not aligned with the school curriculum. Teaching for cultural relevance or social justice is risky in many education settings. This teacher, however, acknowledged that knowing the story had an impact on her behavior as a teacher. The second female teacher also showed movement as she came to realize the impact of her actions on students and families. This is an important change since she blamed students and families for poor performance in her first journal entry. The male teacher also made strides, indicating his support of culturally relevant and place-based instruction. Overall, these excerpts indicated that some of the teachers in the course were beginning to understand that mathematics is a human endeavor and mathematizing real-world activities can provide rich mathematical experiences in the classroom.

Vignette 1.7

On Tuesday, I taught students about proportions. In addition to the Saxon lesson, I taught the “butterfly method” we discussed in our last class. As I was teaching, I decided to put a smiley face on the butterfly if it was proportional and a frowny face if it was not. I also showed students how you can use this technique to compare fractions. It was neat to see butterflies as I was grading homework. It is really rewarding that they used the concepts discussed in class. (White female teacher #1)

Vignette 1.8

I do like the butterfly method for finding the larger value; however, it does not show students WHY the numbers are working the way they are. I found some games to play that encourage using the fractions as numbers in card games and plan to use this in my classroom. The

cards attached to the game are available for a free download. I have found some other valuable ideas on *Pinterest* and *TeachersPayTeachers*. Some of these ideas can be tweaked in a way that can be very self-empowering for children. They can make them their own in a number of ways. All it takes is a creative teacher willing to put forth some extra effort to enable children of all backgrounds to enjoy math and find the power that it gives them in the real world. (White female teacher #2)

Vignette 1.9

I must say that this class has been a pleasant surprise. I assumed that it would just be a traditional methods class, and I was dreading it. This methods class has been valuable to me for a couple of reasons that I would not have predicted—place-based and culturally relevant pedagogy. While teaching at-risk teens, I have had to look for methods that work for my students. There is no cookie-cutter approach that is relevant to the kids that I have worked with. I have had students from farms and ranches that have grown up around cowboy culture, and I have had students who have aligned themselves with gang culture. I have had to build a relationship with them and get to know them as individuals and not just as another student in class of 25. Because of this unique context, I have been more open to the use of culture and place as a means to get students to re-engage in the learning process. (White male teacher)

While the beginning of the course focused on culture and place, I focused on mathematics content and inquiry during the second half of the course. Thus, the two female teachers' journal entries on content were not surprising. However, the second teacher understood the limitations of procedural knowledge and conducted research on her own to find examples to teach fraction concepts to her students. Moreover, she mentioned the importance of creativity and making connections to real-world examples. While the first teacher focused on the Saxon textbook and procedural shortcuts, the third teacher continued to talk about how culture and place influenced his instruction. Furthermore, he understood the importance of building

relationships with his students, which are critical in the teaching-learning process (Aikenhead, 2017; Ladson-Billings, 2009). While the first teacher may have decided it was too risky to focus on culture in her classroom, the two remaining focal teachers appeared willing to apply inquiry-based, culturally based, and/or place-based practices in their classrooms.

Convincing beginning teachers that they should connect culture to their mathematics instruction is a daunting task. Diverse students have ways of learning that are not necessarily consistent with local and national standards. In mathematics education courses, we discussed and analyzed articles related to cultural practices, watched classroom videos of diverse students who learned mathematics in unique ways, and read multicultural children's literature (Leonard, Moore, & Brooks, 2014). At the end of the course, teachers often realized, as the second female teacher did, the political nature of teaching for social justice or implementing cultural pedagogy. Using social justice and cultural pedagogy as tools to engage students in sociopolitical consciousness to analyze social inequality and power relations is a profound idea. Social justice pedagogy allows students to consider societal influences on their education and well-being, weigh alternative decisions, and develop a response (see the liquor store example in Tate (1994) and the housing example in Gutstein (2006)). Cultural pedagogy allows students to experience academic success, develop mathematics identity, and exercise self-determination (Gay, 2010).

Mathematics Identity and Mathematics Socialization

Mathematics is the gatekeeper for access to higher education and higher paying jobs (Gutstein, 2003; Martin, Gholson, & Leonard, 2010). Therefore, all teachers of mathematics should abandon deficit theories (Gorski, 2008) along with pedagogies that perpetuate cycles of poverty (Haberman, 1991; Knapp, 1995). Instead, teachers should help their students to develop the mathematics literacy they need to be successful in the twenty-first century. Mathematical literacy involves knowing

more than the basics. According to Moses and Cobb (2001), “the ongoing struggle for citizenship and equality for minority people is ... linked to ... math and science literacy” (p. 14). The major components necessary to develop mathematics literacy are “(a) constructing relationships, (b) extending and applying mathematical knowledge, (c) reflecting about experiences, (d) articulating what one knows, and (e) making mathematical knowledge one’s own” (Carpenter & Lehrer, 1999, p. 20). In order to make mathematical knowledge personal, it is important to know and understand one’s mathematical identity and to experience mathematical socialization.

Martin (2000) defined the construct of mathematics identity as a person’s belief about “(a) their ability to perform in a mathematics context, (b) the importance of mathematical knowledge, (c) constraints and opportunities in mathematical contexts, and (d) the resulting motivation and strategies used to obtain mathematics knowledge” (p. 19). “Mathematics socialization describes the processes and experiences by which individual and collective mathematics identities are shaped by sociohistorical, community, school, and intrapersonal contexts” (Martin, 2000, p. 19). Teachers can help students to develop mathematics identity and participate in the mathematics socialization process by embracing historical figures who used mathematics and by helping students to understand how they can use mathematics in their everyday lives.

African-American culture can be used to promote the development of mathematics identity and mathematics socialization in a myriad of ways. First, all students should know that mathematics is a part of African-American history. Benjamin Banneker, an African-American who lived during the colonial period, excelled in mathematics. He used his genius to create the first wooden clock and designed plans for the nation’s capital. Bessie Coleman was the first African-American to earn an international pilot’s license in 1921 (Borden & Kroeger, 2001). She excelled in mathematics and used it to accomplish her lifelong dream of becoming an aviator. Twentieth-century

African-American mathematicians include Euphemia Lofton Haynes—who in 1943 became the first African-American woman to receive a PhD in mathematics. Other PhDs in mathematics include but are not limited to Evelyn Granville, Wayne Leverett, David Blackwell, Clarence Stephens, Raymond Johnson, and Freeman Hrabowski (Walker, 2014). On the cusp of the twenty-first century, Tasha Inniss, Sherry Scott, and Kimberly Weems were the first three African-American women to graduate with PhDs in mathematics from the same institution—the University of Maryland. To increase the number of African-American and Latinx PhDs in mathematics, a cohort model may help graduate students develop the social and academic networks of support needed to succeed at predominantly White institutions (PWIs).

Yet, one does not have to earn a PhD in mathematics to understand and appreciate its value. Mathematics is part of the milieu as people of all cultures engage in daily mathematics activity, such as counting, locating, measuring, designing, playing (i.e., games and puzzles), and explaining (Bishop, 1988). Thus, mathematics instruction should be placed within a context that draws upon cultural knowledge to validate different ways of *mathematizing* problems (Tate, 1995). Mathematizing is how students count, measure, classify, and infer mathematical meaning (D'Ambrosio, 1985) and can be linked to culture. Therefore, framing mathematics instruction within the context of diverse students' culture has legitimacy.

Mathematics education that is culturally specific and social justice-oriented has the potential to liberate the poor from social and economic oppression and can ultimately lead to life, liberty, and the pursuit of happiness (Leonard, 2009; Kitchen, Depree, Celedón-Pattichis, & Brinkerhoff, 2007). Dr. Martin Luther King Jr. stated in one of his final sermons, "If a [person] doesn't have a job or an income, he [or she] has neither life nor liberty nor the possibility for the pursuit of happiness. He [or she] merely exists." The entire learning community (i.e., parents, teachers, administrators, and policymakers) must take

responsibility to ensure that all children have access to highly qualified mathematics teachers who value and use students' culture to enhance mathematics learning and achievement.

Theories of meritocracy, which presuppose that cream always rises to the top, are insufficient. Raising the mathematics literacy standard requires the adequate preparation of all students for a college preparatory sequence of mathematics in high school (Moses & Cobb, 2001). Enrollment in advanced mathematics courses is critical to gaining access to higher education. Higher education provides students with broader opportunities to contribute to society and ultimately give back to the community, which develops a legacy of academic achievement.

Chapter 1 Discussion Questions

1. How does a teacher engage a classroom of multicultural students in CSP?
2. How do we know culturally specific pedagogy when we see it?
3. What aspects of students' culture should be used to engage students in authentic mathematics activities?
4. What should be done to change school culture to ensure teachers who want to engage in cultural or social justice pedagogy can do so?
5. Aikenhead (2017) claimed that teachers need to be immersed in their students' culture in order to engage them in cultural pedagogy. What kinds of activities qualify teachers for immersion in students' culture?

Notes

1. Black female is used a demographic variable to include all females in the African diaspora.
2. Latinx is a gender-neutral term used in place of Latino or Latina.
3. Center for Place-Based Learning and Community Engagement website: www.promiseofplace.org/what_is_pbe.

COGNITION AND CULTURAL PEDAGOGY

Culture, Cultural Transmission, and Cultural Capital

Three scholars of color provide definitions of culture for consideration. Gloria Ladson-Billings (1997) defined culture as “deep structures of knowing, understanding, acting, and being in the world” (Ladson-Billings, 1997, p. 700). Sonia Nieto (2002) defined culture:

as the ever-changing values, traditions, social and political relationships, and worldview created and shared by a group of people bound together by a ... common history, geographic location, language, social class, and/or religion ... and how these are transformed by those who share them.

(p. 53)

Etta Hollins (1996) offered a three-part definition of culture. First, she defined culture as artifacts and behavior. Artifacts refer to visual and performing arts and culinary practices, and behavior refers to social interaction patterns, rituals, ceremonies, and dress (Hollins, 1996). Second, Hollins concurred with Nieto that culture includes the social and political relationships and worldview shared by people bound together by common factors. Third, Hollins viewed culture as affective behavior and intellect, which guides the reasoning, emotions, and actions of a particular group of people (Hollins, 1996). Each of these definitions implies that culture is multifaceted and that cultural

knowledge is acquired from caregivers and significant others (Cole, 1992; Sheets, 2005).

Enculturation is the process of being socialized into a specific culture (Malloy & Malloy, 1998; Sheets, 2005). Cultural norms have tremendous power to shape beliefs and values and influence one's behavior (Irvine, 2002; Sheets, 2005). Cultural capital, which embodies the norms, ideologies, language, behavior, mores, and practices of a particular group, is transmitted to children as cultural knowledge (Bourdieu, 1973; Howard, 2003; Sheets, 2005). As a result, children develop different habits of mind and ways of doing things, which may conflict with what is expected of them in school (Howard, 2003; Sheets, 2005). However, the cultural knowledge and background experiences of underrepresented students are often omitted from school curriculum (Aikenhead, 2017; Bishop, 1988), especially mathematics curriculum, which some consider to be universal and culture-free.

In a study that investigated the lives of Navajo students in and out of school, Deyhle (as cited in Nieto, 2002) found that students who did not have a strong Navajo identity and who were rejected by non-Navajos were more likely to experience school failure. On the other hand, students who attended Navajo schools experienced more success than students who attended non-Navajo schools because they were able to affirm and retain their cultural identity. So, one explanation for underachievement among students of color is the cultural incongruence between student culture and school culture (Banks, 1993; Gay, 2010; Nieto, 2002). Thus, culture and cognition are not mutually exclusive.

European culture is the dominant culture in the U.S. It has been institutionalized and incorporated into all aspects of American life including government, industry, education, and mass media (Sheets, 2005). Furthermore, Whiteness and anti-Blackness in the form of White supremacy have emerged from the shadows in demonstrations of overt racism and xenophobia. Notwithstanding the election and reelection of Barack Obama as president of the U.S., Davis (2016) acknowledged that an

“overwhelming number of Black people [are] subject to economic, educational, and carceral racism to a far greater extent than during the pre-civil rights era” (p. 2). Though Obama’s rise to the White House was liberating and inspirational for those who have been marginalized and oppressed, enculturation has taken on new meaning.

If the cultural capital of any child is congruent with the dominant culture, then that child, who understands the rules, subtleties, and verbal and nonverbal nuances of that culture, is more likely to experience success in school (Gee, 1989; Irvine, 1992). Students who are part of a nondominant group or subculture are expected to adapt or go through a process of acculturation (modification of cultural group norms by borrowing traits from another cultural group) or assimilation (adapting dominant group norms to the exclusion of one’s own) in order to succeed in the educational system (Malloy & Malloy, 1998; Sheets, 2005). For some, this means learning English, which is the dominant language in the U.S. (Sheets, 2005) or taking on White middle-class values (Ogbu, 2003). How does one learn the dominant culture and ways of knowing, which are necessary in order to have access to higher education and economic power, without sacrificing his or her own culture and values? A cultural pedagogy that uses the cultural capital that students of color and marginalized others bring to school is a necessary bridge to help them acquire dominant discourses (Gee, 1989). Knowledge and acquisition of mainstream discourse—ways of communicating verbally and nonverbally—are crucial to academic success (Delpit, 1995; Gee, 1989; Ladson-Billings, 1995), but culturally and linguistically diverse children do not need to leave their culture at the schoolhouse door.

In the past two decades, cultural responsiveness and teacher dispositions have become important considerations in teacher preparation programs (Banks et al., 2005; Cochran-Smith, 2004; Leonard & Evans, 2012; Villegas, 2007). Dispositions can be summed up as “tendencies for individuals to act in a particular manner under particular circumstances, based on their beliefs”

(Villegas, 2007, p. 373). Specifically, mathematics teachers' backgrounds and beliefs as they relate to society and schools, in general, may contribute to educational disparities in the mathematics classroom (Leonard & Evans, 2012). If teachers who are not from the same cultural background as the students draw upon knowledgeable colleagues and community leaders who are from the students' background, they can learn to use appropriate examples of students' culture to be more effective mathematics teachers (Joseph, Jett, & Leonard, 2018). When teachers respect their students' culture and develop substantial sociocultural consciousness, they are more likely to exhibit positive and affirming beliefs about their students (Banks et al., 2005).

Theories about Cognition and Culture

There are several theories that support the use of cultural pedagogy with students of color. According to Demmert and Towner (2003), culturally based education is supported by three major theories: cultural compatibility theory, cultural-historical-activity theory (CHAT), and cognitive theory. The basic premise of "cultural compatibility theory is that education is more efficacious when there is an increase in congruence between social-cultural dispositions of students and social-cultural expectations of the school" (Demmert & Towner, 2003, p. 8). CHAT, on the other hand, is a theory of development that "places a great deal of emphasis on community-level elements for connectivity, thereby multiplying the richness of potential associations between student experience and the academic curriculum" (Demmert & Towner, 2003, p. 9). Thus, involving parents and community members as resources to help students develop knowledge is a key component of CHAT. Moreover, CHAT supports the idea that "learning is embedded in social and historical contexts and conceptualized as the product of one's collaborative engagement in social and cultural activity" (Takeuchi & Esmonde, 2011, p. 332). Both cultural compatibility theory and CHAT are congruent in many ways to cognitive theory, which has roots in developmental psychology.

Cognitive Theory

Lave (1988) contended that cognition is a multifaceted social phenomenon that is observed in daily practice and is encompassed by “mind, body, activity and culturally organized settings” (p. 1). Cognitive theory supports the view that culture plays an important role in learning mathematics (Cole, 1992; Saxe 1991; Saxe, Dawson, Fall, & Howard, 1996), and mathematics activity is expressed in unique forms in different situations (Lave, 1988). For example, learning to count is influenced by culture. In Western culture, each finger is used to count by ones while, in East Indian culture, each section of the finger is used in counting (Guha, 2006). In that way, one can count to 40 if each mark on the back of the finger is used.

Vygotsky stressed the importance of children’s use of cultural artifacts and scaffolds to mediate their interactions with the environment (Saxe, 1991; Vygotsky, 1978). Social constructivism recognizes that children are part of a classroom environment in which individual and corporate meanings take place (Steffe & Kieren, 1994). In general, constructivists believe that individuals build new knowledge by connecting it to prior knowledge (Davis, Maher, & Noddings, 1990). For example, fraction concepts are generally difficult for early-childhood and elementary students to understand. However, connecting the concept of fractions to real-life situations such as fair sharing helps children to construct meaningful experiences that can scaffold new knowledge (Garofalo & Sharp, 2003).

Vygotsky’s research drew upon the epistemological underpinnings of Marx and Hegel (Saxe, 1991). The Vygotskian point of view supports the notion that communication and social interaction are central to meaning-making (Vygotsky, 1978). Social interactions are critical to the teaching-learning process as “natural processes in cognitive development [are] redirected by social and historical influences” (Saxe, 1991, p. 10). Moreover, Vygotsky described the zone of proximal development (ZPD), which is the difference between what children can accomplish

on their own and what they can accomplish with an adult or with peers (Saxe, 1991; Saxe, 1999; Vygotsky, 1978). Vygotsky's work provides a richer analysis of the types of cognitive forms individuals might structure to carry out cognitive functions that link to math activities (Saxe, 1991; Saxe, 1999). Moreover, the interdependence of sociocultural and cognitive development processes is evident as individuals exhibit intellectual skills in the context of their activities (Brenner, 1998; Saxe, 1991; Saxe et al., 1996).

Núñez, Edwards, and Matos (1999) offered yet a third view of cognitive theory that is based on a situated approach that incorporates linguistic, social, and interactional influences. In essence, this theory purports that "there is no activity that is not situated" (Lave & Wenger, 1991, p. 33). However, in addition to being grounded in environmental and social factors, Núñez et al. (1999) argued that thinking and learning are situated within biological and experiential contexts to shape our understanding of the world. Núñez et al. (1999) contended that "knowledge and cognition exist and arise within specific social settings ... and that the grounding for situatedness comes from the nature of shared human bodily experience and action, realized through basic embodied cognitive processes and conceptual systems" (p. 46). For example, during LEGO® robotics, students may mimic the physical motions of the robot as it travels along a path while also engaging in reasoning, reflection, discussion, and problem solving to complete a robotics task. Computational manipulatives allow children to engage in analytical and embodied cognition (Sullivan & Heffernan, 2016).

The Saxe Model of Cognition

Saxe (1991) described a constructivist approach to study both culture and cognitive development. The Saxe (1991) model, which is grounded in the developmental theory associated with Piaget (1972) and the constructivist theory of learning advanced by Vygotsky (1978), emphasized the relationship between cognition and culture. Saxe (1991) argued that individuals create

new knowledge while participating in culturally influenced goal-structured activities that often occur in social settings. The model focused on three areas: (a) goals for learning that are structured by common cultural practices, (b) particular cognitive forms and functions created and used to reach goals, and (c) identifiable characteristics involved in the interplay across learning in different cultural contexts (Saxe, 1991). Goals for learning, then, are modified and shaped by the structure of cultural activities and social interactions. Within the African-American context, each of these goals is described below.

First, the *goal structure* of cultural practice consists of the tasks or activities that must be carried out. In the African-American community, an example of goal structure can be found in the game of dominoes (Nasir, 2005). "Games are inherently artifacts of culture through which cultural roles, values, and knowledge bases are transmitted" (Nasir, 2005, p. 6). Such artifacts serve to reflect and reproduce culture simultaneously. In dominoes, the goal is not simply to win but to make appropriate decisions to maximize the number of points one can score (Nasir, 2005).

Second, according to the Saxe model, sign forms—such as counting systems and cultural artifacts—are needed to execute and influence goals that emerge in cultural practice. "In this model, the individual and the social context are linked in multiple ways as individuals appropriate cultural forms to solve socially situated and culturally structured problems" (Nasir, 2005, p. 7). As players move to advanced levels in the game of dominoes, they adjust the rules of the game to fit their own purposes. Thus, there are shifting relationships between particular forms that are used in play and the functions they serve. There are shifting cognitive processes in the game as players conform to meet individual needs and engage in social interaction and cultural practices (Nasir, 2005).

Another example of sign forms is found in my research on the use of culturally based computer modules (Leonard, Davis & Sidler, 2005). Two African-American girls were observed

using joint-finger counting and hand-clapping to solve a problem that involved adding two-digit numbers. Much like the hand-clapping rhythms performed by Celie and Nettie in *The Color Purple* (Spielberg, 1985), these girls created a system of counting (i.e., two girls using 20 fingers) to solve the problem.

Mathematics may be embedded in poems, stories, and music. Some educators have combined mathematics and rap to help students to learn. One math rap used Will Smith's tune, *Gettin' Jiggy Wit It*, to help students learn how to solve trigonometry problems (Westerville South High School [WSHS], 2011). Snippets of the math rap are presented below:

*Gettin' Triggy Wit It (Partial Lyrics)*¹

*On your mark, ready set let's go trigonometry pro I know you know
I go Psycho when I see a triangle just can't sit gotta get triggy wit
it uhh that's it Three angles, three sides T-R-I-G all up in my eye
SOH-CAH-TOA*

*Will tell you where to go you just gotta know about H, A, and O
(Chorus 4x)*

Na na na na na na na nana

Na na na na nana

Gettin' triggy wit it

Helps you to study so ya know-a, when to use each one

If you got the O n' H-Y-P SOH lets you know sine's the way to go

Let's say now you got HYP and the A-D-J,

Then cosine's the way yes, yes, y'all

*But there's one more you got the legs (no hypotenuse) that makes
its tan*

Gettin' triggy wit it

(Chorus)

Of course, middle and high school students need basic knowledge of trigonometry to understand the rap. They have to know HYP stands for *hypotenuse*, SOH stands for *sine equals opposite over hypotenuse*, and ADJ stands for the *adjacent side*. Depending on what facts are given, the student will need the sine,

cosine, or tangent to solve the problem. However, this math rap focuses on procedures and mathematical relationships between the sine, cosine, and tangent. Yet, the rap is limited to students' understanding of *why* certain formulas are used.

The interplay between learning across contexts, the third part of Saxe's (1991) model, addresses the problem of learning transfer. At this particular stage, it is important for students to transfer informal out-of-school tasks, such as trading and bartering, to formal in-school tasks. Previous research studies show that Brazilian children who were proficient with everyday transactions had difficulty with written assessments (Carraher, Carraher, & Schliemann, 1987), and Nigerian children who worked in street trading performed worse than nonworking children on timed assessments in arithmetic (Oloko, 1994). Perhaps language, written text and symbols, or the abstract nature of the assessments limited the transfer of knowledge among children who worked as street vendors. Recall that Hawaiian children performed better when teachers used Hawaiian Creole English to scaffold mathematical understanding (Brenner, 1998).

In my own research, underrepresented students were able to retain information when the content was anchored to cultural experiences, such as the germination of lima beans to learn about measurement (Djonko-Moore, Leonard, Holifield, Bailey, & Almughyirah, 2017). However, additional studies are needed to investigate students' ability to transfer culturally based knowledge to general mathematics applications.

Children's Cognition and Learning in Mathematics

Several research studies that contribute to knowledge of student cognition in mathematics emerged from the literature on cognitively guided instruction (CGI) (Carpenter, Ansell, Franke, Fennema, & Weisbeck, 1993; Carey, Fennema, Carpenter, & Franke, 1995; Fennema, Franke, & Carpenter, 1993). A recent CGI study that included links to culture is described below.

Hankes, Skoning, Fast, and Mason-Williams (2013) conducted a three-year study called Closing the Mathematics

Achievement Gap of Native American Students Identified as Learning Disabled (CMAG). Thirty-four teachers (19 special education and 15 regular education teachers) from eight school districts in Wisconsin that served Native American communities participated in the project. Two hundred students with disabilities and 350 general education students were enrolled in the participating teachers' classrooms. Teachers attended three five-day workshops in addition to four two-day implementation sessions and had a minimum of 10 site visits throughout the study. During the training, they participated in CGI and culturally responsive teaching methods. The CGI training consisted of identifying regularities in children's solutions to different types of mathematics story problems instead of following procedures or algorithms. The training consisted of incorporating practices that Native American educators deemed appropriate for Native American students, such as allowing them to create and solve their own culturally specific problems.

Pre-post mathematics scores on the Wisconsin Knowledge and Concept Exam were reported for 56 target students (fourth- to eighth-graders) out of a total of 550 students. The results of a *t*-test revealed significant gains as mean scores rose from $M=1.68$ ($SD=0.88$) to $M=2.02$ ($SD=0.96$). These scores were aligned with a rubric that categorized the scores as follows: minimal=1, basic=2, proficient=3, and advanced=4. Thus, students' scores increased from minimal to basic, which implied that students' "content knowledge [had] increased significantly" (Hankes, 2013, p. 54).

While Hankes et al.'s study is encouraging, the researchers were vague about the teaching practices that were effective with Indigenous students. According to Aikenhead (2017), one must be immersed in the culture of the community before one can engage in authentic culturally based instruction. Furthermore, it is unclear how many students in the target group were Indigenous or in special education. Other than workshops, it is also unclear whether the teachers made any connections with families or elders to understand Indigenous culture or advocated to

remove students from special education if they did not belong there. Finally, the researchers' focus on the achievement gap or *gap gazing* (Gutiérrez, 2008) is troubling as Indigenous people rarely interpret quantified indicators as measures of success (Aikenhead, 2017).

Student outcomes, such as those reported in CGI studies, do not reveal what happens to students as they progress through school. Are students able to transfer the CGI strategies they learned from one teacher to the next when the next teacher does not share the same philosophy of learning as the previous CGI teacher? McNeal (1995) conducted a case study that coordinated anthropological and cognitive perspectives to examine one student's—Jamey's—learning in mathematics during his second- and third-grade years in school. During second grade, Jamey's mathematics instruction was inquiry-based, and mathematics tasks involved the construction of relationships among real and personal objects (Cobb, Wood, Yackel, & McNeal, 1992). Students were not taught basic algorithms but allowed to invent their own procedures for solving addition and subtraction problems. In these inquiry-based classrooms, children were encouraged to offer conjectures, explain their thinking, and critique each other's mathematical ideas. Thus, the environment could be described as emancipatory as students validated the correctness of mathematics problems in a learner-centered community. During second grade, McNeal (1995) discovered that Jamey's "mathematical constructions were quite stable as evidenced by the use of the same strategies to solve similar tasks" (p. 211).

When Jamey matriculated to third grade, his teacher, Mrs. Rose, did not encourage student use of invented algorithms. Mrs. Rose taught the students specific procedures to solve mathematics problems and reinforced those procedures by discouraging the use of "alternative methods and original ideas" (McNeal, 1995, p. 222). As a result of being placed in this type of learning environment, Jamey lost a great deal of the mathematics confidence he had acquired in second grade. Moreover,

he had difficulty remembering the steps to carry out standard algorithms in addition and subtraction and “abandoned attempts to make sense for himself of the tasks encountered in a school context in favor of trying to recall procedures discussed in class” (McNeal, 1995, p. 228). Thus, teachers’ reliance on the use of algorithms rather than invented strategies or other valid strategies that make sense to the students may have a negative impact on student learning in mathematics.

Culture and Children’s Mathematical Reasoning

Malloy and Jones (1998) conducted a study that examined how African-American eighth-grade students solved mathematics problems and how strategies and problem-solving plans related to their success. Twenty-four students (16 female and eight male) participated in individual, oral, problem-solving sessions where they were observed solving five nonroutine mathematics problems. The researchers used Polya’s (1945) problem-solving framework, which was adapted by Lester, Garofalo, and Kroll (1989): (a) orientation—understand the problem, (b) organization—determine a plan to solve the problem, (c) execution—carry out the plan, and (d) verification—evaluate the solution or plan. Paper, pencils, and calculators were available to the students, who were allowed 10 minutes for four problems and 15 minutes for the most difficult problem—the church problem.

Malloy and Jones (1998) used both quantitative and qualitative methods to analyze the results of this study. Qualitative data sources included transcripts of problem-solving sessions and interviews with the students. Problem-solving process actions and approaches were coded and mapped to a rubric. The rubric was used to rate the students’ conceptual understanding and accuracy. A score of zero to two meant the solution was not correct and the student had no understanding or minimal understanding of the concept. A score of three or four indicated the solution was nearly correct or correct and the student had a conceptual understanding of the problem. Thus, concept scores for any particular problem could range from a low of 0 to a high of 4.

Results of the study revealed students were marginally successful on the five problems. Analysis of concept scores by problem type revealed students were most successful on the car wash problem ($M=3.71$; $SD=0.62$) and least successful on the church problem ($M=0.88$; $SD=1.15$). Both problems were embedded in culture. By eighth grade, students may have experienced a car wash and attended a church service. Both problems are presented below for further analysis.

Car Wash Problem

Nakisha, Gregory, Kerstin, and Brandon had a car wash on Saturday. Nakisha washed twice as many cars as Gregory. Gregory washed 1 fewer than Kerstin. Kerstin washed 6 more than Brandon. Brandon washed 6 cars. How many cars did Nakisha wash?

(Answer: 22)

Church Problem

At a community church, the leader plans to place the page numbers for three different songs on the board in the front of the church. The leader must buy plastic cards to put on the board. Each card has one large digit on it. The leader wants to buy as few cards as possible. The song book has songs numbered from 1 to 632. What is the fewest number of cards that must be purchased to make sure that it is possible to display any selection of three different songs?

(Answer: 65)

Eighty percent of the students were able to use successful strategies to solve the car wash problem. The mean score for students classified as high achievers ($n=11$) was 3.91, 3.90 for average achievers ($n=10$), and 2.33 for low achievers ($n=3$). Scores for high and average achievers were consistent only on the car wash problem, suggesting that this problem may have been more relevant to all of the students' experiences. Twenty-two students

used the “work backward” strategy to solve the car wash problem. A second strategy used by 10 students was making a list or chart, and only one student, who solved the problem incorrectly, did not use a strategy.

However, 87.5% of the students did not solve the church hymn problem correctly. Twelve of the students in the study did not use a single strategy to solve the problem, indicating a high level of difficulty. Nine students used one or more strategies unsuccessfully. The strategies these students used were drawing a picture or diagram, making a list or chart, using patterns, and making logical deductions. Only three students were able to successfully use a list or chart and logical deduction to solve the church hymn problem. The researchers did not explain what errors or misconceptions the students may have had as they attempted to solve this nonroutine multistep problem. However, to solve this problem, students had to understand place value and possess number sense. The students also had to know how many digits were needed to make any number from 1 to 632 three times. Then the students had to identify how many cards were needed for the hundreds’, tens’, and ones’ places. The answer of 65 is obtained by realizing the digits 1 to 5 are needed seven times ($5 \times 7 = 35$) and the digits 6 to 9 and 0 are needed six times ($5 \times 6 = 30$).

One possible explanation for the students’ ease with the car wash problem and their difficulty with the church hymn problem may be their lack of exposure to problems that do not depend on strategies (organization) or execution but representation; that is, understanding the relationship between the variables in the problem (Mayer & Hagerty, 1996). By its familiarity, students did not have as much trouble visualizing and making an appropriate representation of the car wash problem. However, problems like the church hymn problem may not be as easy to represent visually and require additional time to solve. By allotting only 15 minutes to solve this problem, the researchers may have stifled some of the students’ cognitive processes. It is not uncommon for teachers to spend an entire class period

on a problem of this nature (Carpenter & Lehrer, 1999; Fennema et al., 1993; Franke & Kazemi, 2001; Villaseñor & Kepner, 1993). Regardless of the cultural context, students need time and space to solve difficult nonroutine problems.

In another study, Ku and Sullivan (2001) studied the problem-solving ability of 136 fourth-grade Taiwanese students. These researchers claimed that personalized word problems, such as inclusion of personal background information in the problem context, enhanced student outcomes (Ku & Sullivan, 2001). Because the problem context was familiar to the students, these researchers contended that attending to fewer details reduced cognitive load and enabled students to perform better. Furthermore, if students had high interest in the problem, they may have been more likely to persist in problem solving. To test their hypothesis, two forms of a 12-item pre-posttest (personalized and nonpersonalized) were given to students. Results showed students were better at solving personalized rather than nonpersonalized problems. For example, in one problem the words "soft drink" were replaced with "milk tea" in order to personalize it. Mean posttest scores improved from 55% in both groups to 86% for students in the personalized treatment group and 78% for students in the nonpersonalized treatment group. Moreover, students' attitudes were more positive ($M=3.52$), on a scale of 1 to 4, when they solved problems related to their own lives rather than problems that did not ($M=3.31$). These researchers concluded that personalized story problems led to improved performance because children were better able to identify and interpret relevant information (Ku & Sullivan, 2001).

Lipka et al. (2005) conducted a study on the implementation of *Math in Cultural Context* (MCC), a culturally based math curriculum designed for urban and rural Yup'ik (i.e., Native Eskimo) students. The researchers used mixed methods to conduct the 2×2 research design of treatment and control groups in urban and rural settings. Students in the treatment groups in urban and rural settings had the MCC curriculum while those

in the control groups did not. Findings revealed significant statistical differences when pre-post scores in treatment and control groups were compared. Furthermore, the researchers analyzed case studies of two teachers' practices with Yup'ik students.

Specifically, they analyzed teacher–student relationships, student-to-student talk, and mathematics communication. Both of the teachers who participated in the case studies (treatment) had been former teachers in the control group. Thus, the researchers were able to compare teachers' practices before and after the intervention. In one case, the teacher was very traditional in her instruction when she participated as a teacher in the control group. Although she worked with a different group of students in another community, she taught primarily by telling students information and asking them to repeat it (Schifter & Fosnot, 1993). However, when she began using the MCC curriculum, the same teacher's pedagogical style changed. She began to use inquiry-based instruction, and the activities in her classroom changed from teacher-centered to student-centered activities. In the second case, the teacher already had a student-centered teaching philosophy. However, using the MCC curriculum helped her to build stronger teacher–student relationships. Students knew they were in a “safe zone” where they could learn, have fun, and take risks (Lipka et al., 2005, p. 378). Findings revealed that the second teacher's students outscored all of the other students who participated in the project.

Other benefits of using MCC curriculum were: (a) altered social organization and communication in the classroom, (b) guided inquiry to facilitate problem solving and multiple solutions to math problems, (c) positive changes in classroom relationships among teachers and students and between the classroom and the community, (d) pride in culture and identity and ownership of knowledge, and most importantly (e) creation of the “notion of ‘third space’ ... in which historically silenced knowledge of Indigenous peoples such as the Yup'ik is privileged alongside traditional academic discourses” (Lipka

et al., 2005, p. 369). Through the MCC curriculum, a cross-cultural school mathematics program was developed between Western and Yup'ik systems (Aikenhead, 2017). In 2016, 10 modules that were specific to mathematics curriculum in Alaska had been created for Indigenous and non-Indigenous students in grades one through seven. DVDs were provided as case studies to show exemplary practices, such as "literacy activities and stories that develop[ed] cultural, mathematical, and contextual connections for students" (MCC, as cited in Aikenhead, 2017, p. 108).

The final study discussed in this chapter (Leonard et al., 2009) took place during an informal program at a high school in Maryland. Eight science or mathematics teachers participated in a semester-long study that began with professional development that focused on culturally relevant pedagogy (CRP) as a way to improve teachers' mathematics practices during the school day. In order to learn how to implement CRP effectively, teachers developed a unit on fast food called *Downsize Me* that was inspired by the documentary *Super Size Me* (Spurlock, 2004).

The teachers were diverse in terms of gender (three males and five females), race/ethnicity (two Asians, four Blacks, one Latina, and two Whites), and country of origin (one United States, two Nigeria, one Trinidad, two Philippines, and one Columbia). Twelve ninth- and tenth-grade English for speakers of other languages (ESOL) students, who were participants in Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP), also participated in the study. The high school students were also diverse in terms of language, gender (nine males and three females), race/ethnicity (two Asians, nine Blacks, and one Indigenous), and country of origin (one Bangladesh, one Congo, one Côte d'Ivoire, one Ghana, one Guinea, one Jordan, four Nigeria, one Togo, and one Trinidad).

While the teachers learned to create lessons that focused on building sociopolitical consciousness, the *Downsize Me* unit was not culturally relevant to the students' lives. The students learned to collect and represent data in the form of a box-and

whiskers-plot, but they were not part of the McDonald's culture owing to their international origins. These students did not eat fast food and had healthier diets than typical American teenagers. Students understood that: "If you eat at McDonald's everyday [*sic*], ... you will get fat real quick" and "I think that eating fast food for a month everyday [*sic*] ... three times a day is very bad for you [*sic*] health" (Leonard et al. 2009, p. 18). Thus, the study is a cautionary tale about how to implement CRP effectively with diverse ESOL students.

Reform-Based Mathematics Education and Opportunities to Learn

Although a great deal of evidence exists that shows positive student outcomes when reform-based pedagogies such as constructivism and inquiry are used (Carpenter et al., 1993; Fennema et al., 1993; Villaseñor & Kepner, 1993), getting teachers to change from traditional mathematics pedagogy to a constructivist or inquiry-based one is challenging. In some cases, students may offer some resistance and express a desire for more traditional activities when it comes to the subject of mathematics (Lubienski, 2000; Martin, 2000). Lubienski (2000) found that poor females were particularly resistant to learning mathematics when a problem-solving approach was used. Because teachers in high-poverty schools have stressed low-level skills that require little effort and thinking on the part of the student (Kitchen, 2007), it may have been difficult for these students to communicate their mathematical thinking because they were unaccustomed to the inquiry approach (Martin, 2000). Yet, constructivist practices that allow students to articulate their ideas in meaningful problem-solving situations have led to more successful performance outcomes for all students regardless of demographic variables (Hankes et al., 2013; Kitchen, 2007; Villaseñor & Kepner, 1993).

Data obtained from reform-based and traditional mathematics classrooms suggest that students of color learn different kinds of mathematics because of their race and low teacher

expectations (Martin, 2013). Often, the justification for these inequitable practices is standards, including the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), which support teaching computational fluency. While it is important to have computational fluency, it should not be used primarily to teach students of color basic skills and mathematical operations to their detriment. Furthermore, while it is appropriate to give students of color challenging and rigorous problems, those problems should not be so difficult that they negatively influence students' motivation and interest in mathematics.

As the mathematics expert in my family, the parents of two fifth-grade boys sent me a text of two different word problems on the same day in November 2017. The two boys are African-American. One boy attended school in Pennsylvania with the following racial demographics: 91% African-American, 3.8% White, 2.1% Hispanic,² and 3% Other (i.e., 1.3% Asian, 1.3% two or more races, and <1% Native American). He was given a worksheet with the following word problem for homework:

A basket with 12 apples has a mass of 3,105 grams. The same basket with 7 apples has a mass of 1,980 grams. Each apple has the same mass. What is the mass of the basket?

The Philadelphia boy used division to solve this problem in two steps:

$$3,105/12 = 258 \text{ r } 9$$

$$1,980/7 = 282 \text{ r } 6$$

The other boy attended school in Texas with the following demographics: 51.4% White, 21.8% Hispanic,³ 14% African-American, 8.6% Asian, and 3.2% two or more races. He was given the following word problem for homework:

This week, Maddie worked $2\frac{1}{2}$ hours on Monday, $2\frac{2}{3}$ hours on Tuesday, and $3\frac{1}{4}$ hours on Wednesday. How many more hours will Maddie need to work this week to make her goal of $10\frac{1}{2}$ hours a week?

The multiple-choice response options to the problem were as follows:

- A. $2\frac{1}{12}$
- B. $8\frac{5}{12}$
- C. $18\frac{11}{12}$
- D. $5\frac{1}{3}$

The two problems reveal differences in scope and sequence in the two states. Despite the Common Core, inappropriate practice was given for homework to students in grade five. Furthermore, the use of homework for standardized test preparation was given without acquiring conceptual understanding.

To solve the first word problem, the child divided and found the average weight of the basket and apples. However, this problem cannot be solved with long division. Algebra is needed to solve the basket problem. How would a fifth-grader know to set up two equations: $12x + y = 3,105$ g and $7x + y = 1,980$ g? Then, how would he know to subtract to eliminate the y variable to obtain $5x = 1,125$ g, then solve for x to obtain $x = 225$ g for the weight of an apple? Finally, one has to insert 225 g in the original equations to get 405 g for the weight of the basket. Without algebraic reasoning, this problem is very difficult for a fifth-grader to solve, even with the use of a calculator. What was the purpose of giving such a problem for homework? Do such problems, while rigorous, frustrate capable students to the point that they dislike mathematics?

On the other hand, fraction problems are appropriate for grade five. However, the second word problem required six steps using the following procedures: (a) find the lowest common

denominator (i.e., 12), (b) find equivalent fractions, (c) add the whole numbers and the fractions to obtain $7\frac{17}{12}$ (d) change $7\frac{17}{12}$ to $8\frac{5}{12}$, (e) change $10\frac{1}{2}$ to $10\frac{6}{12}$, and, finally, (f) subtract $10\frac{6}{12}$ from $8\frac{5}{12}$ to get $2\frac{1}{12}$. Problems of this nature are difficult to solve using mathematics procedures. Conceptually, one could use estimation to solve the problem. Two and one-half is halfway between two and three. Two and two-thirds is closer to three than two. Three and one-fourth is closer to three than four. Thus, the sum would be a little more than eight. If the student had this understanding and knew to subtract to find how many more hours Maddie needed to work, the only reasonable answer is $2\frac{1}{12}$, since $10-8$ is 2. Teachers should be able to explain this problem using conceptual rather than procedural methods. While the fraction problem is appropriate content, the number of steps required to solve it procedurally is inappropriate for fifth-graders.

Summary

Mathematical reasoning develops in classrooms where students are able to actively participate in knowledge construction characterized by classroom discourse (Herbel-Eisenmann & Cirillo, 2009; Kitchen & Beck, 2016; Wood, 2001). In these types of classrooms, students are expected to explain the thinking that led them to use a particular strategy to get a solution to a problem (Leonard, 2000; Wood, 2001). “As advocated in the reform documents, learning mathematics with understanding is thought to occur best in situations in which children are expected to problem solve, reason, and communicate their ideas and thinking to others” (Wood, 2001, p. 116). In order to foster productive learning environments, teachers should resist the inclination to teach by telling (Schifter & Fosnot, 1993; Wood, 2001), limit oversimplifying problem-solving tasks (Crespo, 2003; Wood, 2001), and refrain from assigning problems that no one other than a tutor can solve. Mathematics problems should be appropriate for the developmental level of the students. Finally, teachers must allow students enough time

to solve the problems and the freedom to use strategies that make sense to them as they develop mathematical cognition (Herbel-Eisenmann & Cirillo, 2009; Leonard, 2000; Wood, 2001). “Teachers’ attitudes and expectations, as well as their knowledge of how to incorporate the cultures, experiences, and needs of their students into their teaching, significantly influence what students learn and the quality of their learning opportunities” (Banks et al., 2005, p. 243).

Chapter 2 Discussion Questions

1. What is the role of constructivism and inquiry in twenty-first-century classrooms?
2. How do teachers balance the need to develop students’ computational fluency and problem-solving ability?
3. How does one learn the dominant culture and ways of knowing without sacrificing his/her own culture and values?
4. There is substantial evidence that connecting students’ culture to school mathematics improves student achievement. What elements are needed to balance cultural knowledge with rigorous mathematics to ensure all students succeed?
5. What happens to student motivation and interest when problems are too difficult for students to solve?

Notes

1. For complete lyrics see: www.youtube.com/watch?v=t2uPYYLH4Zo.
2. Categorization of Hispanic includes both White and Black races as defined by census data. District demographics derived from the Pennsylvania Enrollment Management System (PIMS) for the 2015–2016 school year.
3. Categorization of Hispanic includes both White and Black races as defined by census data. District demographics derived from the Texas Education Agency for the 2015–2016 school year.

CULTURAL PEDAGOGY

The Need for Cultural Pedagogy

Issues of race, ethnicity, and social class continue to influence the quality of education that students of color receive in U.S. schools. In 2016, approximately 14 million or 19% of all children in the U.S. lived in poverty (Annie E. Casey Foundation [AECF], 2017a). In the states of Mississippi, New Mexico, and Louisiana, one out of three children were vulnerable to living in poverty (AECF, 2017b). Poverty rates for children of color are two to three times that of Asian and White children: American Indian 34%, Black or African-American 34%, Hispanic 28%, Asian/Pacific Islander 12%, and non-Hispanic White 12% (AECF, 2017b). These data imply there is a relationship between race and poverty (Sheets, 2005). Students of color are more likely to be poor and attend large urban schools where highly qualified teachers and adequate resources tend to be less abundant compared to middle-class, suburban schools (Imazeki & Reschovsky, 2006; Leonard et al., 2009).

When educational tools, such as computers, laptops, and iPads, are available, they are often underutilized in high-poverty schools because some teachers lack technology training and/or fail to understand the importance of using such tools, especially in mathematics (Kitchen & Beck, 2016). Thus, students in high-poverty schools often receive a different kind of mathematics education than affluent students (Martin, 2000; Turner, Celedón-Pattichis, Marshall, & Tennison, 2009). This differential

instruction contributes to differences in achievement outcomes (Ladson-Billings, 2006, 2017).

Studies that compared the mathematical ability of early-childhood students by socioeconomic status emerged in the 1990s (Jordan, Levine, & Huttenlocher, 1994; Kerkman & Siegler, 1993; Wright, 1994). Kerkman and Siegler's (1993) study examined individual differences among poor and middle-class first-grade children's retrieval and use of backup strategies on mathematics tasks. Results revealed no significant differences among first-grade students, controlling for gender and SES: suburban ($M=79.0$, November testing); urban ($M=84.5$, April testing). These findings concur with the findings of Jordan et al. (1994).

However, achievement differences among students of diverse economic backgrounds become evident in mathematics by fourth grade (Lesh, Post, & Behr, 1987; Martin, 2000). While there is a plethora of reasons for underachievement in mathematics, what happens in the teaching-learning context in mathematics classrooms contributes to student failure and success (Ladson-Billings, 2017; Martin, 2000; Rousseau & Tate, 2003). Additional mathematics studies that examined cultural factors, such as *verve* (Carter, Hawkins, & Natesan, 2008) and communal learning (Coleman, Bruce, White, Boykin, & Tyler, 2016), are described below.

Studies on Verve and Communal Learning

Carter, Hawkins, and Natesan (2008) conducted a study on the relationship between *verve* and African-American children's achievement in reading and mathematics. Boykin (1983) described *verve* as one of nine traits in African-American culture that has its roots in West Africa. Carter et al. (2008) described *verve* as "having energy, being intense, and having expressive body language, which also implies a propensity to remain stimulating and lively" (p. 31). In this study, Carter et al. linked *verve* to culturally responsive pedagogy. The sample consisted of 104 European-American (59 males and 45 females)

and 107 African-American (60 males and 47 females) eighth-grade students, who were enrolled in one of two urban schools in the southwestern U.S. The students completed the 18-item Child Activity Questionnaire, which utilized a five-point Likert scale. The survey was developed by Boykin (1983) to determine students' levels of verve. The reliability of the instrument, using Cronbach's alpha, was 0.75, which is in the acceptable range. Univariate linear regression analysis was used to determine the relationship between verve and students' reading and mathematics scores on the Texas Assessment of Knowledge and Skills (TAKS 2003–2004) test.

The results revealed African-American students reported significantly higher verve levels than European-American students ($p < 0.05$). Furthermore, African-American females had higher verve scores than African-American males. However, there was no significant difference on reading scores controlling for mathematics among African-American students. Yet, one major weakness in this study was the assumption made about verve prior to implementation. Just because students report higher verve does not mean they are allowed to have more movement in their reading and mathematics classes. During my teaching career, I have observed students reading while lying on bean bags under their desks and moving freely during mathematics class, particularly when they were engaged in project-based learning. It is unclear what freedom of movement, if any, students were allowed to have in Carter et al.'s study. Thus, mixed methods or qualitative studies that examine the classroom setting are important in culturally based mathematics studies.

Coleman et al. (2016) examined differences in fraction problem solving among 96 African-American students in third through sixth grade. The student participants were recruited from two public schools in the eastern region of the U.S.; 100% of the students received free or reduced lunch. The researchers conducted a quasi-experimental study where students were placed into one of two treatment groups: communal or individualistic. They contended that educational practices that

included *fundamental cultural assets*, such as communalism, improved African-American students' performance in formal learning environments (Coleman et al., 2016; Hurley, Allen, & Boykin, 2009). Communalism refers to "the importance or priority individuals place on their social bonds, interconnectedness, and interdependence with others as individuals consider duty to one's social group to be more important than individual rights and privileges" (Coleman et al., 2016, p. 545).

In Coleman et al.'s study, students engaged in nine lessons using the Problem Solving with Fractions Tasks (PSFT) curriculum, as well as pattern blocks and circle pieces. In the communal group, students were dependent on each other and expected to support one another during the learning tasks. Students in the individual group worked alone with no interaction with their peers. Using analysis of covariance (ANCOVA), the results of a pre-posttest analysis of 15 mathematics items revealed a main effect for the learning context ($F[1,73]=38.13$, $p<0.01$). Moreover, there were significant posttest differences for students in the communal learning group ($M=12.61$, $SD=2.10$) who outperformed students in the individualized learning group ($M=8.34$; $SD=4.10$). There was also a medium effect size (Cohen's $d=0.55$). The findings support the idea that a cultural assets approach, such as communal learning, results in higher performance among African-American students attending Title 1 schools. These findings are consistent with prior studies of this nature (Boykin, Lilja, & Tyler, 2004; Hurley et al., 2009).

The studies described above elucidate the importance of appropriate cultural practices in the development of African-American students' mathematics content knowledge. Yet, many teachers of underrepresented urban and rural students do not understand what cultural pedagogy is or how to use it in everyday classrooms.

Types of Cultural Pedagogy

Cultural pedagogy has historical roots in American Indian and Native Hawaiian education (Brenner, 1998; Demmert & Towner,

2003). Researchers who conducted the Kamehameha Early Education Program (KEEP) believed cultural dissonance or conflict between Native Hawaiian children's culture and school culture was one of the causes of underachievement (Brenner, 1998). In 1998, Native Hawaiian children (24%) represented the largest group of minority children in Hawaii. Today, Native Hawaiians are 21% of the island's population, while Asians make up the largest demographic group, at 37% (Goo, 2015). Brenner (1998), hypothesized that an approach that linked ethnographic and cognitive considerations in the form of cultural pedagogy would improve ethnic minority children's academic success. The researchers developed culturally compatible programs to improve the academic achievement of Native Hawaiian children in reading (Tharp, 1982) and mathematics (Brenner, 1998). Results revealed that vocabulary and reading comprehension subtest scores were superior for KEEP students compared to students in a control group (Demmert & Towner, 2003). In mathematics, results favored students who were taught using a culturally based approach. Overall, findings revealed that culturally based instruction added value to a standards-based curriculum (Demmert & Towner, 2003).

Over the years, a number of terms have emerged to describe pedagogical practices that include cultural considerations. Terms such as culturally responsive pedagogy (Erickson, 1987), culturally relevant pedagogy (Ladson-Billings, 1994, 2009), culturally congruent instruction (Au & Kawakami, 1994), culturally responsive teaching (Gay, 2000), culturally specific pedagogy (CSP) (Irvine, 2002), culturally sustaining pedagogy (Paris, 2012), and culturally responsive instruction (Hankes et al., 2013) have emerged to describe what effective teachers do to enhance learning opportunities for students of color. Among these pedagogies, there are both similarities and differences in approaches to improving learning outcomes for students of color. While the pedagogies offer alternative means to improve learning and achievement among students of color, they also provide different ends, as some focus on cultural norms and

values (i.e., culturally responsive teaching), cultural competence and sociopolitical consciousness (i.e., CRP), linguistic and cultural pluralism (i.e., culturally sustaining pedagogy), or cultural and linguistic knowledge and empowerment (i.e., culturally relevant instruction). A brief description of these pedagogies is presented in the following sections, along with examples from research and practice.

Culturally Responsive Pedagogy

The term culturally responsive pedagogy emerged in the 1980s to describe the politics and culture of school failure and success. School failure in the 1980s was attributed to cultural and linguistic differences between children from diverse racial and ethnic backgrounds and predominantly White teachers. Erickson called this the “communication process explanation” for school failure, which led to systematic and recurrent miscommunication in the classroom (Hymes, as cited in Erickson, 1987). A second explanation for school failure in the 1980s was Ogbu’s (1987) labor market explanation, which essentially argued that:

the main reason for low school achievement of many minority students in the United States is that those students (and their parents and peers) are convinced that school success will not help them break out of the cycle of poverty that they attribute to racism.

(Erickson, 1987, p. 340)

Market-driven forces continue to be the impetus in the U.S., particularly in mathematics education, which has been linked to national security and international competitiveness (Martin, 2013). “Mainstream mathematics education research and policy, particularly in the United States, can be implicated in the production and reproduction of racial ideologies, meanings, disparities, hierarchies, and identities” (Martin, 2013, p. 322). Moreover, the market explanation does not explain how some students from high-poverty communities succeed in U.S. schools and go on to college (Erickson, 1987; Leonard, 2008).

Erickson (1987) argued that both the communication process and labor market explanations were inadequate to describe school failure and stigmatized student identity. Resistance theory (Giroux, as cited in Erickson, 1987) was referenced as a framework to consider alternative explanations for school success and failure. Deficit-oriented approaches that focus only on closing the *achievement gap* between underrepresented students (i.e., African-Americans, Alaska Natives/Pacific Islanders, Latinx, & Native Americans) and White and Asian children should be rejected (Martin, 2013). On the contrary, cultural assets-based approaches (Boykin, 1983; Coleman et al., 2016), which seek to affirm underrepresented students' values and identities and aim to broaden their opportunities for academic and economic success, should be embraced.

Culturally Relevant Pedagogy

Culturally relevant pedagogy (CRP) has been described as an effective way to meet the intellectual and social needs of African-American children (Ladson-Billings, 1994). It supports the following three goals: (a) student learning, (b) cultural competence, and (c) sociopolitical consciousness (Ladson-Billings, 2009). Ladson-Billings (1994) described the following set of behaviors as those most closely associated with CRP:

- Treat students as competent;
- Provide instructional “scaffolding” in order for students to move from what they know to what they need to know;
- Demonstrate that instruction has high priority;
- Extend students' thinking and abilities; and
- Possess in-depth knowledge of both students and subject matter.

(pp. 123–125)

Moreover, CRP acknowledges the link between culture and learning and views diverse students' cultural capital as advantageous to school success (Howard, 2003). Additionally, teachers

who practice CRP use nontraditional means, such as role-playing, skits, poems, rap, and group projects, to assess what students know. Despite clear descriptors of what CRP is, how to implement culturally relevant teaching in mathematics classrooms is not always apparent to novice teachers (Albert, 2000; Leonard et al., 2009).

REFLECTING ON CULTURALLY RELEVANT PEDAGOGY

Albert (2000) described her dilemma with CRP in the mathematics classroom. She gave her seventh-grade mathematics students an assignment that required them to write an essay about a mathematician. Albert believed the assignment was standards-based as it met one of the five process standards articulated in the National Council of Teachers of Mathematics (NCTM) *Principles and Standards* (2000): communication. The goal of the lesson was for students to learn how to communicate their ideas and then clarify, refine, and consolidate their thinking (Albert, 2000; NCTM, 1989). However, Albert, an African-American teacher educator, was surprised to learn that she had missed the mark with her African-American students.

Five African-American males approached Albert about changing the assignment to include writing a rap instead of an essay (Albert, 2000). The request caused Albert to reflect critically upon her pedagogy. She realized that her lesson projected European-American middle-class values and did not reflect the interest, needs, and cultural backgrounds of her students (Albert, 2000; Howard, 2003). Unwittingly, Albert had marginalized the voices of diverse students by censoring the type of writing she expected from them. She realized her lesson, while well intended, was not culturally relevant to her students' lives. In an effort to make the lesson culturally relevant, Albert revised the assignment to allow students to write about the historical contributions that women and persons of color have made to the field of mathematics. Moreover, the mode of writing was expanded to include poems, plays, long or short essays, creative stories, and rap. Such lessons also challenge the view

that mathematics is a male domain (Fennema & Sherman, 1976). Students could report on female mathematicians, such as Maria Agnesi, Sophie German, Evelyn Boyd Granville, Hypatia, Ada Lovelace, Maryam Mirzakhani, Amalie Emmy Noether, Mary Somerville, and others to learn about their contributions to the history of mathematics.

By matching the assignment to students' interests and experiences, Albert (2000) found a more equitable and empowering way to teach mathematics. Goffney (2010) defined equitable mathematics instruction as:

practices that create a fair distribution of opportunities to learn mathematics among students, with special emphasis on the learning of students who are members of ethnic and social groups currently— “underperforming” in mathematics, and those students who depend on schools for their primary access to learning.
(p. 7)

Yet, teachers must be reflective in order to engage in equitable mathematics instruction. Teacher reflection was a major component of Albert's shift toward CRP. Thus, CRP can be used to increase access, opportunity, and participation in mathematics to engage underrepresented students in equitable mathematics teaching (Ladson-Billings, 2009; Leonard et al., 2010).

Culturally Congruent Instruction

According to Au and Kawakami (1994), “studies of cultural congruence are based on the premise that school learning takes place in particular social contexts, often through teacher-student interactions” (p. 5). The premise of culturally congruent instruction is that underrepresented students have poor performance in school because of a cultural mismatch between school culture and home culture. Similar to Erickson's (1987) communication process explanation, culturally congruent practices are based on the assumption that “members of certain ethnic communities may have a preference for values and

communication processes different from those of the mainstream” and that “students of diverse backgrounds will have better learning opportunities if classroom instruction is conducted in a congruent manner” (Au & Kawakami, 1994, p. 6). However, the majority of studies that used culturally congruent instruction examined dialects and home languages to improve children’s achievement in reading. In addition to other cultural considerations, language has implications for learning mathematics.

THE ROLE OF LANGUAGE AND MATHEMATICS

According to Espada (2012), using the native or first language “creates a smoother path for the young learner to understand and acquire basic math concepts, knowledge and skills” (p. 359). Thirty-four kindergarten children participated in Espada’s quasi-experimental study in the Philippines. The sample was divided into treatment and control groups with 17 students each. The same mathematics teacher taught both groups of students, who were comparable in terms of age, SES, literacy, and home language (i.e., Waray). The teacher used similar instructional practices for both groups of students, with the exception that children in the experimental group participated in the Mother Tongue-Based Multilingual Education program while children in the control group received instruction in English.

Mathematics content in Espada’s study focused on counting, patterns, addition, subtraction, fractions, time, ordering and classifying, measurement, geometry, data analysis, etc. The students were given pre- and posttests comprised of 37 items that tested their basic skills on the content. However, it was unclear how long the children were taught before they took the posttest. The results of three *t*-tests revealed the following: (a) higher posttest scores for the experimental group ($M=31.2$) than the control group ($M=20.6$), (b) a higher mean gain for the experimental group ($M \text{ gain}=10.65$), and (c) a statistically significant difference between the mean gain for the experimental and

control groups ($p=0.000$). As a result of these findings, the researchers concluded that kindergarten students exposed to their native language performed better in mathematics than students who were taught in English.

Culturally Responsive Teaching

The concept of culturally responsive teaching emerged from the multicultural education literature of the 1970s. Gay (2000) defined culturally responsive teaching as “using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant and effective for them” (p. 29). Some of the characteristics of culturally responsive teaching include:

- Acknowledgment of the legitimacy of different ethnic groups’ cultural heritages as worthy content to be taught in the formal curriculum;
- Building meaningful bridges between home and school experiences as well as between academic abstractions and sociocultural realities;
- Using a wide variety of instructional strategies that are connected to different styles of learning;
- Teaching students to know and praise their own and others’ cultural heritage; and
- Incorporating multicultural information, resources, and materials in all subjects and skills routinely taught in schools.

(Gay, 2000, p. 29)

Culturally responsive teaching is validating, comprehensive, multidimensional, empowering, transformative, and emancipatory (Gay, 2000, 2010). It is validating because it affirms and strengthens students’ identities. It is comprehensive because it addresses the needs of the whole child. It is multidimensional because it encompasses the curriculum, learning environment, student–teacher relationships, instructional strategies, and

formal assessments (Gay, 2000). It is empowering because it enables students to be successful learners and productive citizens (Gay, 2000; Moses & Cobb, 2001). It is transformative because it challenges the use of traditional pedagogical practices among students of color (Gay, 2000). Finally, culturally responsive teaching is liberating in creating a *third space*, which is defined as “newly re-contextualized content and an environment that surrounds learning that content” (Lipka, Yanez, Andrew-Ihrke, & Adam, 2009, p. 266)—where ethnic ways of knowing are valued alongside dominant canons of knowledge (Gay, 2010).

In sum, culturally responsive teaching “simultaneously develops, along with academic achievement, social consciousness and critique; cultural affirmation; competence and exchange; community building and personal connections; individual self-worth and abilities; and an ethic of caring” (Gay, 2000, p. 43). The ethic of caring is one of the most consistent and powerful findings in research studies related to underrepresented students’ academic achievement (Gay, 2000; Irvine, 2002). “Students defined caring teachers as those who set limits, provided structure, had high expectations, and pushed them to achieve” (Irvine, 2002, p. 141). When teachers truly care about students, they hold them in high esteem and view them as competent. Students, in turn, rise to the occasion by exhibiting high levels of social, ethical, cultural, and scholarly behavior (Gay, 2010; Ladson-Billings, 2009). The ethic of care is the hallmark of culturally responsive teaching.

Culturally Specific Pedagogy

Irvine’s (1992) research on cultural synchronization led to the articulation of culturally specific pedagogy. It acknowledges the style, language, behavior, and tradition of the students’ community (Cooper, 2002), and supports the use of curriculum materials that highlight a distinct ethnic background. To teach mathematics, diverse storylines may be used to frame historical and contemporary experiences that genuinely depict a particular

aspect of an ethnic group's way of life. Capitalizing on significant genres and events in African-American history, such as the Underground Railroad, African-American music, and Black aviators, teachers may use specific elements of the African-American experience to make explicit connections to engage students in culturally specific mathematics tasks (Leonard, Davis, & Sidler, 2005; Leonard & Hill, 2008).

To supplement a reform-based mathematics curriculum, I helped to develop culturally specific multimedia. The creative work, also known as "The Freedom Train" (funded in part by Temple University and the National Science Foundation), underscores the importance of using culturally specific materials to motivate African-American students to learn mathematics and science (Leonard, Davis & Sidler, 2005; Leonard & Hill, 2008). The prototype multimedia module was developed to tell a story based on the Underground Railroad (Leonard & Leonard, 2003). The module was field-tested with African-American students in Philadelphia, New York, and Chicago with positive results.

Unlike some computer-assisted instruction (CAI) projects that isolated students from their peers (Kitchen & Beck, 2016), the module enabled student participants to learn from culturally specific texts. African-American children's literature was used to help them acquire the background knowledge needed to succeed on the multimedia task. Further, children in third- and fourth-grade classes identified with the literary characters and engaged with the text on an emotional level. Students and teachers negotiated classroom norms and attempted to develop shared understandings about what it meant to travel on the Underground Railroad. The multicultural books provided a third space where knowledge, different ways of knowing, and self-determination came together in a culturally specific context to learn mathematics and science (Leonard & Hill, 2008; Lipka et al., 2005).

This study fit within the framework of CSP outlined in Irvine's (2002) study of African-American teachers in the

CULTURES project. In CULTURES, African-American teachers engaged in critical reflection as they examined how their ethnic identity, beliefs, and practices influenced the achievement of their African-American students (Irvine, 2002). Cooper (2002) stated that effective teachers of African-American children engage in the following practices:

- Commit themselves to the Black community and provide a sense of family;
- Promote positive racial identity;
- Help students to succeed in school endeavors, despite the racist nature of both the institution and society in general, by using alternative instructional methods when necessary;
- Take personal responsibility for their students' learning;
- Know their subject matter; and
- Demand excellence of students in all areas, including curriculum and discipline.

(p. 52)

All teachers, regardless of race, gender, or socioeconomic status, can be effective teachers of ethnically diverse students if they immerse themselves in their students' culture and ethnic ways of knowing and use that knowledge as a springboard for learning (Aikenhead, 2017; Leonard et al., 2009).

HISTORICAL SIGNIFICANCE AND CULTURALLY SPECIFIC PEDAGOGY

Historical facts and statistical data can be used to develop culturally specific mathematics lessons. For example, on a visit to the Reginald F. Lewis Museum of African American History in Maryland with former Project SEED colleague Ivan Shkurko,¹ in September 2006, we learned from a museum poster that a \$40,000 reward was offered for the capture of Harriet Tubman in 1856. A lively discussion about what the reward would be worth in 2006 dollars ensued between Ivan and me. I estimated

that the reward would be worth about \$1,000,000. Ivan thought the reward would be worth a lot more, given 150 years of inflation.

A mathematics lesson could begin with a fact sheet about Harriet Tubman and the reward. Then students could estimate what they think the reward would be worth in the current year using a CPI calculator² in a lesson in which mathematics is integrated with background information about inflation and the Consumer Price Index (CPI). For older students, an algebraic formula could also be used to calculate how much purchasing power one dollar in 1856 had in 2006: $(2006 \text{ Price} = 1856 \text{ Price} \times (2006 \text{ CPI}/1856 \text{ CPI}))$. The CPI in 1856 was estimated to be 27, and the CPI in 2006 was estimated to be 604.3. Substituting these values in the formula yielded the following result: $\$40,000 \times (604.3/27) = \$895,200$. My estimate of \$1,000,000 was a bit high but not unreasonable. Students could then discuss the implication of placing such a steep reward on Harriet Tubman's head.

Many credit Harriet Tubman, an icon in Black history, with making more than 19 trips to the South to free more than 300 slaves from 1851 to 1858 (Public Broadcasting System, n.d.). However, this figure could be inaccurate. Harriet Tubman is quoted as saying: "I freed a thousand slaves. I could have freed a thousand more if only they knew they were slaves" (ThinkExist, 2006). In this historical context, another math problem that could be calculated is the average number of fugitive slaves Harriet Tubman assisted on each trip given a minimum of 300 and a maximum of 1,000. Harriet Tubman was courageous but perceived to be dangerous. The \$40,000 reward is equivalent in value to rewards posted for fugitives on today's FBI's 10 most wanted list.

Another example of Black history and math involved a visit to the Laramie Plains Museum at the historic Ivinson Mansion in Laramie, Wyoming, in September 2017. I learned about the first African-American woman to attend the University of Wyoming. Born in 1888, Carrie Burton was 15 when she

enrolled at the university. After four years of studying piano in the School of Music, she moved to Washington, DC, where she was a student and employee at Howard University (The Carrie Burton Overton Collection, n.d.). The archives revealed that she married a teacher, Mr. George Overton, in 1913. In 1923, the couple moved to New York City, where Mrs. Overton studied music at The Juilliard School and English literature at Columbia University. She was also a secretary for the National Association for the Advancement of Colored People (NAACP), the National Urban League, and the Eastern Division of Colored Voters. Math problems could be developed around the cost of Ms. Burton's travel from Laramie, Wyoming, to Washington, DC, the cost of tuition at Howard University in 1910, and the cost to attend Juilliard and Columbia in the 1920s.

A visit to The Cotton Museum at the Memphis Cotton Exchange in 2018 also allowed me to develop math problems related to Black history. African-American labor in the form of slavery and sharecropping helped to build a cotton industry that created enormous wealth for the South, and the nation in general, as documented by world-renowned photographer J. C. Coovert, who captured African-American life in the Mississippi Delta during the Jim Crow era (Gorton & Adams, 2003). Coovert's photograph of an African-American family negotiating the price of their cotton (see Figure 3.1) and data on the price of cotton (see Figure 3.2) can be used to solve contextualized mathematics problems. An example of a mathematics problem for middle school students about the price of cotton during Jim Crow is as follows:

The Weaver family sold bales of cotton in Mississippi during the 1940s. In 1942, the average price of cotton was 19.05 cents per pound. If the Weavers were allowed to keep 50% of the profit as sharecroppers, how many pounds of cotton (rounded to the nearest pound) did the Weavers need to sell to earn \$100.00?

Problems of this nature can be used as a springboard to discuss the unjust sharecropping system. In this economic and social

Figure 3.1 Cotton: J. C. Coovert Photograph #1201.³

order, Black sharecroppers did not receive a fair price for their goods. They had to spend money earned in the general store owned by landowners for seed, supplies, and food. Thus, poverty was perpetuated through this system with ramifications that have lingered for generations.

Finally, some Whites have also experienced economic hardship and inadequate education in the U.S. This is especially true of Whites from Appalachia. On a visit to the Museum of Appalachia in November 2017, I learned that the Appalachians have a distinct history and culture. The farm on the grounds of the museum includes a sawmill, gristmill, smokehouse and granary, corn crib, hen house, blacksmith shop, leather shop, and loom house (see Figure 3.3). A myriad of problems could be developed around farm life.

The museum has about 250,000 artifacts in three different buildings. There is a vast array of folk art, baskets, musical

*Figure 3.2 Cotton Exchange Display.*⁴

*Figure 3.3 Appalachian Loom.*⁵

instruments, and quilts, including baskets and arrowheads produced by the Cherokee tribe that lived in the region. One of the baskets made by an Appalachian couple, which is about four feet long, is acclaimed as the world's largest basket (see Figure 3.4). A story problem about the basket follows:

Russ and Nancy Rose worked nine months to make what they claimed to be the world's largest basket. How many years would it take to make four baskets if they worked at the same pace?

Culturally Sustaining Pedagogy

Paris (2012) introduced culturally sustaining pedagogy, asserting that culturally responsive and culturally relevant pedagogies do not go far enough to include the languages, literacies, and other cultural practices needed to benefit marginalized students due to ever-changing U.S. demographics and globalism. He proposed culturally sustaining pedagogy, which is defined

Figure 3.4 World's Largest Basket.⁶

as a method that “seeks to perpetuate and foster—to sustain—linguistic, literate, and cultural pluralism as part of the democratic project of schooling” (Paris, 2012, p. 93).

Paris’s (2012) critique of culturally responsive and culturally relevant pedagogies is valid if one considers cultural pedagogy as a global concept. However, ethnically diverse communities in the U.S. are not monolingual or monocultural, as citizens from many different cultures speak a variety of languages and dialects. While Paris stated the need to reject deficit theories, policies, and pedagogies, he never moved beyond a definition of culturally sustaining pedagogy to provide salient examples. While some cultural pedagogies may not be explicit about language, they are explicit about the construct and what it entails. When equitable teaching practices are made explicit—that is, the invisible is made visible—then teacher preparation and professional development can be effective regardless of the terms we use.

Culturally Responsive Instruction

Powell, Cantrell, Malo-Juvera, and Correll (2016) defined culturally responsive instruction (CRI) as “instructional practices that connect learning to the cultural knowledge and experiences of students and draw on students’ cultural and linguistic strengths and frames of reference in instruction, thereby resulting in higher levels of student achievement” (p. 3). Moreover, the researchers developed a tool known as the Culturally Responsive Instruction Observation Protocol (CRIOP), which consisted of seven elements—(a) classroom relationships, (b) family collaboration, (c) assessment, (d) curriculum (no longer part of the instrument), (e) instruction, (f) discourse, and (g) sociopolitical consciousness—to measure teachers’ ability to implement CRI in the classroom. The researchers used the CRIOP to determine whether teachers’ implementation of CRI increased after professional development, whether students’ achievement increased as a result of CRI in reading and mathematics, and what teachers’ perceptions were of implementing CRI.

Powell et al. conducted a study on CRI in a Midwestern city in the U.S. with 23 teacher participants during the 2012–2013 academic year. A repeated measures analysis of variance (ANOVA) revealed significantly higher CRIOP scores for teachers in this study from pre- to posttest ($F[1,22]=13.64$, $p<0.001$, partial eta squared=0.38), as well as a large effect size. Student results were based on participating teachers in two out of four schools because they were the only schools to administer the Measures of Academic Progress (MAP) test. There was a total of 456 students in this sample (325 at School A and 131 at School D); 87% of the students received free or reduced lunch, and 28% were English language learners (ELLs). The researchers used the ANCOVA to compare students' spring MAP scores using the fall MAP scores as a covariate while classifying teachers as high or low implementers of CRI as a fixed factor. Results revealed students whose teachers were rated as high implementers had significantly higher mathematics scores ($F[1,186]=25.39$, $p<0.001$, partial eta squared=0.12), with a medium effect size. However, teachers noted a number of challenges in implementing CRI. The most common challenges teachers experienced were related to incorporating every element of CRI into daily lessons, meeting state standards, student performance on state mandated tests, and whether they were implementing CRI correctly.

Powell et al.'s study makes a significant contribution to the extant literature on culturally based instruction. It provides a clear definition of CRI that includes culture and language as well as an instrument to measure it. While pre-post results were significant for teachers (i.e., CRIOP) and students (i.e., MAP), teacher concerns about implementation were valid. Teachers struggled to incorporate the sociopolitical aspect, which is a critical component of culturally based pedagogies. Furthermore, the rubric tended to essentialize students' experiences as one-size-fits-all and was limited in its ability to capture the evolving nature of culture. Nevertheless, the CRIOP provides a foundation for teachers to learn how to implement cultural pedagogy in the classroom.

Funds of Knowledge

Although the term *funds of knowledge* does not bear the word *culture*, it is defined as “historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being” (Moll, Amanti, Neff, & González, as cited in Civil, 2016, p. 46). The goal is to develop innovative teaching practices that build on “the background, knowledge, and experiences (i.e., the funds of knowledge) of students, their families, and communities” (Civil, 2016, p. 46). This resource-based pedagogy emerged during the Funds of Knowledge Project conducted in Arizona. Teachers and researchers used an ethnographic approach with Mexican-American students and families that entailed home visits to gather information about family and labor history, household activities, and parental attitudes to build mutual respect and trust (Civil, 2016). Thus, everyday knowledge and practices were valorized along with school knowledge and practices, including those related to STEM. While the concept of a third space for learning was referenced to “examine the interplay between everyday STEM practices in non-dominant communities and the practices in STEM disciplines,” language should also be taken into account, especially in regard to classroom discourse (Civil, 2016, p. 56). In order for teachers to engage in equitable teaching practices using funds of knowledge, they must ensure that every voice is heard and that every voice counts regardless of the language spoken by the children in the classroom (Civil, 2016).

Summary

Each of the cultural pedagogies described above explicitly and implicitly emphasizes the importance of students’ culture in the teaching–learning process. Teachers should not only use students’ culture as a springboard for student learning, but they should also infuse students’ language into the mathematics curriculum to diminish cultural dissonance. By positioning the

learning of mathematics within specific cultural and linguistic contexts, students are socialized to learn mathematics and develop mathematics identity. As a result, students learn how mathematics is useful in their lives, and they may be less inclined to ask, “When am I ever going to use this?” When teachers make mathematical connections specific to students’ everyday lives, students are motivated to learn more mathematics and are empowered to use it to accomplish their personal goals (Albert, 2000; Civil, 2016; Nasir, 2005).

No classroom is void of cultural influences on teaching and learning. CSP promotes style, language, behavior, and tradition. The purpose of this text is to highlight specific strategies that teachers can use to support the mathematics learning of ethnically diverse students in their classrooms. Students of color continue to struggle in U.S. schools when teachers attempt to assimilate rather than acculturate them into mainstream culture (Howard, 2003; Malloy & Malloy, 1998; Sheets, 2005). Teachers must learn to validate these students’ out-of-school knowledge alongside in-school mathematics knowledge to promote learning transfer (Civil, 2016).

In sum, effective teachers believe diverse students can learn “despite inadequate material resources and social hostilities, claiming Du Bois’ vision of schools as liberating forces” (Cooper, 2002, p. 62). This principle has been used in culturally specific contexts with Alaska Native (Lipka et al., 2005), Hawaiian (Brenner, 1998; Tharp, 1982), Latinx (Gutstein, 2003 & 2006), and African-American students (Djonko-Moore et al., 2017; Irvine, 2002; Leonard, Davis, & Sidler, 2005; Leonard & Hill, 2008). Moreover, qualitative and quasi-experimental studies provide evidence that cultural pedagogy improved student outcomes among Alaska Native (Lipka et al., 2005), Native American (Hankes et al., 2013), Hawaiian (Brenner, 1998), and African-American students (Coleman et al., 2016) in mathematics. As is the case with ethnomathematics—“the mathematics that is practised among identifiable cultural groups” (D’Ambrosio, 1985)—the use of CSP recognizes the richness of

diverse mathematical practices and systems around the world (Brenner, 1998).

Nevertheless, in order to change the way mathematics is taught to underrepresented students, we must examine how teachers are prepared (Howard, 2003; Irvine, 2002). “In the case of teacher education, a crucial goal must be to promote fundamental shifts in the perspectives of beginning teachers” (Remillard, 2000, p. 132). Critical reflection of one’s own race and cultural identity is prerequisite to understanding the racial and cultural identities of students and is a precursor to developing pedagogical strategies that infuse culture into the curriculum (Howard, 2003; Remillard, 2000). In short, teaching is a transformative journey where teachers learn about students and learn from students (Nieto, 2000; Rodriguez & Kitchen, 2005). By using cultural pedagogy, affirming students’ identities, and recognizing that everyone is unique, novice teachers can learn to engage in equitable teaching practices in the mathematics classroom.

Chapter 3 Discussion Questions

1. What does each type of cultural pedagogy have in common? How are the types different?
2. How are language and culture intertwined in culturally relevant pedagogies?
3. How can teachers support students’ home languages in the mathematics classroom?
4. How can teachers use rap and hip-hop cultures effectively in the mathematics classroom?
5. How might teachers use history and current events in ethnically and linguistically diverse classrooms to create culturally specific mathematics problems?

Notes

1. Ivan Shkurko passed away on September 7, 2017.
2. www.bls.gov/data/inflation_calculator.htm.
3. Covert photograph taken by Jacqueline Leonard with permission from The Cotton Museum at the Memphis Cotton Exchange: www.memphis-cottonmuseum.org.

4. Photograph of display taken by Jacqueline Leonard with permission from The Cotton Museum at the Memphis Cotton Exchange: www.memphiscottonmuseum.org.
5. Loom photographed by Jacqueline Leonard and used with permission from the Museum of Appalachia in Clinton, Tennessee: www.museumofappalachia.org.
6. Basket photographed by Jacqueline Leonard and used with permission from the Museum of Appalachia in Clinton, Tennessee: www.museumofappalachia.org.

COMPUTATIONAL THINKING, COMPUTER SCAFFOLDING, AND GAME DESIGN

Technology can be used to scaffold students' learning as well as provide opportunities to embed culture into digital games and computer simulations. Computer coding has been used to motivate learning and to broaden students' opportunities in STEM (Leonard, Buss, et al., 2016). The benefit of learning to code includes the development of computational thinking (CT) skills (Falloon, 2016; Leonard, Buss, et al., 2016; Moreno-León, Robles, & Román-González, 2016; Repenning, Webb, & Ioannidou, 2010; Wing, 2008). Students can develop CT (i.e., abstraction, algorithmic thinking, and learning transfer) across disciplines and in multiple contexts (Mouza, Marzocchi, Pan, & Pollock 2016; Weintrop et al., 2016), allowing them to "learn computer science and be equipped with the CT skills they need to be creators in the digital economy, not just consumers, and to be active citizens in our technology-driven world" (Smith, 2016, n.p.).

With the development of the smartphone and tablets, communication patterns and ways of human interaction have changed in the twenty-first century. Thus, the term *digital native* has taken on new meaning. In fact, digital native as a concept is gendered, raced, and classed (De Castell, Boschman & Jenson, 2008), and the educational use of digital games to advance twenty-first-century learning can be highly demanding (Jenson, Droumeva, & Fraser, 2016). Simply being familiar with digital technologies and using computers in everyday life does not necessarily translate into learning (Livingstone, 2008). Moreover,

the notion that today's students are de facto digital natives does not apply to all students as familiarity or facility with basic computer programming skills and competencies differ by focus and interest (Jenson et al., 2016). Yet, the current media landscape and familiarity with digital game design can provide under-represented children with multiple entry points to acquire the CT skills needed in the twenty-first century (Jenson et al., 2016).

Computational Thinking

Computational thinking (CT) is a term first coined by Seymour Papert (1980) in his classic *Mindstorms* text. However, CT is not about computation and rote learning. Rather, CT is a systematic process that “involves solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science” (Wing, 2006, p. 33). Computational thinking tools must help users through three fundamental stages of CT: problem formation (abstraction), solution expression (automation), and execution/evaluation (analysis) (Repenning, Basawapatna, & Escherle, 2017). While the term computational thinking continues to evolve, an operational definition set forth by the International Society for Technology in Education and the Computer Science Teachers Association (ISTE/CSTA, 2011) suggests that CT is a problem-solving process that includes: formulating problems; logical organization of analysis of data; representation of data through abstractions; identifying and automating solutions through algorithmic thinking; analyzing and implementing possible solutions; and generalizing and transferring the problem-solving process.

Simulations and Game Designs

In order to foster CT in K–8 education, the coding should consist of a “low floor and high ceiling” (Resnick et al., 2009). Beginners should be able to cross an easy threshold to create a working program (low floor), and the tool should be complex enough to meet the needs of advanced students (high ceiling).

Microworlds EX, Scratch, and Scalable Game Design are generating interest in developing K–8 students' CT skills because they scaffold student learning, enable knowledge and transfer, support equity, and are systematic and sustainable. Each of these design programs were field-tested for appropriate use with elementary and middle school students in a research study.

Microworlds EX

Microworlds EX is an advanced web-based version of LOGO (i.e., logic-oriented graphic-oriented), which is a programming language used to enhance cognition in children by incorporating computers and technology into geometry instruction (Papert, 1993). Microworlds EX is based on the theory of constructionism, which focuses on students' ability to build knowledge structures regardless of the learning environment (Papert & Harel, 1991).

To field-test this learning environment, researchers at the University of Wyoming and I conducted a Saturday academy in Denver, Colorado. Seventeen participants from African-American and Mexican-American communities participated in the study at a community-based center in spring 2014. Nine males and eight females participated in 115-minute sessions for five weeks. The majority of the participants were fifth- and sixth-grade students who attended elementary or middle school in Denver. In this study, they used simple code to develop simulations of their choosing, once the LOGO terminology was learned (see Figure 4.1). In this particular simulation, the student used place as Colorado is known for snowboarding. Recall that place is defined as landscapes, experiences, and so on.

Given the small sample, the Related-Samples Wilcoxon Signed Rank Test, a nonparametric test, was used to assess students' self-efficacy in technology (Ketelhut 2010), twenty-first-century skills, and attitudes toward STEM (Friday Institute, 2012). All surveys utilized a five-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). Results revealed increases from pre- to posttest but no significant differences in self-efficacy in technology. However, there were

Figure 4.1 Snowboarding Simulation.

significant differences in twenty-first-century skills: pretest $M=3.80$ ($SD=0.77$); posttest $M=4.23$ ($SD=0.55$); $p=0.026$. During computer-based tasks, students expressed a greater willingness to work with peers and to assist with group tasks. Furthermore, science attitudes improved significantly: pretest $M=3.35$ ($SD=0.59$); posttest $M=3.70$ ($SD=0.71$); $p=0.036$. Attitudes toward mathematics and technology/engineering improved but were not significant. Nevertheless, it should be noted that students' pretest scores were highest on the engineering/technology subscale, and the posttest may have been influenced by ceiling effects. The short duration of the study may have also influenced the survey results.

Scratch

Scratch is an open-source software program developed by the Massachusetts Institute of Technology (MIT). Scratch is a prominent tool because of its syntax-free drag-and-drop interface. Mouza et al. (2016) conducted a study to assess students' learning of computer science concepts, development of Scratch programming skills, and attitudes and motivation toward

computer science. Results of the study revealed student participants ($n=41$) exhibited significant improvement from pre- to posttest on their knowledge of computer science concepts. In terms of their programming skills, 71% of the projects were coded as interactive while 29% lacked interactivity. Furthermore, 68% of the students selected sprites from the Scratch library, while less than 8% created their own sprites. Roughly 58% of the students created functional projects, but 66% of the projects were not unique as they included explicit statements that contained just enough information to run the program. The findings revealed the need to encourage creativity over functionality in the Scratch environment.

Lawanto, Close, Ames, and Brasiel (2017) explored students' strengths and weaknesses while comparing a group of 183 seventh- and eighth-graders' performance in a Scratch environment. Dr. Scratch is an assessment tool to analyze students' projects for elements of CT. Dr. Scratch focuses on elements of CT, such as logic, data representation, parallelism, synchronization, user interactivity, flow control, and abstraction. However, researchers found it was difficult to assess CT in real-time. Close, Janisiewicz, Brasiel, and Martin (2015) proposed evaluating students' CT by analyzing their projects using a rubric that utilized the aforementioned elements of CT. Scoring on the four-point rubric ranged from zero to three: 0—Uses only the most basic interactive block; 1—Uses other types of interactive blocks (mouse clicking, sprite clicking); 2—Uses complex interactive blocs (webcam and microphone); and 3—All Scratch blocks are used in chronological working order. Assessment results revealed student strength in flow control ($M=2.35$, $SD=0.49$); synchronization ($M=2.66$, $SD=0.89$); parallelism ($M=2.69$, $SD=0.65$); and user interactivity ($M=2.00$, $SD=0.11$). Weaknesses were noted in abstraction ($M=1.05$, $SD=0.30$) and data representation ($M=1.52$, $SD=0.51$). Students had average performance on logic. While the findings were not generalizable, they revealed the need to develop students' CT as it relates to representation of data through abstraction (ISTE, 2011).

Scalable Game Design

Scalable Game Design (SGD) has been used successfully with middle school students as children at this age tend to read fluently and work independently (Repenning et al., 2015). Moreover, 64% of girls and 69% of underrepresented students expressed high interest in game design after participating in a study on SGD (Repenning et al., 2010; Webb, Repenning, & Koh, 2012). The SGD curriculum utilizes instructional units in game design and science simulations to support CT patterns, such as generation, absorption, collision, transportation, diffusion, polling, and hill climbing.

Generation is used to multiply the number of agents in the game. Absorption does just the opposite, allowing agents to be removed from the game. Collision occurs when agents collide in the game, which often results in points being scored and/or agents disappearing or taking on different forms (i.e., living or deceased). Transportation allows one agent to carry another to safety in the game. Diffusion allows agents to follow a smell or a scent to chase other agents in the game. Polling allows the game to keep track of how many agents are in the game at one time. This feature can be used to determine when the game is won or lost. Finally, hill climbing allows a player to advance to more difficult levels within a game. Thus, computational thinking patterns (CTP) allow students to engage in CT as complex decisions are made with if/then statements to determine how the agents behave in a game. Figure 4.2 depicts the first level of a maze game produced by students in an Innovative Technology Experiences for Students and Teachers (ITEST) study (to be described).

Learning CTP provides students with a useful high-level language to begin thinking about a problem before coding begins. Users can recognize these patterns across contexts and implement them in projects. SGD consists of two programming tools: AgentSheets (2-D) and AgentCubes (3-D), which support problem formation by enabling users to organize information

Figure 4.2 Level-One Worksheet for Maze Game.

visually, setting the stage for coding after using a whiteboard for drawing. Agents can be organized in 2-D or 3-D space with no coding involved. Visual thinking is supported by an agent matrix. AgentSheets and AgentCubes offer drag-and-drop features that provide conversational programming to annotate program behaviors. Abstractions allow for object interactions such as collision and diffusion. During the execution stage, learning is supported through debugging, which allows users to confront their misconceptions and correct coding errors. Live programming helps users to instantly see the consequences of any change to a program.

Teaching with Emerging Technology

Using computers in the mathematics classroom has primarily taken the form of computer-assisted instruction (CAI) to reinforce basic skills (Kitchen & Beck, 2016). While many of these types of programs limit students' interactions with each other as well as the instructor, simulations like *Riding the Freedom Train* (Leonard & Leonard, 2003), involved connecting children's science and mathematics knowledge to multicultural literature in large- and small-group settings (Leonard et al., 2005; Leonard & Hill, 2008). In the year 2000, educational software was limited to CD-ROM and static web-based environments that limited children's creativity. Now, with interactive web-based technology, students can create their own games.

Game design requires using drawing tools to create unique characters (i.e., agents or sprites) and game boards (i.e., worksheets) using specific codes (i.e., if/then statements) to move the characters through challenges to win the game. Game design engages students in CT through writing and debugging code (Repenning et al., 2015). Various theories such as learning for use and universal learning design have been used to understand student cognition during game design. A brief review of the literature related to these theories follows.

Learning for Use

Learning-for-use (LfU) was developed by Daniel Edelson (2001) at Northwestern University. Based on four principles, LfU is a technology design framework that recognizes the following: (a) knowledge construction is incremental in nature, (b) learning is goal-directed, (c) knowledge is situated, and (d) procedural knowledge needs to support knowledge construction (Edelson, 2001). The first and fourth principles of the LfU model include the incremental process of developing new knowledge and procedures. Connecting prior knowledge to new knowledge is the key component in this theory. Students incrementally apply new concepts to memory, while subdividing existing concepts or developing new connections between concepts. In LfU, procedural strategies for scaffolding incremental learning include observation, discussion, reflection, and application. Newly acquired knowledge may encourage metacognition, enlightening students as they become proactive in their own learning.

The second and third principles of LfU recognize that knowledge acquisition is goal-directed and situated. The realization of knowledge gaps as the result of curiosity or external demand can be used as the motivation to acquire new knowledge. For example, if students learn that diffusion can be used for one agent to chase another agent, they may be willing to learn new techniques to raise the stakes in a digital game (Webb et al., 2012). Goal-directed tasks are needed for students to create games and simulations to apply CT skills, which are needed to learn computer science.

Universal Learning Design

Another theory that allows teachers to engage in technology and CSP simultaneously is universal learning design (ULD). The principles that guide ULD are as follows: (a) multiple means of representation, (b) multiple means of expression, and (c) multiple means of engagement (Center for Applied Special

Technology [CAST], 2012). ULD has been used with culturally and linguistically diverse students to scaffold learning across the curriculum (Rao, 2015). Professional development for classroom teachers on the use ULD may enhance their implementation of game design from a holistic approach. Rather than teachers providing students with tutorials to learn to code, students may develop their own aides using scanned photos, screenshots, aerial images, or video clips to learn the basic principles of Alice, Scratch, SGD, Unity, and other game designs. These helpful hints could also be placed on a blog to assist peers at multiple sites.

Instead of adhering to deficit theory, teachers and researchers should view their students' cultures as assets upon which to build new knowledge (Bracey, 2013; Leonard, 2008; Leonard, Buss, et al., 2016). In STEM education, understanding the importance of other ways of knowing is crucial to helping students to cross cultural borders (Aikenhead, 1997; Leonard, 2008). ULD offers teachers the opportunity to scaffold students' knowledge of computer science with cues children can create on their own.

The ITEST Study

I served as the principal investigator (PI) for an ITEST project that was awarded to the University of Wyoming by the National Science Foundation (NSF) in 2013. The project, Visualization Basics: Using Gaming to Improve Computational Thinking, also known as uGame-iCompute, was a three-year study that examined two treatment variables: robotics and game design. Teachers learned to implement LEGO® EV3 robotics, Scalable Game Design (SGD), and Scratch to elementary (grades four and five) and middle school students (grades six to eight). Researchers examined the teaching–learning process as well as the influence of robotics and game design to improve students' spatial ability and CT skills. An overview of the results is presented to inform the research community about the quality of teaching and learning during each year of the project as well as to lay the foundation for researchers who wish to replicate the study.

The Purpose of the Study

The primary purpose of the uGame-iCompute study was to enhance teachers' culturally responsive teaching beliefs and outcome expectancy, CT attitudes, and engineering beliefs, as well as student participants' self-efficacy in technology, twenty-first-century skills, attitudes toward STEM, and CT skills. Data on teachers and students are presented to examine the teaching-learning process and how culture was used as the context for learning. After obtaining institutional review board (IRB) approval, the research team developed a counterbalanced, quasi-experimental research design to examine changes in teacher beliefs and student outcomes. During Year 1, teachers focused on gaming, robotics, or a combination of the two to test the treatment variables in formal (technology classes) and informal instructional settings (see Leonard, Buss, et al., 2016). In Year 2, variables were isolated to study the impact of each intervention (i.e., robotics or game design). A combined intervention was used to examine the impact of gaming and robotics in Year 3.

Participants and Setting

The uGame-iCompute project was implemented in 13 rural school districts in Wyoming with 41¹ teachers and 807 students during the fall and spring terms. The distribution of participants over the three-year duration of the study was: 11 teachers in Year 1, 24 teachers in Year 2, and 25 teachers in Year 3. Additionally, in Year 3, eight teachers and 108 students in Philadelphia, Pennsylvania, participated in the study during the fall term. Students enrolled in the Pennsylvania schools were predominantly African-American (93%), whereas Wyoming students identified as 77.8% White, 15.3% Hispanic, 3.6% Asian, 2.2% Native American, 2.1% African-American, and 2.5% two or more races. In terms of gender, students were predominantly male in both settings (Pennsylvania: 64% male and 36% female; Wyoming: 70% male and 30% female).

Methodology

Mixed methods were used to collect and analyze data in the uGame-iCompute study. The literature is replete with examples that show how quantitative data alone do not fully explain the complexities of classroom environments and teacher actions (Demmert & Towner, 2003). In the Creswell (1998) tradition, the researchers used thick descriptions to illustrate the nuances observed in the teaching–learning context. In particular, micro-ethnographic research methods were used by “combining participant-observation with detailed analyses of audiovisual records of naturally occurring interaction” (Erickson & Mohatt, 1982, p. 133). Specifically, the case study was the micro-ethnographic method used to learn about participating teachers’ practices (Bogdan & Biklen, 2006). Selecting case studies of focal teachers each year allowed the research team to examine the complexity of enacting culturally relevant pedagogy (CRP) in gaming environments, which adds to the extant literature related to innovative technology and education.

Instrumentation

The teacher participants completed surveys to determine how their beliefs about culturally responsive pedagogy and CT attitudes were influenced by the study.

CULTURALLY RESPONSIVE TEACHING BELIEFS

Based on concern for equitable teaching and culturally sensitive instruction, Siwatu (2007) developed a measure of teachers’ sense of efficacy based on Bandura’s (1997) efficacy scales. Rather than using a Likert scale, Siwatu (2007) believed that a scale from 0 to 100 was psychometrically stronger and would result in greater discrimination. Teachers completed a two-part efficacy survey: Culturally Responsive Teaching Self-Efficacy (CRTSE) and Culturally Responsive Teaching Outcome Expectancy (CRTOE). The CRTSE consisted of 40 items, and the CRTOE consisted of 26 items with internal reliability of 0.96

and 0.95 (Cronbach's alpha), respectively. The CRTSE measures the extent to which teachers have a sense of efficacy for engaging in specific instructional tasks related to culturally responsive teaching. The CRTOE measures the extent to which teachers learn to associate positive outcomes with culturally relevant teaching.

COMPUTATIONAL THINKING ATTITUDES

Yadav, Zhou, Mayfield, Hambruch, and Korb (2011) developed an instrument to assess teachers' attitudes and understanding related to CT. In addition to the surveys, teachers learned to use AgentSheets (Repenning et al., 2010) to facilitate CT among their students.

SELF-EFFICACY IN TECHNOLOGY

Students also completed surveys to measure their self-efficacy in technology. The Self-Efficacy in Technology Survey (SETS) developed by Ketelhut (2010) was modified to measure changes on three technology constructs: videogaming (eight items), computer gaming (five items), and using the computer to solve problems (five items). Sample items include: *I am certain I can master any videogame I play*; *I can keep winning at computer games for a long time*; and *I can find information on the web using a search engine*. The Cronbach's alpha coefficients of these constructs were 0.93, 0.84, and 0.79, respectively, which were in the acceptable range.

STUDENT ATTITUDES TOWARD STEM

The survey developed by the Friday Institute (2012) was modified to assess attitudes toward mathematics (eight items), science (nine items), and engineering/technology (nine items). Sample items include: *I am the type of student to do well in math*; *I will need science for my future career*; and *I am good at building and fixing things*. Cronbach's alpha coefficients were greater than 0.83, which were in the acceptable range.

COMPUTATIONAL THINKING RUBRIC

As the PI of this study, I developed a rubric to assess CT during game design (see Appendix A). The three-point rubric used for game design was established with an interrater reliability of 86%. Scores on the rubric ranged from 1 for emerging, 2 for moderate, and 3 for substantive evidence of CT using the ISTE framework as criteria. Survey results are reported for Year 3 teacher and student participants only since Year 1 and Year 2 results have been reported elsewhere (Leonard, Buss, et al., 2016; Leonard et al., 2018).

Year 1 Highlights

Initially, 12 teachers (Cohort 1: spring 2014) were recruited to participate in the study in Year 1: eight females and four males. The racial makeup was nine White, one African-American, one Native American, and one two or more races. However, one teacher withdrew from the study because of retirement. During this part of the study, the researchers examined the learning environments, as well as the training platform, in order to gain insight into teacher development and models for best practices and optimal learning. One-hundred-and-twenty-four students from eight schools in Wyoming participated in Year 1.

Teachers' received eight weeks of online training that focused on culturally responsive pedagogy, robotics, and game design. The teachers were required to maintain a journal as they engaged student participants in a minimum of 50 hours of instruction in one or more learning contexts (i.e., before, during, or after school). Four focal teachers were selected for further study to examine their transition from training to facilitating informal STEM education. The lesson plans, journal entries, and work samples (i.e., game designs) that these teachers developed during the online course were analyzed for themes and patterns. Cross-case analysis allowed for comparing and contrasting these teachers' strategies and instructional practices.

Four focal teachers—two females and two males—were selected as a convenience sample. One female teacher was a

member of the Arapaho tribe. The second female teacher identified as Native American and White. The two male teachers identified as European-American or White. Each teacher was observed two or three times by different members of the research team, including the PI. The researchers collected copious field notes during the observations that documented the participating teachers' instructional strategies. The artifacts created during the course (e.g., teacher journals, field notes, and lesson transcripts) provided evidence of culturally responsive teaching and effective STEM teaching practices.

TEACHERS' JOURNALING

Excerpts of these focal teachers' journaling are presented below in Table 4.1, revealing some of the challenges and successes they experienced while teaching LEGO® EV3 robotics and/or Scalable Game Design (i.e., AgentSheets and AgentCubes).

The journal entries revealed challenges with LEGO® EV3 robotics programming as well as AgentSheets and AgentCubes programming and commands. In the game design context, teachers employed the Scalable Game Design (SGD) tutorial or the Project First approach. Project First views game design from a holistic perspective as teachers help students to understand the coding needed to create the entire game rather than using the step-by-step process provided by the developers of SGD.

Mrs. A used a cultural approach with her Indigenous students that included scaffolding before allowing them to program on their own. However, she also reported students' discomfort with the programming. Likewise, Mr. P concluded: *Students did not enjoy the AgentSheets development environment. Many students felt that the programming style was clunky.* On the other hand, Mr. Q only identified the difficulty students had with following directions: *As the students continued working, they learned that they needed to follow ALL of the instructions if the game was to work correctly.* Mr. P, who used the Project First approach, implied the AgentSheets program limited student creativity: *A fair number of students wanted to program commands and controls into*

their game but found the programming far too complicated so they ditched their ideas. However, Mrs. B appeared to have the most success with AgentSheets. In contrast, Mrs. B reported that her students enjoyed coding with game design more than they did with robotics MINDSTORMS® programming. However, she noted difficulty with AgentCubes running effectively.

In terms of successes, all four teachers found that student autonomy was very important for game design. Mrs. A mentioned that student confidence increased as a result of the program and that once eighth-grade students learned the rules they were not afraid to “ditch” the tutorial: *Eighth grade refused the packet, and said they could build the game without the directions.* Mrs. B’s students mastered AgentSheets and also engaged in simulations. She noted: *Students were excited and exclaimed, “We wrote our own program, on the first day!”* Some of her advanced students also created games in Scratch and Python. Mr. Q discussed the range of creativity in his class and how even *he* enjoyed playing the games students designed: *The creativity ranged from ninjas to semi-trucks to lava to skulls, and I enjoyed trying to play each and every one of the games.* Mr. P also noted: *Almost all students flat-out loved making and playing games.* Field notes revealed that none of his students’ games were identical. Rather, they were rich and colorful, with the capacity to keep score and announce a winner at the end of the game.

GAME DESIGN LESSONS

According to their lesson plans, Mrs. A taught game design to seventh- and eighth-graders exclusively for six weeks. Mr. P taught game design to sixth-graders for 10 weeks during the school day. Mrs. B and Mr. Q worked with middle school students, facilitating both robotics and game design. Mrs. B taught for 10 weeks, while Mr. Q taught for eight weeks. Mrs. A, Mrs. B, and Mr. Q relied mainly on the AgentSheets tutorial. In Mrs. B’s class, students engaged in remixing or overwriting someone else’s code to create another game rather than starting from the beginning. It is important to note that this shortcut

Table 4.1 Excerpts of Focal Teachers’ Journaling

Teacher	Challenges	Successes
Mrs. A	<i>This week was all about learning AgentSheets. I let the students play Frogger one day and then we set out to build the program. All the students wanted to start together as a group. They were not comfortable with the programming. Each class started with me on the smart board. I discarded my own Frogger game and began working with the students. This is very common behavior for American Indian students. They want to have everything modeled before they venture out on their own.</i>	<i>I am seeing more confidence in the gaming. Students asked if they could now try building their own game. I downloaded AgentSheets and AgentCubes onto the student computers. The 7th grade group has started their own game; 8th grade moved to their own individual games in the AgentCubes. Eighth grade refused the packet and said they could build the game without the directions. I am observing and listening to their conversations about how the program works.</i>
Mrs. B.	<i>Students, when given a choice, chose programming in AgentSheets to programming in LEGO robotics. One student tried AgentCubes, but it would not open. He went on to make his own game. Some students’ programming with LEGO robotics was not successful.</i>	<i>Students found red light—green light on programs. They used the red brick and green brick to tell robot to respond. Students then wrote their own program—Black light follow me. They converted red light—green light to all black and tested it. Students were excited and exclaimed, “We wrote our own program, on the first day!” On the second day, a student brought his own EV3 robot.... One of the female students worked with Scratch directions to make forger game, replacing Frogger sprites with unicorns and cars. Another male student used AgentSheets and gamed with ultimate Pacman. Two other male students use Python to program—they got it free from Python.com. Students were involved and self-motivated to create games with AgentSheets.</i>

Mr. P

As a whole, students did not enjoy the AgentSheets development environment. Many students felt that the programming style was clunky. A fair number of students wanted to program commands and controls into their game but found the programming far too complicated so they ditched their ideas. Several students had issues with the software itself. Far too frequently a file would become corrupt and a student would lose their entire game.

Mr. Q

I was surprised that each student had trouble following the instructions at times, even though I thought the Frogger instructions we used were extremely easy to follow.... Once the students understood the basic skills necessary to build the game, they started to skip sections of the instructions. I find this just as true in my ... 6th grade math class, but did not think it would happen during the club. As the students continued working, they learned that they needed to follow ALL of the instructions if the game was to work correctly. This also showed up as we built forest fire simulations. The students were better at following all of the instructions, but many of them wanted to change the names of certain parts of the simulation. As a result, the program was referring to agents and rules that were either spelled differently or were named something completely different.

Almost all students flat-out loved making and playing games. After we worked through an in-class example game together, students developed their own game idea. I was nervous that students would either just copy the game we made together while changing the agent depictions or they would try to program something much too ambitious. They did surprisingly well at coming up with legitimate game ideas that were challenging but doable.

One part of the club that interested me was the aim to push students to deeper levels of problem solving and spatial abilities. Math can be challenge to all students at times. This club has given me a model I hope to use next year in my teaching. What I liked about teaching [AgentSheets] was the ability for students to take a set of directions and create a game that had a much different look and feel than the directions outlined. The first set of directions students followed, were the instructions for the game Frogger. When I built the game, I was very time constrained, so I did not step out of the boundaries of the instructions, and instead made what many would consider a bland version of Frogger. My students, however, took the game and made it their own. None of the Frogger games in my club are the same. The creativity ranged from ninjas to semi-trucks to lava to skulls, and I enjoyed trying to play each and every one of the games.

bypassed the opportunity to learn CT because abstraction and debugging may already have been done. Mr. P was the only teacher to use the Project First approach.

The transcript of Mr. P's lesson taught in May 2014, along with field notes, is presented below to show how he infused information technology and computer science into his lesson on game design. The lesson described below, as well as the information he elicited from the students, helped them to understand the speed and power of computing. The lesson also provided a pathway to computer science careers by allowing the students to learn and use the language of computing.

LESSON TRANSCRIPT

Mr. P opened an old computer to show his students the CPU. Then he placed the computer on his desk to expose the circuitry. A projection of an emerging game in AgentSheets was displayed on an interactive whiteboard in the front of the classroom.

T: *What is this thing?* [Holds up a small object.]

S: *A CPU.*

T: *Good. Central processing unit. A processor is what?*

S: *... a memory bank*

T: [Raises an eyebrow at student's response, and fields an additional response from another student.]

S: [Inaudible]

T: *Yeah, it can't really think but it is pretty close. What kind of thinking can it do? What is it really good at?*

S: *... billions of seconds.*

T: [Nodding.] *Good ... billions of what kind of things per second? You said computing.*

S: *Gigahertz!*

T: *Yeah, yeah ... and what does it do?*

S: [Inaudible]

T: *Good, usually it is good at math and that's what we are going to do today. We are going to use it to keep score.*

Mr. P continued the class discussion by pulling out various other pieces of hardware from the computer frame including a hard drive and a memory card. He provided students with a specific example of a game on his laptop, which was visible on the interactive whiteboard.

T: *This is in your laptop. So how much of this [waving a memory card] do we have?*

S: *Zillions!*

T: *Good. Do you remember how many billions?*

S: *A thousand.*

S: *Four billion.*

T: *Very good! So, it depends on the computer. Your [tablet] has a different amount of RAM than that computer and your phone has a different amount of RAM than your [tablet] but this computer has four gigabytes of memory. Okay ... so what does that prefix giga- mean?*

S: *Billions! [in chorus.]*

T: *So ... this is something you can look up before you buy your [game system]. The more RAM you have, the more things you can work with right now, the better your graphics inside your game and the smoother things will run inside your computer.*

T: *What do we call commands that we repeat a lot?*

S: *Procedures.*

T: *Good. Sometimes we might call it program ... or we might call it ... what else do we use? Function or method. They all just mean the exact same thing. In the same way, we call variables a bunch of things. In AgentSheets one of the things we call it is properties.*

In addition to computer science, the lesson above also allowed students to develop number sense. This was one of the most exemplary lessons observed in Year 1, which was shared with Year 2 teachers. Year 2 teachers also had the benefit of learning how the Arapaho teacher embedded culture into her lessons.

Year 2 Highlights

In Year 2, the robotics and game design treatment variables were isolated as continuing and newly recruited teachers were encouraged to teach either robotics (Cohort 2: fall 2014) or game design (Cohort 3: spring 2015). Year 2 results focus on game design rather than robotics since that is the heart of this chapter. Eleven teachers (eight new and three continuing from spring or fall 2014) and 92 elementary students participated in game design in spring 2015. A case study of three focal teachers who co-taught at one elementary school were selected as a convenience sample. These teachers focused on AgentCubes during the lunch hour and two hours per week after school for 14 weeks to complete the minimum 40 contact hours (number of hours decreased from Year 1).

GAME DESIGN LESSONS

The objective for the afterschool club was to develop a three-dimensional game using AgentCubes. Students discussed the differences between 2-D and 3-D figures and the basics of drawing figures in the geometric plane. The elementary students learned to create agents in 3-D as well as how to move them around and set goals to win the game. Field notes and a transcript of the game design lesson taught by the focal teachers in May 2015 are presented below.

LESSON TRANSCRIPT

One of the three teachers opened the lesson with a discussion that described the learning goals for the day: development of a 3-D version of the AgentCubes game and comparison of AgentCubes to AgentSheets. The three teachers are identified as T1, T2, and T3.

T3: [Pointed out choices of animals, identified choices and prompted students to create their own agents] *There are some choices, but what's the fun in using something already made?*

T3: [Redirected a student who jumped ahead of the discussion]

Please don't get ahead of us.

T2: *I know it's tempting, but we will give you time.*

T3: *Think about how you should modify your agents.*

GIRL 1: *Double click it.*

T3: *Don't forget that you can use the mirror image button.* [T3 coached T2 on how to create a symmetric image.]

GIRL 2: *Frogs are boring.* [She created a dragon agent for her game.]

BOY 1: *I made a red poison tree frog. This is a species of frog that can be found in Virginia.*

BOY 2: *They are also in North Carolina.*

[T2 became the lead facilitator.]

T3: *You can do what, if you want to repeat a rule?* [Prompted students to think about shortcuts in game design.]

ALL: *Duplicate.*

BOY 3: *My image is inverted.* [T3 went over to help.]

BOY 3: *I hate inverted ... like in Battlefield. I like flying jets and my boards are usually inverted, so I usually end up crashing in the first 10 seconds!*

BOY 4: *How'd you get it to move?*

BOY 5: *I like to mess around.*

T1: *Who has trouble moving your frogs?* [Several hands go up.] *Try the green play button.* [Students began to have success.]

T2: *Try moving at a different angle and move your frog.*

GIRL 3: *This is so much fun!*

T2: *Sharkbait!* [This is a phrase that the teacher used to get students' attention.]

ALL: *Bru-ha-ha.* [Student response to affirm attention was given.]

T3: *How do we win?*

ALL: *We move to the grotto.*

T3: *So, we're going to build our grotto.* [T3 directed students to build the grotto agent.]

BOY 6: *Can we choose any one of them?*

T3: *Yes, but we're going to name it grotto.*

[Students continued to tinker with sounds as more and more students created unique win condition noises.]

T2: *Create a specific sequence of commands to play sound, show message, and reload world.*

[Students finished making agents. Students were directed to stop the simulation and to save their games.]

The three teachers worked well together to reach the learning goals. Each teacher made valuable contributions to student learning and assisted students as needed. The students' comments above revealed the flexibility they had to design agents and games of interest. While producing the traditional *Frogger* game, a pair of students discussed different kinds of frogs that were specific to the southeastern U.S. (see Figure 4.3). The student artifact below revealed some of the coding that was required to run the game. Random movement, rotation, and transportation were some of the commands that were embedded in the game. Students also learned different coding techniques, such as duplicating rules and rotating images in the plane. Finally, students were creative in their use of sounds to signal that the game was won after the agent reached the grotto.

Figure 4.3 Red Poison Tree Frog.

Year 3 Highlights

In Year 3 of the project, 30 teachers (Cohort 4: fall 2015; Cohort 5: spring 2016) and 380 students in elementary and middle school participated in the combined robotics and game design intervention. These teachers and students were located at two project sites. Eight teachers and 67 students in three urban elementary schools in Pennsylvania and 14 teachers and 161 students in 10 rural elementary schools in Wyoming participated in the study in Year 3. Seven middle school teachers and 143 students in six middle schools and one teacher and nine students from one alternative high school also participated in the study.

In Year 3, the project focused on teacher variables related to culturally responsive teaching, computation thinking attitudes, and engineering beliefs, while student variables related to spatial ability, self-efficacy in technology, attitudes toward STEM, and CT during game design. Given the aim of this chapter, the only teacher outcomes reported are those related to culturally responsive teaching and CT attitudes. Student outcomes related to self-efficacy in technology and CT skills are analyzed for relevance.

TEACHERS BELIEFS AND OUTCOMES

Aggregate data on all teachers new to the study were analyzed to examine changes in teacher beliefs in Year 3 (eight urban and 11 rural; 13 elementary schools, five middle schools, and one alternative high school). The results of culturally responsive teaching beliefs (i.e., CRSTE & CRTOE) and CT attitudes are shown in Tables 4.2 and 4.3, respectively.

Table 4.2 Comparison of Pre-Post Culturally Responsive Self-Efficacy and Outcome Beliefs

<i>Construct</i>	<i>Pretest</i>	<i>SD</i>	<i>Posttest</i>	<i>SD</i>	<i>Gain Score</i>
CRTSE (<i>n</i> =19)	82.55	13.71	84.32	12.72	1.77
CRTOE (<i>n</i> =19)	85.39	12.63	87.51	8.82	2.12

Table 4.3 Comparison of Pre-Post Computational Thinking (CT) Attitudes

<i>Construct</i>	<i>Pretest</i>	<i>SD</i>	<i>Posttest</i>	<i>SD</i>	<i>Gain Score</i>
CT (<i>n</i> =19)	3.31	0.30	3.43*	0.31	0.12

Note
* $p<0.05$.

The results showed no significant increases from pre-post on the CRTSE or the CRTOE. These results were similar to the findings in the Year 2 study (see Leonard et al., 2018). However, there was a significant difference from pre-post on CT attitudes for new teachers in Year 3 ($t[19]=-2.651$; $p=0.016$). There was a small effect for this result (Cohen’s $d=0.39$). Gain scores on CT attitudes were similar to those of teachers in the gaming-only learning environment in Year 2 (see Leonard et al., 2018). Thus, the gaming environment may have influenced teachers’ attitudes toward CT more than robotics did.

SELF-EFFICACY IN TECHNOLOGY

The Self-Efficacy in Technology Survey (SETS) was analyzed using the *T*-statistic. Each of the subscales (i.e., videogaming, computer gaming, and computer use) was analyzed for all elementary students, regardless of locale, and also disaggregated by state (see Table 4.4).

T-test results revealed significant differences from pre-post on all subscales for the entire group: videogaming ($t[197]=-1.973$; $p=0.050$; Cohen’s $d=0.15$); computer gaming ($t[196]=-2.517$; $p=0.013$); Cohen’s $d=0.21$); and computer use ($t[195]=-2.070$; $p=0.040$; Cohen’s $d=0.15$). However, the effect for these results was small. Scores for Wyoming students on these constructs increased significantly from pre-post on computer gaming ($t[136]=-2.409$; $p=0.017$; Cohen’s $d=0.23$) and computer use ($t[135]=-1.976$; $p=0.050$; Cohen’s $d=0.19$). Again, the effect was small. While nonsignificant, results show higher scores in Pennsylvania on computer gaming and computer use, which may indicate possible ceiling effects. Nevertheless,

Table 4.4 Analysis of Year 3 Self-Efficacy on Technology and Science Survey (Elementary)

<i>Constructs</i>	<i>Pretest</i>	<i>Std. Dev.</i>	<i>Posttest</i>	<i>Std. Dev.</i>	<i>Gain Score</i>
<i>Videogaming</i>					
All students ($n=197$)	4.04	0.67	4.14*	0.65	0.10
Wyoming ($n=137$)	4.04	0.68	4.14	0.65	0.10
Pennsylvania ($n=60$)	4.04	0.64	4.14	0.66	0.10
<i>Computer Gaming</i>					
All students ($n=196$)	3.95	0.69	4.09*	0.65	0.14
Wyoming ($n=136$)	3.92	0.71	4.08*	0.67	0.16
Pennsylvania ($n=60$)	4.04	0.65	4.11	0.61	0.07
<i>Computer Use</i>					
All students ($n=195$)	3.92	0.82	4.04*	0.74	0.12
Wyoming ($n=135$)	3.87	0.83	4.02*	0.75	0.15
Pennsylvania ($n=60$)	4.02	0.80	4.09	0.73	0.07

Note

* $p < 0.05$.

these results show the blended environment significantly increased students' self-efficacy in technology. These results concur with findings regarding the SETS in Year 1 (see Leonard, Buss, et al., 2016).

The analysis of covariance (ANCOVA) was also used to determine if there was a significant difference among elementary students by gender. The adjusted means by gender were: males ($n=113$) $M=4.22$ ($SE=0.057$); females ($n=68$) $M=4.00$ ($SE=0.075$). Results show a significant main effect but no significant interaction on videogaming by gender: $F(1,177)=5.772$, $p=0.017$, partial eta squared 0.032, which is a small effect.

Data were also analyzed for middle school students. Only middle school students in Wyoming participated in the study. Results are shown in Table 4.5. Data for students at the alternative high school were not analyzed owing to the very small sample and age of the students (typically older than middle school).

Results of a paired t -test revealed significant differences from pre-post on videogaming ($t[114]=-2.099$; $p=0.038$; Cohen's

Table 4.5 Analysis of Year 3 Self-Efficacy on Technology and Science Survey (Middle School)

<i>Constructs</i>	<i>Pretest</i>	<i>Std. Dev.</i>	<i>Posttest</i>	<i>Std. Dev.</i>	<i>Gain Score</i>
<i>Videogaming (n=114)</i>	3.85	0.78	3.96*	0.78	0.11
<i>Computer Gaming (n=114)</i>	3.70	0.76	3.76	0.84	0.06
<i>Computer Use (n=114)</i>	3.90	0.73	3.83	0.92	(0.07)

Note
* $p<0.05$.

$d=0.14$). The effect size for this result was small. While there was an increase in computer gaming, it was not a significant result. Interestingly, survey results for middle school students show a decline on computer use. However, this decline was not significant.

ANCOVA was also used to determine if there was a significant difference by gender. Findings revealed a significant main effect but no significant interaction for gender on videogaming: $F(1,104)=8.840$, $p=0.004$, partial eta squared 0.078, which is a small effect size. The adjusted means by gender for videogaming were: males ($n=70$) $M=4.08$ ($SE=0.064$); females ($n=38$) $M=3.74$ ($SE=0.091$). Findings also revealed a significant main effect but no significant interaction for gender on computer use: $F(1,104)=4.020$, $p=0.048$, partial eta squared 0.037, which is a small effect size. The adjusted means by gender for computer use were: males ($n=70$) $M=3.93$ ($SE=0.082$); females ($n=38$) $M=3.65$ ($SE=0.111$). Given the male adjusted mean is above the mean on the t -test for the entire group (see Table 4.5), the decline in overall scores was attributed to females. There were no significant gender differences for computer gaming. However, females' self-efficacy on videogaming (i.e., elementary and middle school) and computer use (i.e., middle school) raised concerns. Given that girls were outnumbered in most of the afterschool programs, being in the minority may have attributed to their technology beliefs. Further research is needed to determine the results for equal gender groups.

COMPUTATIONAL THINKING AND GAME DESIGN

Student participants in Wyoming and Pennsylvania completed 20 hours of game design combined with 20 hours of robotics for a total of 40 hours of instruction. CT appeared to be more robust in this type of learning environment. Sixty-seven student participants at three schools in Pennsylvania participated in Year 3. There were three groups of students at one of the schools, which had the majority of students enrolled in the study. Given the limitations of this book chapter, data analysis focuses on the game designs of elementary students in Pennsylvania. In this environment, students developed maze and *Frogger* games.

Using the aforementioned rubric (see Appendix A), CT was rated in seven categories: formulating problems; abstraction; logical thinking; using algorithms; analyzing and implementing solutions; generalization and problem transfer; and use of pop culture (i.e., off-the-shelf games). Table 4.6 delineates the ratings for students at two of the Pennsylvania sites by school and classroom. Students' games at the third site could not be evaluated owing to the fact that most of the games were incomplete.

While there is some variation, the scores in each category are fairly consistent for this sample of elementary students in Pennsylvania on game design. Recall, rubric scores were emerging=1, moderate=2, and substantive=3. The strongest categories were abstraction ($M=2.50$) and generalization and transfer ($M=2.07$), which trended toward substantive and moderate, respectively. The weakest categories were problem formation ($M=1.71$), algorithms ($M=1.72$), and analyzing and implementing ($M=1.77$). Yet, these scores trended toward moderate. Overall, students' scores were moderate ($M=1.94$).

From Research to Practice

After the uGame-iCompute project began, I incorporated computer science in my mathematics methods courses. Novice

Table 4.6 Ratings of Pennsylvania Students' Game Designs for Computational Thinking

School/Class	Problem Formulation	Abstraction	Logical Thinking	Algorithms	Analyzing & Implementing	Generalization & Transfer	Use of Culture	AVG
School A	1.70	2.70	1.90	2.00	1.80	2.50	1.80	2.06
Class 1 ($n=10$)								
Class 2 ($n=9$)	1.67	2.78	1.89	1.67	1.89	2.22	2.00	2.02
Class 3 ($n=12$)	1.92	2.33	2.00	1.83	1.75	2.00	2.00	1.98
School B	1.55	2.18	1.91	1.36	1.64	1.55	1.64	1.69
Class A ($n=11$)								
AVG	1.71	2.50	1.93	1.72	1.77	2.07	1.86	1.94

teachers in a middle-level mathematics certification program were required to develop Scratch games (see Appendix B). In fall 2016, 11 teachers developed games that they subsequently used with students in their classrooms. One game focused on centimeter conversion, and the other focused on measuring perimeter and area.

The teacher who developed the centimeter conversion game wrote the following excerpt as part of a reflection paper:

This game focuses on converting meters to centimeters or centimeters to meters. I drew a sprite that makes a few statements and then asks the player to convert a number to meters or centimeters based upon whether the player hits the left or right arrow key. The coding for this was pretty basic because once I created a variable “answer,” I simply had to multiply or divide it by 100 in order to get the correct answer. The sprite said, “Great Job” and then a clapping sound played. If the answer is incorrect, the sprite said, “Try Again” and a cymbal sound played. When the score hit 3, the screen changed to the win or lose screen, and the wizard moved down while saying, “Don’t give up now! Try again!” When the score hit 5, the screen changed to the win or lose screen, and the wizard moved up while saying, “You are a conversion champion.” The clapping sound played with the winning score, and the cymbal sound played with the losing score. I developed this game in order to build my students’ confidence in converting numbers from meters to centimeters and centimeters to meters. This game can also be used to practice basic decimals and to introduce the powers of 10.

The teacher who developed the perimeter and area game wrote the following excerpt on her reflection paper:

This project was my second attempt at creating a usable math game and was based off of my own ideas and goals of exploring the Scratch program. I currently have a student working on perimeter, area, and volume, and I wanted the student to be able to

play the game. As in my previous game, either my student(s) or I can add and build onto the game. This allowed my student(s) to become familiar with the duplication feature of the program (which I did when developing this game). In this second game, I also used voice recordings. The voice recordings for this game are the voices of two second-grade students.

The foregoing examples and excerpts from reflection papers show how teacher educators can incorporate game design in their methods courses to help prospective and novice teachers understand CT and how to develop it among their students. The sprites and the backgrounds in the games can express culture and/or place, allowing students to embed objects that are meaningful to them. Thus, students may be motivated to persist even when game design is difficult and requires debugging.

Summary

The projects described above provide some examples of how culture as well as place can be used with emerging technology to help students develop CT skills. From snowboarding to red poison tree frogs, students can create and design games using a myriad of characters and backgrounds. Overall, the study described above shows that students' games were functional and CT skills were in the moderate range. Data revealed that teacher efficacy, as it related to culturally responsive teaching, was malleable and CT attitudes improved significantly. Student participants' self-efficacy in videogaming, computer gaming, and computer use increased significantly among elementary students. Self-efficacy in videogaming also increased significantly among middle school students. Evidence suggests the combined robotics and gaming environment provided rural and urban students with multiple opportunities to learn. However, more attention should be paid to recruiting and sustaining females in robotics and game design.

Chapter 4 Discussion Questions

1. What are the benefits of using SGD tutorials to teach students how to design digital games?
2. What are the benefits of using the Project First approach instead of tutorials?
3. How can game design be incorporated into the core curriculum (i.e., reading/language arts, mathematics, science, and social studies) during the school day?
4. What are the benefits of using open-source material, such as Scratch, to teach game design?
5. How can teachers scaffold learning to ensure a low floor and high ceiling when facilitating game design?
6. How might teachers' use digital game design to improve K–8 students' problem-solving skills?

Note

1. Some teachers participated in more than one year; thus, the number of teachers per year does not equal the sum of the stated distribution across three years.

ROBOTICS, SPATIAL ABILITY, AND COMPUTATIONAL THINKING

Robots are used in a variety of industries. For example, the ATLAS robot (built by Boston Dynamics) has sensors that allow it to lift large packages and stock shelves, and it can move and balance itself as it carries out these tasks (Miley & Housiaux, 2016). Other places where robots are used include dairy farms in order to corral and milk cows; hospitals also use robots to perform complicated surgeries (Miley & Housiaux, 2016). Robots are also portrayed in the film industry (e.g., BB-8 and CP3O in *Star Wars: The Force Awakens* [Kennedy, Abrams, & Burk, 2015]). More recently, Saudi Arabia granted citizenship to its first robot, Sophia, who has the ability to speak and exhibit emotions (O'Neill, 2017). Thus, using robotics to engage students in STEM is not a novel idea.

Robotics has been used successfully to engage K–8 students in pre-engineering and general STEM (Blanchard, Judy, Muller, Crawford, and Petrosino, 2015; Karp & Maloney, 2013; Leonard, Buss, et al., 2016). Specifically, robotics has been shown to improve spatial ability (Francis, Khan, & Davis, 2016; Nugent, Barker, Grandgeneet, & Adamchuk, 2010), student attitudes toward science and engineering (Blanchard et al., 2015; Karp & Maloney, 2013), and computational thinking skills (Sullivan & Heffernan, 2016). Robotics may also be used for cultural relevance as students can program the robot to play a tune (e.g., blues, jazz, country music) or perform a specific task. This chapter highlights the robotics aspect of the uGame-iCompute study referenced in Chapter 4. The teaching–learning

process is examined during robotics instruction to understand the development of students' spatial ability and computational thinking (CT). The robotics context is also examined through the lens of cultural brokering—crossing borders from the culture of family and peers to the subculture of science (Aikenhead, 1997).

Spatial Abilities

Spatial abilities allow students to create three-dimensional images that can be manipulated to solve a myriad of problems (Pattalis & Christou, 2010). Spatial abilities, which are correlated with high performance in engineering and mathematics, can be placed into three categories: spatial perception, spatial orientation (i.e., mental rotation), and spatial visualization (Linn & Peterson, as cited in Nagy-Kondor, 2017; Pattalis & Christou, 2010). Spatial perception “requires a subject to determine spatial relationships with respect to orientation ... to rotate a two-dimensional or three-dimensional figure accurately; [and] spatial visualization ... requires the subject to demonstrate an ability that involves complicated, multi-step manipulations” of spatial information (Nagy-Kondor, 2017, p. 36). Spatial reasoning, on the other hand, is a complex set of critical elements (Francis et al., 2016) that refers to the skill of “representing, transforming, generating, and recalling symbolic nonlinguistic information” (Linn & Peterson, as cited in Nagy-Kondor, 2017, p. 37).

Francis et al. (2016) conducted a study on spatial reasoning with 18 nine- and 10-year-old children who participated in LEGO® EV3 robotics. Using MINDSTORMS® programming software, “the learner can trigger the robot to move by dragging-and-dropping ... coding blocks” that function as object-oriented codes or commands (Francis et al., 2016, p. 10). After programming the robot, students received feedback from direct observation of the robot's behavior. Forms of observable spatial reasoning that students exhibited during MINDSTORMS® programming included: “*locating* and *orienting* in two

dimensions and then *locating*, *orienting*, and *pathfinding* in three dimensions” (Francis et al., 2016, p. 11). Thus, children in the LEGO® robotics study engaged in “Bruner’s enactive-iconic-symbolic topology of representations ... simultaneously rather than sequentially” (Francis et al., 2016, p. 1). This finding challenges the notion that children experience concrete, semi-concrete, and abstract activities in a linear fashion.

Computational Thinking and Learning Progression

In addition to spatial reasoning, student engagement in robotics tasks allows for the development of CT (Gura, 2012; Ortiz, 2015; Sullivan & Heffernan, 2016). The researchers defined computational manipulatives as tools that have internal computing capabilities, programming, or microcomputers embedded in the hardware. Grounded in the LOGO programming language (Papert, 1993), computational manipulatives allow children to engage in analytical and embodied cognition. For example, during LEGO® robotics, students may mimic the physical motions of a robot as it travels along a path while they also engage in reasoning, reflection, discussion, and problem solving to complete a task (Francis et al., 2016). Thus, robotics construction kits have a dual function as students engage in both physical and cognitive aspects of learning, which suggests that students follow a learning progression (Sullivan & Heffernan, 2016).

A learning progression marks the intermediate learning points between two ends or anchors (National Research Council, 2007). Until Sullivan and Heffernan described learning progression in terms of CT, it was difficult to measure exactly which CT skills were developed. Sullivan and Heffernan (2016) claimed that students follow a learning progression model of sequencing, causal inference, conditional reasoning, and systems thinking to develop CT during robotics tasks. In the uGame-iCompute study, this model was modified to include proportional reasoning also. Sequencing involved following specific steps to put the robot together and program it to move;

proportional reasoning was used to determine the number of rotations needed to move the robot a certain distance; causal inference relied on the use of if/then statements to adjust the program; conditional reasoning involved using logic to program specifications, such as sensing color or touch; and systems thinking consisted of understanding how different components interacted to produce specific outcomes. Many of these steps were observed during LEGO® robotics tasks in the uGame-iCompute study.

Cultural Brokering

The concept of cultural brokering emerged from Aikenhead's (1997) work with secondary Native American science students in Canada. For the vast majority of students, regardless of Western or non-Western origin, science is a *foreign* or strange subject (Aikenhead, 2001). Students perceive science to be strange because there is incongruence between the real-life culture of students and culture embraced by members of the science community, the students' world view and views commonly accepted by Western scientists, and the social contexts for learning science and using scientific knowledge (Aikenhead, 1997). In order to reconcile these conflicts, Aikenhead (2001) suggested that science teachers exhibit the following behaviors:

- Recognize Western science as a cultural entity in itself;
- Acknowledge that most students experience cultural border crossings when moving from their life-worlds into the world of school science;
- Consider the myriad of ways students deal with cognitive conflicts arising from culture clashes; and
- Help students as they negotiate their border crossings to reduce cultural conflicts.

(p. 181)

Furthermore, Aikenhead (1997) defined border crossing as the movement between cultures and microcultures. For many

students, border crossing from the microculture of family and peers to the microculture of school science is tenuous, and the transition from the students' culture to school culture in the science classroom is a cross-cultural experience (Aikenhead & Jegede, 1999). Cultural brokering eases this transition as teachers help students to move fluidly between their culture and the microculture of school science or, in the case of this chapter, pre-engineering (i.e., robotics tasks) by addressing conflicts that may arise in interpretation and task implementation (Aikenhead, 1997).

Theoretical Framework

The theoretical framework that undergirds robotics is constructionism, which was articulated by Papert and Harel (1991). The simplest definition of constructionism is learning-by-doing (diSessa & Cobb, 2004) to build knowledge structures despite the type of learning environment (Papert & Harel, 1991). Within this framework, there is a great deal of autonomy as the learner is guided by the work that proceeds rather than a protocol. Moreover, the framework allows students to be active learners as they think about an idea, investigate that idea, discuss it with peers, and make adaptations within a complex system of programming language such as LOGO (Papert & Harel, 1991).

Seymour Papert (1980) developed LOGO to enhance cognition in young children by incorporating computers and technology into the teaching of geometry. The LOGO programming language fosters and encourages creativity by having students design and apply geometric concepts that they learn while using technology. Turtle geometry is used as the drawing tool in LOGO programming. Students are able to use coding to move the turtle in various directions in two-dimensional space (Francis et al., 2016). The latest version of LOGO relies on a graphical user interface (GUI), which is similar to using MINDSTORMS® to program robots. Students learn to program in two-dimensional space while the robot functions in three-dimensional space (Francis et al., 2016). As a result, students

engage in spatial reasoning as they shift between two-dimensional and three-dimensional representations of the robots' movements (Francis et al., 2016). Thus, the constructionist framework supports the development of spatial reasoning with LEGO® robotics kits (Berland & Wilensky, 2015; Francis et al., 2016).

The Study Context

Recall that teachers in the uGame-iCompute study learned to implement robotics and/or game design with fourth- through eighth-grade students in Wyoming (Years 1–3) and third-through sixth-grade students in Pennsylvania (Year 3 only). Students' use of spatial orientation skills was examined as they manipulated two- and three-dimensional figures mentally and physically during robotics instruction (Francis et al., 2016; Metz, Donohue, & Moore, 2012). LEGO® EV3 robotics kits were used as a treatment variable to improve elementary and middle school students' spatial ability. In addition to spatial ability, students' CT skills were examined during robotics tasks.

Initially, the researchers believed spatial ability was limited to the manipulation of three-dimensional LEGO® robotics kits and CT was limited to game design. However, this was not the case because students were able to create three-dimensional images in game design with AgentCubes and engage in CT in robotics via learning progression. An overview of the results is presented in this chapter to inform teaching and research communities about the benefits of using robotics tasks to engage underrepresented students in STEM.

Research Questions

The research questions specific to the aims of this chapter are as follows:

1. How did middle school students' spatial orientation change as a result of participating in the robotics-only or the combined robotics and game design treatment?

2. Which spatial reasoning and CT skills emerged among elementary and middle school students during robotics tasks?
3. In what ways did students experience cultural brokering during robotics tasks?
4. What challenges and successes did participating teachers report during robotics implementation?

Participants and Setting

Fifteen teachers (Cohort 2) in Wyoming participated in the robotics-only context in Year 2. Thirty teachers (Cohorts 4 and 5) in Wyoming and Pennsylvania participated in the combined robotics and game design context in Year 3. Twelve of the 22 rural teachers had previously participated in one or more years of the study. However the eight urban teachers participated in the study only in Year 3. To ensure reliability, the research questions and analyses focus only on teachers and students new to the study.

Methodology

To evaluate the efficacy of the interventions, a counter-balanced, quasi-experimental research design was developed to examine changes in students' spatial orientation, spatial reasoning, and CT skills. Students received the robotics intervention (40 hours of instruction) in Year 2 and the combined robotics and game design intervention (20 hours of instruction for each treatment) in Year 3. Quantitative data, however, do not totally explain changes in student behavior. Thus, mixed methods were used to collect and analyze data in this part of the study.

Data Sources

Quantitative data sources consisted a modified spatial ability test that was administered to middle school students on a pre-post basis (Newton, 2009). Qualitative data sources included teacher journals, transcripts of focus group interviews with teachers,

screenshots of students' MINDSTORMS® programming, and transcripts of students' discourse during robotics lessons to examine their spatial reasoning and CT.

Instrumentation

A spatial ability test was field-tested with 25 students from three schools during the pilot year. The original assessment consisted of 25 card rotation items and 20 multiple-choice items for a total of 45 items (Newton, 2009). Pilot-testing revealed that students did very poorly on the multiple-choice items. Therefore, only the 25 card rotation items that measured spatial orientation skills were given to students in Years 2 and 3 of the uGame-iCompute study. The Cronbach's alpha coefficient on the modified spatial ability test was 0.91, which indicated very good reliability (DeVellis, 1991). Students in Cohort 2 completed Spatial Ability Test 2, while students in Cohort 4 completed Spatial Ability Test 4. Two different forms of the tests were used to ensure internal validity.

Results

The results of the robotics context in the uGame-iCompute study are presented in two parts to address the foci of the research questions: (a) student learning and (b) teacher beliefs and practices. First, student data are presented to highlight students' spatial orientation. Second, transcripts of robotics lessons are analyzed to examine students' spatial reasoning and CT. Third, the transcripts are analyzed for evidence of cultural brokering. Finally, teacher data are presented in the forms of journaling and focus group interviews as they noted challenges and successes in the robotics environment.

Spatial Orientation

The spatial ability test was given to middle school students in Wyoming (Cohorts 2, 4, and 5) to measure spatial orientation. Only a small sample of students in Cohort 2 completed the pre-post spatial test because of a limited number of middle

schools and student participants. While 31 middle school students completed the study, only 16 students completed both pre- and posttests. In Year 3, 143 middle school students (Cohorts 4 and 5) participated in the study, but only 61 students completed both pre- and posttests. The number of students by school and setting and the number of students in the analytic sample are shown in Table 5.1 below.

The *T*-statistic was used to compare pre-posttest scores on the spatial tests by cohort. However, the confidence interval was 0.90 for Cohort 2 (Year 2), given the smaller sample size. Results of the paired *t*-tests are shown in Table 5.2 below.

Table 5.1 Number of Students in Spatial Ability Sample by School, Cohort, and Setting

<i>Schools</i>	<i>Setting</i>	<i># Students in the Study</i>	<i># Students in Analytic Sample</i>
School 1 ^{a c}	After School	7	4 (2 girls; 2 boys)
School 2 ^a	After School	11	2 (1 girl; 1 boy)
School 3 ^{a c}	Regular and After School	13	10 (2 girls; 8 boys)
School 4 ^b	After School	13	12 (3 girls; 9 boys)
School 5 ^{b c}	After School	14	11 (4 girls; 7 boys)
School 6 ^b	Regular and After School	23	16 (1 girl; 15 boys)
School 7	Regular	35	Missing data
School 8 ^b	Regular	10	5 (2 girls; 3 boys)
School 9 ^{b c}	After School	32	17 (8 girls; 9 boys)
School 10	Regular	16	Missing data
Total all schools		174	77

- Notes
a Schools included in SV Analysis (Cohort 2).
b Schools included in SV Analysis (Cohorts 4 and 5).
c Title 1 schools.

Table 5.2 Comparison of Pre-Post Spatial Orientation Scores by Cohort

<i>Spatial Test</i>	<i>Pretest</i>	<i>SD</i>	<i>Posttest</i>	<i>SD</i>	<i>Gain Score</i>
Cohort 2 (<i>n</i> =16)	19.13	5.64	20.44*	5.14	1.31
Cohorts 4&5 (<i>n</i> =61)	19.39	4.41	20.85**	3.72	1.46

- Notes
* *p* < 0.10.
** *p* < 0.05.

Spatial ability scores were significant for participants in Cohort 2 (Year 2) ($t[15]=-1.815$; $p=0.089$), as well as Cohorts 4 and 5 (Year 3) ($t[60]=-2.636$; $p=0.011$). There were small effects for these results: Cohen's d was 0.24 (Cohort 2) and 0.36 (Cohorts 4 and 5), respectively. No between-group comparison was drawn given the unequal variance of these cohorts. However, the results show participation in robotics-only (Cohort 2) and combined robotics and game design (Cohorts 4 and 5) significantly improved middle school students' spatial orientation skills.

Scores were disaggregated by school for Year 3 participants to determine if any trends could be found in the robotics and game design context. Descriptive data (see Table 5.3) revealed that students at School 4 and School 9 had the highest pre-post mean scores, while students at School 8 had the lowest pre-post mean scores. Students at School 4 and School 5 had the highest gain scores (2.4 and 1.7, respectively). Students at School 8 and School 9 tied for the median gain score (1.4). Interestingly, students at School 6, who experienced regular school and after-school programs, had the lowest gain score (0.7). Overall, students exhibited gains on the spatial orientation test regardless of the type of learning environment. Additional research is needed to examine the results of these different types of learning environments on middle school students' spatial ability.

*Spatial Reasoning, Computational Thinking,
and Cultural Brokering*

Robotics lessons in Cohorts 2 and 4 were videotaped and transcribed verbatim to examine students' spatial reasoning and CT

Table 5.3 Pre-Post Spatial Ability Scores by School ($n=61$)

<i>School</i>	<i>Pretest (Std. Dev.)</i>	<i>Posttest (Std. Dev.)</i>	<i>Gain Score</i>
School 4 ($n=11$)	20.5 (3.15)	22.9 (1.73)	2.4
School 5 ($n=10$)	18.4 (5.28)	20.1 (4.46)	1.7
School 6 ($n=16$)	18.8 (4.82)	19.5 (4.62)	0.7
School 8 ($n=5$)	16.6 (5.27)	18.0 (2.55)	1.4
School 9 ($n=17$)	20.6 (3.72)	22.0 (2.55)	1.4

skills. Vignettes of three different robotics lessons are presented below as examples of the learning that took place during after-school clubs at selected elementary and middle schools. The data are also analyzed for evidence of cultural brokering.

Vignette 5.1

An afterschool club at an elementary school in Wyoming participated in the study in October 2014. Seventeen students (15 boys and two girls) were observed during a lesson. Students worked in teams of three or four. The goal of the lesson was to get the robot to move around an obstacle course and to push a ball into a box. A team of four boys discussed the strategy for getting the robot to perform the task.

BOY 1: *We just want to see degrees.*

BOY 2: *We can also do this.* [Demonstrates with robot on the course.]

BOY 1: *No, that's way too hard.*

[Another boy on the team demonstrates a different pathway.]

BOY 1: *Yeah. I like that.*

BOY 2: *I know what we should do because we don't have a straight angle here, but we will if we go over here.*

BOY 3: *Guys, I would just like to say. Here's what I'm thinking. Straight from Point A, make a minor turn, go to Point B, then go straight, make a tiny turn and the robot turns this angle.*

BOY 2: *I disagree.*

BOY 1: *I kind of agree.*

BOY 2: *What do you agree with?*

BOY 1: *I agree kind of to here. But I think we ... can have a straight on angle, we have a better chance of getting the ball in the box.*

BOY 3: *How wide is the EV3?*

BOY 1: *Yeah about this wide.* [Shows with hands.]

BOY 3: *We have to make sure to stay inside the taped line. I'll go get it.* [Leaves to get robot.]

BOY 4: *Whatever I make you can believe it actually works.*

BOY 2: *This is what I think we should do. Go like you said, minor right turn here, minor right turn there.*

BOY 3: *Remember we are not at all accurate at this. We can't get it to turn like you did with your hand.*

BOY 1: *I just think it's too much of a risk.*

BOY 2: *I see that.*

BOY 3: *I'm just saying both of our things are not as accurate.*

BOY 4: *How about going like this?* [Walks and shows with the robot.]

BOY 1: *Can you show us the idea just gently pushing the robot?*

BOY 4: *Just making all the shapes* [Shows with the robot.]

BOY 1: *That's kind of risky, too. What if it runs over the line? We go from A and go through here so we don't have to worry about going out the lines.*

The MINDSTORMS® program consisted of choosing the move tank and programming degrees for rotation after traveling a certain distance. For example, in their initial attempt, the boys programmed the first tank block to move straight (0°) for 25 centimeters and then make a 4° turn. However, they went back to the drawing board to tweak the program two more times before it worked the third time. The final program is shown below in Figure 5.1. The difference between the initial program and the final program was changing the rotation in the fifth block from 4° to 2° and the rotation in the last programming

Figure 5.1 MINDSTORMS Programming—Trial 3.

block from 4° to 9° degrees as the robot moved straight to push the ball into the box. As is evident from the discourse, students learned about angles and degrees as the robot moved along the obstacle course.

ANALYSIS OF VIGNETTE 5.1

The discourse in Vignette 5.1 revealed that three of the four boys were deeply engaged in programming and field-testing to determine the code needed for the robot to traverse the obstacle course and push a ball into the box. One of the boys moved in tandem with the robot as it attempted to perform the task, which supports the finding that children engage in enactivism during robotics lessons (Francis et al., 2016). In terms of spatial reasoning, the team engaged in pathfinding (i.e., planning the robot's path), imagining and visualizing (i.e., anticipating the robot's moves based on the program), and moving (i.e., crawling behind the robot) (Davis, Okamoto, & Whiteley, 2015).

Relative to the CT learning progression, the students engaged in sequencing (i.e., alternating straight movement and turns), proportional reasoning (i.e., programming 90 degree turns when appropriate), causal inferences (i.e., assessing why the robot did not push the ball), conditional reasoning (i.e., anticipating what would happen next), and systems thinking (i.e., analyzing risks and course completion). Thus, the team engaged in all five steps of the modified CT learning progression.

According to Aikenhead (1997), students engage in cultural brokering or border crossing when they move from the microculture of peers (e.g., group dynamics) to the microculture of science. There is evidence of cultural brokering as the students tinkered with the MINDSTORMS® program and engaged in several trials until they were able to get the robot to complete the task. Thus, the students engaged in scientific processes (observing, hypothesizing, experimenting, etc.), which implied that they crossed borders and, as a result, cultural brokering took place.

Vignette 5.2

During a geometry lesson that was videotaped in November 2014, six middle school students (four males and two females) in Wyoming worked on programming robots to move in the shape of a triangle, square, and rhombus. These six students worked in pairs of like gender (i.e., two girls and two boys) to complete geometric tasks. They programmed robots to make a triangle with angles of 72, 72, and 36 degrees. The transcript below revealed the thinking of a pair of boys as they tried to get their robot to move in the shape of a triangle. The teacher's comments are denoted by "T."

[After a few trials and errors, the team of boys made some observations.]

BOY 1: *That's way off!*

BOY 2: *Yeah!*

BOY 1: *It's supposed to end up back here and it ended up over there*
[Uses his feet to show where robot should be]. *So, our 72 degree angles are off. Or this one is off.*

BOY 2: *They are both identical.*

BOY 1: *So, if they are both identical, then they are both off. Cause if it is ending up over here* [Shows the place with his feet], *they need to turn a lot more.*

BOY 2: *Yeah!*

[The team makes adjustments, and the robot makes three turns.]

BOY 2: *It's drifting on the floor.*

BOY 1: *Yeah!*

T: *Try it twice to see how it comes out the second time.* [Robot makes three turns again.]

BOY 1: *That's further apart. Now, this is even further off.*

BOY 2: *It keeps on getting further off.*

BOY 1: *We are trying to make a triangle.*

The PI videotaped two different robots moving in the shape of a square or rhombus using an iPad. Students made final

adjustments to the program, and the robots completed the paths to make the shapes (see Figure 5.2).

T: *How did you solve the problem?*

BOY 1: *We adjusted 2mm for the distance. We had to increase this angle by 0.01.*

ANALYSIS OF VIGNETTE 5.2

In this vignette, students engaged in spatial reasoning as they used rotating, locating, orienting, and pathfinding to program the EV3 to move in geometric patterns (Francis et al., 2016). Like the students in Vignette 5.1, they conducted several trials and engaged in scientific processes to get their robots to perform the tasks. In the end, all teams were able to get their programs for triangles, squares, and/or rhombi to work after some debugging.

When CT skills were analyzed, the evidence shows the students engaged in sequencing as they programmed the robot to

Figure 5.2 Students Programming in MINDSTORMS.

make three turns and conditional reasoning as they determined why the robot's turns were off: *It's supposed to end up back here and it ended up over there.* The boys also engaged in proportional reasoning and causal inference: *So, if they [angles] are both identical, then they are both off. Cause if it is ending up over here, they need to turn a lot more.* Student engagement in systems thinking was evident as they knew the goal was for the robot to end up where it started: *It's drifting on the floor.* Thus, this pair of middle school students engaged in all five steps of the modified learning progression (Sullivan & Heffernan, 2016).

In terms of cultural brokering, the data revealed students learned a great deal about triangles and other polygons. Thus, they crossed borders as they moved from the microculture of peers into the microculture of science as they engaged in scientific processes and the microculture of mathematics as they used MINDSTORMS® programming to learn about the properties of polygons.

Vignette 5.3

During a robotics lesson that was videotaped in January 2016, two African-American male students in Pennsylvania were programming a robot, which was shaped like a basic car. These same students worked on the MINDSTORMS® code to race the car. As the researcher (denoted by R), I asked the boys to explain their thinking.

R: *Why are you programming the robot to do what I'm seeing there on the screen?*

BOY 1: *We are trying to make it go as fast as it can, and then we are trying to add to the special effects. Probably like the flashing lights, and this blue stops the program when it's finished.*

R: *So, what do you know about how far it can go?*

BOY 2: *Ok. If we want it to go at least three feet we have to put it in seconds or per second. We then have to make it go 120 seconds, which is one minute ... it's like one minute and 20 seconds, but that's how long to make it do three feet.*

ANALYSIS OF VIGNETTE 5.2

The two students worked to build a basic car and programmed it to race against other students' vehicles. Therefore, the task was focused on design and speed. In terms of spatial reasoning, these two students engaged in imagining, visualizing, and moving as they programmed a three-dimensional object in two-dimensional space on the computer (Francis et al., 2016).

CT skills were observed as the boys engaged in sequencing (i.e., steps to make the car go faster), proportional reasoning (i.e., associated time with distance), and systems thinking (i.e., special effects). Thus, three of the five steps of the modified learning progression were evident during the vignette.

In terms in cultural brokering, the two students demonstrated an understanding that speed was a rate: "...the car could go three feet in 120 seconds." However, the time was converted from seconds to minutes incorrectly. The boy who tried to explain the program exhibited a common misconception that was based on his prior knowledge of base 10. Therefore, he reasoned that 100 seconds was equal to one minute. However, time relies on knowledge of base 60 (i.e., 60secs.=1min.; 60min.=1hr.). Therefore, according to the student, the car would have traveled three feet in two minutes, which is quite slow. In fact, LEGO® robotics kits and programming rely on metric units. A more reasonable explanation was that the car traveled 120 centimeters in three seconds. While there was some use of cultural brokering from the microculture of group dynamics to the microcultures of science and mathematics to get the car to move, cultural brokering was limited to coding and scientific processes as the boys experimented with speed and measuring the distance the car traveled. A data sheet that teachers may use to reinforce measurement and variable concepts using Knex kits may be found in Appendix C.

Teacher Reflections on Robotics Lessons

In addition to student data, teacher data provided a great deal of insight about the robotics context. Evidence of teachers'

challenges and successes during robotics instruction were obtained by examining their journals and transcripts of focus group interviews. Table 5.4 shows some of the comments made by teachers in Cohort 2 (Year 2, robotics-only), and Cohort 4 (Year 3, combined robotics and game design). Several themes emerged from the teachers' journal reflections and focus group comments, some of which were described as challenges and some as successes.

One challenge for teachers was programming the robot beyond the basic functions. Two teachers in Cohort 2 acknowledged their limited knowledge and their use of tutorials and other resources. One of these teachers explained that the professional development did not provide her with sufficient background knowledge to implement the program. Other challenges were related to debugging or attaching the correct LEGO® pieces. Debugging is required with all programming, whether its MINDSTORMS® or AgentSheets. Rather than allowing the students to become frustrated, these teachers relied on students with more background knowledge to serve as peer coaches. This was an excellent way to boost students' confidence and resolve debugging issues. One teacher who taught in Cohort 4 was challenged to think outside of the box. Realizing that students had fewer behavior problems during the robotics afterschool club than in regular classrooms, she implied that more hands-on tasks were needed during the school day.

In terms of successes, several patterns emerged from the data. First, it should be noted that a teacher from the Arapaho tribe (Year 1 participant) conducted a lesson for Year 2 teachers to help them understand how to embed Indigenous culture into mathematics lessons. The Arapaho teacher explained how geometry and symmetry could be used to make connections to cultural symbols. As a result, one teacher of Indigenous students in Cohort 2 allowed her students to use Photoshop to create game boards to depict Native American culture (Leonard, Buss, et al., 2016). Another teacher in the focus group integrated polygons with a lesson on Columbian culture.

Table 5.4 Teacher Reflections on Robotics Tasks

Teachers by Cohort	Challenges	Successes
Cohort 2	<p>I had absolutely no background [with] robots. I didn't even know what these things looked like. I think our kids could have figured it out without me knowing anything. I think that we have a technical side of the robot where they are having a lot of experiential learning ... and taking their background knowledge of their own technical skills and getting to go to Starbase. [Students] are using their background knowledge to be successful but this turns me into a resource too—not a very good one—but it's kind of turning me into one. (Focus group)</p> <p>[Robotics] gave me the opportunity to have assignments to do that I then went and found tutorials online and read and learned more on my own trying to figure out how to get the robot to do what we were supposed to get it to do. The [course] did not really do that for me. I had to go and teach myself. (Focus group)</p>	<p>So, with the kids, we ... figured out the formula for polygons, and I was like 'we can do this on a robot.' So, then I pulled out the robots and some ... created regular polygons ... [they] were just immense. And now I can take them and integrate it back into ... so like we're doing Columbian cultures. And they're going to make mazes and so the other team has to do the robots through the cultures. It gave me avenues to extend it back into other places in my curriculum. (Focus Group)</p> <p>I found several aspects of the fall 2014 robotics class useful to my own learning and teaching the robotics club. One aspect is that I had to learn enough basic content to be able to relay the correct information and guide my students to be able to plan. Second, it allowed me to learn more about the Arapahoe culture and what their symbols stand for. Third, this class allowed me the opportunity to work with robotics and learn how they are programmed. (Focus Group)</p>

Cohort 4

There was some apprehension with one of the students who did not have EV3 experience. One girl was so apprehensive that she was not sure that she wanted to attend robotics. She agreed to attend for two weeks and would inform me if she wanted to quit. It was not an issue after that. (Ms. T—journal)

Just like the kids, I had to step outside the box to kind of think about how they were programming the robots. I really saw it as a time to reflect and think about what I was doing with them and how I need to come outside of the box myself, to make things work better. I have noticed that [when] the kids who have behavior problems ... come to robotics, it's gone. (Focus group)

The EV3 software had the ability to precisely control the robot, but the robot would sometimes behave unpredictably in the real world. If a wheel was too dusty, it would slip ever so slightly and throw off the entire program. (Mr. S—journal)

With the exception of three students, all had prior experience constructing and programming the LEGO [r] EV3. All students were extremely excited to be starting with robotics because for the first time they were attending First LEGO League (FLL). The students formulated a plan about how to complete the various missions on the game board. They worked in groups but also a team while running the robot on the board. (Ms. T—journal)

The independent learning part was big for me. It actually totally changed the way I teach. The kids were able to go to the web site and look up how to build different things [with the robot]. They were in charge of their own learning. One group built a guitar totally on their own after we showed them the basics. (Focus group)

Students self-selected groups of three to five members. All students were required to take turns with the LEGO bricks and the computer software. Some students started to specialize in different aspects of design. Within a group, students worked together to design, build, and program the robot, and across groups, students helped each other to over the similar problems they encountered. All groups constructed a robot that moved around an obstacle and reach a goal. (Mr. S—journal)

To understand the importance of such activities, students should be interviewed to ascribe denotative (i.e., what is depicted) and connotative meanings (i.e., ways in which values and ideas are expressed) to the images they create (Johnson & Christensen, 2017).

In other learning environments, including the urban context, students learned how to program the robot to draw polygons, how to use sensors, and how to work together in collaborative groups. Students also engaged in cooperative learning and scaffolding when they helped one another to solve debugging issues. Additionally, one teacher also noted that robotics influenced students' problem-solving and spatial abilities. Most importantly, the independent learning and research skills that teachers observed revealed students' willingness to engage in highly cognitive tasks. Subsequently, student success changed some teachers' perceptions about student learning. One teacher stated, "It actually totally changed the way I teach."

Other cultural connections include music and history. As previously stated, LEGO® EV3 robots are capable of playing any musical tune that students can program; therefore, culturally specific lessons can be developed for the robot to play tunes that are relevant to hip-hop or pop culture (Leonard et al., 2018). To make connections to history, teachers can develop robotics lessons related to time. For example, people from ancient Babylon and Mali used a sexagesimal, or base 60, number system. The Mayans used a vigesimal, or base 20, number system. Students can enjoy learning how to count and write numerals in these systems to reinforce concepts about time to avoid the misconceptions and conversion errors that were noted in Vignette 5.3.

Limitations

The results of this study are limited to the participants and the school sites in Wyoming and Pennsylvania. The results were also influenced by small samples, in some cases, which limited the power of quantitative analyses (i.e., spatial tests for Cohort 2)

and the gender of the participants. Many of the school sites, especially in Wyoming, had a significant number of boys compared to girls participating in the study. This was much more evident in robotics than in game design. While students also engaged in cultural brokering (i.e., border crossing into the subcultures of science and/or mathematics), cultural artifacts such as musical scores and game boards were sparse in the robotics context. By comparison, the gaming environment allowed students to express greater autonomy and to embed richer cultural elements. Furthermore, the level of female participation and interactions were more salient in game design.

Summary

It is widely held that participation in robotics provides students with hands-on experiences that support teamwork and create opportunities for engagement in multidisciplinary tasks (Caron, 2010; Karp & Maloney, 2013). The students in this study were no exception. Robotics allowed them to develop mathematics content knowledge (i.e., angles, two- and three-dimensional figures, measurement, and proportional reasoning). While students' spatial orientation skills improved significantly from pre- to posttest, the results were more robust in Year 3, when robotics and game design were combined for the intervention. Students also exhibited spatial reasoning skills as they engaged in robotics tasks. Moreover, several focal students exhibited moderate to high levels of computational thinking, engaging in sequencing, proportional reasoning, causal inferencing, conditional reasoning, and systems thinking at different points as they planned how to program robots to complete specific tasks. Also, like game design, robotics programming allowed students to experience a low floor and a high ceiling (Resnick et al., 2009) since students were able to learn how to use basic and advanced program blocks.

Yet, this study fell short in recruiting females to participate. However, the researchers learned that Wedo 2.0 (another LEGO® product) had fewer and more colorful pieces and was

recommended for children in grades one through four. Wedo 2.0 was piloted in the uGame-iCompute study in Year 3 with third-grade girls. Findings revealed these younger females successfully completed Wedo robotics tasks, which helped them to develop spatial orientation and computational thinking skills. Future robotics studies should be conducted with sufficient samples of males and female using a variety of robotics construction kits.

Chapter 5 Discussion Questions

1. How might teachers use robotics to help students better understand the metric system?
2. What might teachers do to prep students for debugging during robotics?
3. What strategies might teachers use to recruit more girls to participate in robotics?
4. How can teachers promote cultural brokering in science and mathematics during robotics tasks?
5. What aspects of students' culture may be used to increase student creativity with robotics construction kits?

WOMEN IN AVIATION AND SPACE

The Importance of Gender Role Models

The stories of Elizabeth “Bessie” Coleman, the first African-American to receive an international pilot’s license, and Amelia Earhart, the first woman to fly solo across the Atlantic Ocean, are awe-inspiring. These women persevered despite gender barriers and, in the case of Bessie Coleman, racial barriers, to accomplish their dreams of becoming pilots. They stand as icons and role models who indubitably inspired contemporary women like Christa McAuliffe, the first teacher in space, and Mae Jemison, the first African-American female to become an astronaut. Such notable achievements should inspire girls and women of all backgrounds to believe like one of the descendants of Elizabeth Cady Stanton, an advocate for women’s suffrage, that “anything’s possible for anyone” (Bumiller, 1998, p. B6).

The history of women working at the National Aeronautics and Space Administration (NASA) is largely obscure. Yet, extraordinary women worked for NASA as human computers, conducting calculations by hand and plotting data (Berman, 2016). Shetterly (2016) discovered that five White women joined the pool of computers at Langley in 1935, and five Black women began working as mathematicians on the segregated west side of Langley in 1943. By 1946, 400 women had been hired as computers. Katherine Goble Johnson was one of these computers. She distinguished herself as the mathematician who calculated John Glenn’s orbital trajectory during his historic flight around Earth. These women’s stories were unknown prior to the release of *Hidden Figures* (Melfi & Gigliott, 2016) by

Twentieth Century Fox. During an interview, Taraji P. Henson, the actress who played the part of Katherine Goble, said, “I’m 46, I went to college, and I don’t know this [story]” (Berman, 2016, p. 94). With the movie’s nomination for best picture at the 2017 Academy Awards, Katherine Johnson, Dorothy Vaughn, and Mary Jackson are hidden figures no more. They represent examples of intersectionality (Thomas, Joseph, Williams, Crum, & Burge, 2018) and Black feminist thought (BFT) (Collins, 2009). Moreover, these women challenged Black stereotypes in the twentieth century by helping to advance the U.S. space program with their knowledge and expertise in mathematics, computer science, and engineering. Dorothy Vaughn learned FORTRAN and headed programming in the Analysis and Computation Division at Langley, and Mary Jackson became the first African-American female engineer at NASA after petitioning the court in Hampton, Virginia, to take engineering classes at a White high school (Berman, 2016). Thus, they paved the way for other women to develop racialized and gendered identities in STEM.

Firsts for women of color continue to this day. I became the first African-American director of the Science and Mathematics Teaching Center at the University of Wyoming in 2012. Dr. Monica Cox earned a Presidential Early Career Award for Scientists and Engineers (PECASE) from President Barack Obama in 2010 and became the first African-American female to be promoted and tenured in the College of Engineering at Purdue University in 2011. Dr. Cox is professor and department chair of engineering education in the College of Engineering at The Ohio State University. In 2014, Maryam Mirzakhani, born in Iran, was the first and, since its inception in 1936, only woman to date to win the prestigious Fields Medal. Professor of mathematics at Stanford University, Dr. Mirzakhani died at the age of 40 in July 2017 after battling cancer. Despite these notable achievements, women, in general, and women of color, in particular, remain underrepresented in most STEM fields. As we embark upon another

decade in 2020, may there be more firsts as men and women of all backgrounds continue to break barriers.

Only 1% of American engineers in the 1970s were Black (Shetterly, 2016). More recently, the American Society for Engineering Education (ASEE) has been tracking data on underrepresented minorities and women in engineering (Yoder, 2017). In 2016, 3.9% of Blacks graduated with bachelor's degrees in engineering, while 4.7% graduated with master's degrees. However, the percent change in bachelor's degrees awarded to Blacks from 2007 to 2016 was -20.4%. In fact, the number of Blacks graduating with degrees in engineering declined from 2007 to 2014. However, there was an increase from 3.5% in 2014 to 4.0% in 2015. In contrast, the number of Hispanic students graduating with engineering degrees has been increasing since 2007. In 2016, 10.7% of Hispanics graduated with bachelor's degrees, and 8.3% graduated with master's degrees. The percent change in Hispanics awarded bachelor's degrees from 2007 to 2016 was 72.58%. The number of female engineers has also increased. In 2016, 20.9% of women received a bachelor's degree, and 25.4% received a master's degree. From 2007 to 2016, the percent change in women receiving bachelor's degrees in engineering was 8.2%. However, fewer women majored in computer (12.3%) and electrical (12.7%) engineering, while the most popular female majors were biomedical (41.4%) and environmental (45.6%) engineering.

In order to attract and retain students of color and females in engineering and other STEM fields, interest must be cultivated during childhood (Djonko-Moore, Leonard, Holifield, Bailey, & Almughyirah, 2017; Leonard, Chamberlin, Johnson, & Verma, 2016). Educational initiatives, beginning with Goals 2000 under the Clinton administration, aimed to broaden U.S. students' STEM participation. President Obama made STEM education a priority with *Race to the Top* in 2009 and *Computer Science for All* in 2016. Another Obama initiative was the recruitment goal of 100,000 elementary and secondary mathematics and science teachers by 2021. While these initiatives

spurred unprecedented levels of funding at the U.S. Department of Education and the National Science Foundation, as prior ASEE data show, STEM participation continued to be uneven among underrepresented demographic groups (Yoder, 2017). Overall, women and persons of color remain underrepresented in STEM fields.

Gender Equity in Mathematics and Science

Hanna (2003) categorized gender research into two distinct waves or time periods. During the first wave, in the 1970s, researchers attributed the low participation and achievement of women in mathematics and science to differences in spatial ability and other cognitive factors (Fennema, 1974; Hanna, 2003; Leder, 1992; Tartre & Fennema, 1995). In general, the commonly held belief was science and mathematics were male domains (Hanna, 2003). Therefore, it was accepted that men excelled in mathematics and science, while women did well in reading and writing (Hanna, 2003; Nosek, Banaji, & Greenwald, 2002; Parker & Rennie, 2002). If women performed poorly in mathematics, they often interpreted their failure as lack of ability, but men were more likely to place blame on teachers or lack of effort (Fennema, 1974; Hanna, 2003). Some women considered themselves lucky if they were successful in mathematics, but men attributed their success to natural ability (Fennema, 1974; Hanna, 2003).

The second wave of research on gender differences in mathematics and science in the 1990s marked a major departure from the focus on innate biological factors (Hanna, 2003). Gender-focused researchers suggested that the sociocultural context of learning mathematics was problematic (Buerk, 1985; Campbell, 1989, 1995). For example, the view that mathematics is an absolute body of knowledge with one correct method and answer, and exact symbols, caused some women to avoid the discipline (Buerk, 1985; Campbell, 1989).

In order to attain gender equity in mathematics classrooms, Ambrose, Levi, and Fennema (1997) asserted that teachers

must address gender disparity. They found certain standards-based strategies, such as facilitating discourse, created dilemmas for some female students. Girls were more likely to lack assurance in their mathematics ability and to be skeptical of their competence (Campbell, 1995). As a result, some girls did not participate in mathematics discourse because they were ambivalent about explaining their thinking (Ambrose et al., 1997; Celedón-Pattichis, 2007). Other girls were uncomfortable when debate or disagreement occurred in the mathematics classroom (Ambrose et al., 1997). Rather than focusing on whole-group discussion, a feminist pedagogy of teaching mathematics was suggested (Buerk, 1985; Jacobs & Becker, 1997).

The feminist pedagogy stressed four principles to foster gender-equitable, multicultural learning environments in mathematics classrooms: (a) using students' experiences, (b) integrating writing, (c) facilitating cooperative learning, and (d) developing a community of learners (Jacobs & Becker, 1997). Furthermore, Campbell (1995) suggested the following teacher behaviors to enhance equity in the mathematics classroom: (a) holding similar expectations for students regardless of gender or race, (b) involving students as active learners, (c) providing students with hands-on activities, (d) identifying and correcting academic deficiencies, and (e) allowing students to have fun (Campbell, 1995). Conversely, the extensive use of lecture, seatwork, homework, and tests has been associated with females dropping out or discontinuing their study of mathematics (Fey, as cited in Campbell, 1995). In response, specific strategies to enhance the learning of mathematics included the following:

- Provide time to experience and clarify a problem (situation) before focusing on a solution.
- Include a historical perspective to help students become aware of the person-made quality of mathematics.
- Acknowledge and encourage alternative methods and approaches, such as approximation, guessing, estimation, partial solutions, and the use of intuition.

- Answer questions with questions that both clarify the students' questions and help the students realize their own potential as problem solvers and problem posers.
- Encourage students to share ideas, partial solutions, and different interpretations of problems with one another.
- Encourage the asking of new questions and create an atmosphere where both teacher and student are free to wonder out loud.
- Make a concerted effort to avoid absolute language.
- Set as a goal the development of each student's internal sense of power, of confidence, and of control over the material.
- Offer opportunities for students to reflect in writing about their ideas and feelings about mathematics.
- Don't rush to closure.

(Buerk, 1985, p. 69)

Views on gender differences in mathematics suggest that physical and intellectual barriers do not impede the participation of women in STEM (Campbell, 1995; Nosek et al., 2002). Some researchers believe the underrepresentation of women in STEM careers is the influence of cultural and social barriers such as curriculum, learning environments, differential treatment by teachers and parents, and stereotypical sex-role identification (Hanna, 2003). In a longitudinal study of gender differences among 60 students (32 female and 28 male) at sixth, eighth, tenth, and twelfth grade, Tartre and Fennema (1995) found no significant differences between male and female students' mathematics scores, except at eighth grade. When affective variables were compared, the only significant gender difference was male domain; that is, males stereotyped mathematics as a male domain to a greater extent than females did (Tartre & Fennema, 1995). Furthermore, Nosek et al. (2002) found the constructs of math attitude, math identity, math-gender stereotypes, and gender identity to be factors that influenced women's achievement and participation in

mathematics. These findings helped to change prior assumptions about females' achievement in mathematics.

Gender and Academic Achievement in Mathematics

International and national assessments have been analyzed to measure gender gaps in achievement. The International Association for the Evaluation of Educational Achievement conducted studies known as the First (FIMS) in 1964, Second (SIMS) in 1980, and Third International Mathematics Study in 1995 (now simply referred to as Trends in International Mathematics and Science Study) (TIMSS) (Hanna, 2003). Initial results on the FIMS revealed boys outscored girls in mathematics in 10 out of 12 countries at age 13 and in 10 out of 12 countries at age 17 (Hanna, 2003). Results of the SIMS for 13-year olds showed no gender differences between boys and girls in five out of 20 countries on all mathematics subtests (Hanna, 2003). However, in 10 countries, there were differences favoring boys on two of five subtests, and in five countries there were differences favoring girls on two of five subtests (Hanna, 2003). Among 17-year-olds, there were no gender differences between males and females in three out of 15 countries on six of seven subtests, but there were differences favoring boys in 12 countries on two out of six subtests (Hanna, 2003). On the 1995 TIMSS, there was no gender difference noted among 13-year-olds in overall achievement in 37 out of 39 countries. Moreover, eighth-grade girls scored slightly higher in 12 countries in algebra (Hanna, 2003). When 17-year-olds were compared, no differences were found in five out of 16 countries. However, boys scored higher in four countries in two content areas and in seven countries in three content areas (Hanna, 2003).

On the national level, the SAT, which is used as a predictor of college success, had one of the largest observed gender gaps in mathematics in 1995 (Nosek et al., 2002). The difference in SAT scores between males and females in 1995 was 42 points on the math section of the SAT (boys: $M=519$; girls: $M=478$) (College Board, 2005). Although SAT scores in mathematics

have improved over time, there was still a 30-point difference between the average scores of males and females in 2016 (boys: $M=524$; girls: $M=494$) (Perry, 2016). This significant difference between males and females was consistent across all ethnic groups. While the gender gap was least among Black students (boys: $M=430$; girls: $M=422$), Blacks had the lowest scores on the SAT, which implies that this demographic group is not well served in high school mathematics classrooms. For example, the literature is replete with studies that show tracking in mathematics classrooms continue to have a negative effect on Black students' achievement in mathematics (Oakes, 2005).

At the K–12 level, National Assessment of Educational Progress (NAEP) test results revealed that 40% of fourth-graders and 33% of eighth-graders were at or above proficiency in mathematics in 2015. However, average mathematics scores for students in grades four ($M=240$) and eight ($M=282$) declined one and two points in 2015, respectively (on a 0 to 500-point scale), compared to 2013 scores (National Center for Educational Statistics [NCES], 2016). Black and Hispanic students made greater gains than White students in 2015 compared to 2009 mathematics scores. Yet, gender gaps remained at grades eight and 12, while there was no significant gender difference at grade four. These data are consistent with SAT data, which revealed a gender gap among twelfth-grade students that has persisted for more than 40 years (Perry, 2016) and concurs with research findings that “small but persistent math gender disparities favor[ed] males at fourth, eighth, and twelfth grade, with gaps of roughly 0.1 SDs or less” (Robinson & Lubinski, 2011, p. 270). Clearly, there is more work to do to close gender gaps in K–12 mathematics education, which may be linked to teacher practices as well as course-taking patterns.

Gender and Teacher Preparation

Gender issues are difficult to eradicate in mathematics classrooms when teachers, who are predominantly female, have had negative experiences and inadequate preparation to teach the

subject matter. Two female preservice teachers in a mathematics methods course that I taught while tenured at Temple University, Myrtle and Julia (pseudonyms), shared some of their high school experiences in their reflection papers.

I was in an advanced math class in my senior year of high school. I had a teacher who was new to the building and was used to teaching in a male private school. He was always choosing the males in the classroom to answer questions and calling on me when he saw I was puzzled and unsure. Some teachers would take an initiative to clear up confusion in a math class, but this teacher took me out of the classroom, reminded me that this was an advanced class and suggested that I drop to a lower level. Being a stubborn young lady, I politely told him that I have been in advanced classes my whole high school career and was always successful. I told him I'll stick it out, and I'll finish with a good grade. I did not appreciate his negativity towards females, especially because there were males in the class that were doing as poorly as I was. I could not help but observe that the majority of the students were struggling in the class. This obviously reflected the quality of teaching that was happening in the class.

(Myrtle, fall 2006)

Not one math teacher ever told me that I can do it if I tried, or encouraged me to ask or answer questions in math class. I have always felt "stupid" when it came to these classes and felt I couldn't relate or understand. In addition to being split up according to academic level in high school, girls were not expected to do exceedingly well in math and science. I always received Cs and Ds in math and was always placed in the average track classes. In addition to this, I had all male math teachers every year until my freshman year of college. However, in my senior year of high school, I had a male teacher who sat with me one-on-one so that I could understand. This was the first time that I received a B in math since fourth grade.

(Julia, fall 2006)

These excerpts revealed that teachers hold a great deal of influence when it comes to student enrollment and persistence in advanced mathematics courses. More often than not, teacher recommendations, as well as past grades and test scores, determine whether students are permitted to enroll in advanced courses. Additionally, even when females and students of color are enrolled in advanced mathematics courses, how they are perceived and treated by teachers impact their retention. In the essay above Myrtle, described her awareness of her own efficacy and her decision to persist, while other students may have dropped out of the course. On the other hand, Julia's essay reinforced the importance of caring, nurturing, and supportive teacher behaviors in mathematics classrooms. Research has shown that gender-inclusive teaching strategies aimed at fostering equity in mathematics classes narrow gender differences (Buerk, 1985; Hanna, 2003; Parker & Rennie, 2002).

More recently, Robinson and Lubienski (2011) conducted a study to determine if girls continue to be shortchanged by examining gender gaps in reading and mathematics among elementary and middle school students. The researchers argued that male students who "score lower in elementary reading assessments, tend to get worse grades and are less likely to complete high school and attend college than females" (Robinson & Lubienski, 2011, p. 269). Also, the extant literature revealed teachers' beliefs that math is a male domain continue to result in higher expectations and positive attitudes toward male students (McKown & Weinstein, 2002; Robinson & Lubienski, 2011). However, teachers disproportionally referred males who had poor reading ability to special education (Hibel, Farkas, & Morgan, 2006; Robinson & Lubienski, 2011). To investigate teacher beliefs and student outcomes, these researchers used the Early Childhood Longitudinal Study (ECLS-K) data set, which consisted of archival data collected by the U.S. Department of Education, to analyze reading and mathematics trends in a sample of 7,075 students.

Robinson and Lubienski examined teacher beliefs and achievement scores at the 10th, 50th, and 90th percentiles from kindergarten through eighth grade. In mathematics, the researchers found that gaps among male and female students declined at the 10th and 90th percentiles between fifth and eighth grades. Overall, the researchers found that the gender gap in mathematics narrowed among males and females during middle school but not in elementary and high school. In reading, a gender gap emerged between the 10th and 50th percentiles as males and females progressed from kindergarten to eighth grade. By eighth grade, females' reading scores were significantly higher (i.e., 0.1 to 0.24 SDs) than males at each of the three percentiles. Furthermore, males were twice as likely as females to be "among the bottom 5% of readers" (Robinson & Lubienski, 2011, p. 288).

While teachers generally rated girls as more knowledgeable than males in reading and mathematics, their beliefs did not necessarily mirror performance trends. Girls began "on par with males mathematically" in kindergarten but lost "ground in math during their elementary school years" (Robinson & Lubienski, 2011, p. 298). While girls began above par with males in reading, males in the 90th percentile gained ground. However, males in the 10th percentile consistently lagged behind. Some researchers argue that single-sex education may level the playing field for females in mathematics (American Association of University Women [AAUW], 1992).

Single-Sex Education

Because prior research indicated that girls from ages nine to 15 suffer from lower interest and self-esteem in mathematics and science than males, single-sex education was deemed efficacious for girls (AAUW, 1992; Ambrose et al., 1997; Campbell, 1989, 1995). Furthermore, research also revealed girls who attended single-sex schools tended to hold less stereotypical views about women's roles in society and were more focused on academics (Celedón-Pattichis, 2007). These young women also viewed

mathematics and science as less of a male domain than their coeducational counterparts (Haag, as cited in Celedón-Pattichis, 2007) and were more likely to develop greater confidence in *doing* mathematics (Leder & Forgasz, 1997). In fact, the literature is replete with examples of successful single-sex schools (Celedón-Pattichis, 2007; Singh, Vaught, & Mitchell, as cited in Parker & Rennie, 2002).

Celedón-Pattichis (2007) conducted a case study of seventh-through twelfth-grade girls from working-class backgrounds who attended The Young Women's Leadership School (TYWLS) in New York City. The school's population of 360 young women was 63% Latina and 37% African-American. Preliminary results of the study revealed the emergence of four themes relative to the success of single-sex schools: (a) creating a culture of success, (b) constructing a collaborative and supportive learning environment, (c) expecting girls to become leaders, and (d) establishing a sense of belonging. These themes were evident in a number of ways. First, all girls were expected to complete pre-calculus prior to graduation and apply for college (100% of the students were accepted to college in 2001 and 2002). Second, girls had the freedom to do board work at any time during instruction, debate with their peers and the teacher, and collaborate with their peers on mathematics assignments. Third, older girls mentored younger girls, and all students completed 60 hours in a community service project. Finally, the girls viewed the school as a home away from home as teachers enacted the ethic of care and took on the role of *other mothers* (Gay, 2000; Irvine, 2002). As a result of these practices and adequate resources, TYWLS is a highly successful single-sex school for girls (Celedón-Pattichis, 2007; Kitchen, 2007).

While some studies have shown that female participation in mathematics and science courses was greater in single-sex classrooms (Celedón-Pattichis, 2007; Parker & Rennie, 2002), gender-inclusive strategies were also effective in coeducational classrooms (Parker & Rennie, 2002). Strategies that encouraged

female participation in mathematics included cooperative group work and collaborative problem solving (Campbell, 1995; Leonard, 2001; Parker & Rennie, 2002). Other strategies included the implementation of innovative curriculum and activities that were culturally specific to women. Drawn from the tenets of CRP (Ladson-Billings, 2009), “culturally specific” means the curriculum focuses on components from a distinct ethnic or gender background that are framed by historical and contemporary experiences that genuinely depict a particular way of life among members of the group. One example is the Bessie Coleman Project, which addresses issues of gender and race by allowing students to learn about the significant contributions that men and women from underrepresented groups have made to aviation and space flight.

The Bessie Coleman Project

Through earlier work with colleagues at Temple University, I envisioned the Bessie Coleman Project 10 years before it was funded in 2018 by the National Science Foundation. This project builds upon the uGame-iCompute study described in Chapters 4 and 5. The purpose of the Bessie Coleman Project (funded from 2018 to 2021) is to develop, implement, and study the potential benefits of an intervention that fosters female and underrepresented students’ successful achievement and positive attitudes toward STEM. The goals of the project are to develop computational thinking (CT) and spatial reasoning skills among fourth- through eighth-graders by engaging in computer modeling, game design, and flight simulation. The lessons are unique in that they rely on African-American, Latinx, and women’s storylines to encourage interest and persistence in STEM. BFT is an underlying framework for African-American women’s experiences.

The themes in the Bessie Coleman Project provide a progressive approach to integrating aviation and space science. In the elementary grades, computer modeling exposes fourth- and fifth-graders to aviation-related content through the use of

interdisciplinary content that includes photography, perspective, and geography (see *Sculptris* bison tutorial in Appendix D). To engage in computer modeling successfully, students must consider the landscape view (eye-level), worm's eye view (ground-up), bird's eye view (high elevation), and aerial view (top-down). Zoom Earth is used to capture the aerial view of any location in the world via satellite and to obtain the coordinates for latitude and longitude.

Using Zoom Earth and Photoshop

Learning about latitude and longitude is directly connected to aviation and aerospace. In the movie *Hidden Figures* (Melfi & Gigliott, 2016), Taraji P. Henson, who portrayed Katherine Goble Johnson, calculated John Glenn's reentry point for Friendship 7 (launched in 1962) to be 50.667° North and 77.333° West. This was a goof in the movie because the location indicated by those coordinates is in Quebec, Canada, and not the Atlantic Ocean. The correct latitude was closer to 25° North. Second, when the TV commentator announced Alan Shepard's launch in 1961, he stated that Shepard would be launched into space on Freedom 7 at an altitude of about 116 miles an hour. The goof was stating the units for altitude as miles per hour instead of feet. Furthermore, the commentator provided a speed that was well below the 5,134 miles per hour that Shepard actually traveled (See blog for goofs).¹ These goofs can be used to teach students about the importance of accurate units for latitude, longitude, speed, and altitude. Zoom Earth is used with fourth- and fifth-grade students to find locations. Photoshop is used to create aerial views related to specific themes.

Flight Simulation

Flight simulation software can be used to model any airport in the world. Thus, students may simulate take-off and landing at Charles de Gaulle Airport in Paris or Beijing Airport, designed by the late Zaha Hadid. Lessons may also be derived from

Mission Mathematics (NCTM, 1997). After students create and conduct trials with model airplanes, data may be collected on flight times and distance or height, as appropriate, to enhance student learning in mathematics and science. Furthermore, these lessons may be integrated with social studies to help children learn about women and minorities who were pioneers in aviation and aerospace (e.g., Bessie Coleman, Amelia Earhart, Sallie Ride, Ellen Ochoa, Mae Jemison, Joan Higginbotham, Tracy Caldwell Dyson, Catherine Coleman, Shannon Lucid, Karen Nyberg, and many others). A sample mathematics task related to flight follows:

Bessie went to Paris, France, to learn how to fly. Figure 6.1 shows Bessie watching planes in the airfield when she was a student at a Paris flight school in the Village of Rue. Along with a partner,

Figure 6.1 Bessie at Flight School.

toss a glider or balsa wood plane three to five times each. Find the average distance of the flight trials from the same starting point. Mark the spots where the plane landed. Create a scatterplot of the results. Using a coordinate grid, label the points (i.e., x & y coordinates) associated with each of the landings. Compare your results to the work of another pair of students.

Computer Modeling

In addition to learning history and engaging in project-based activities related to flight, students can engage in computer modeling and game design to learn CT and hone their spatial reasoning skills. Unity is a professional, state-of-the-art, 3-D game engine that is popular with commercial, as well as amateur, game developers. Thus, fourth- and fifth-grade students can create games in Unity related to interdisciplinary themes.

To build a game in Unity, Ruben Gamboa (co-PI on the Bessie Coleman Project) contends that students should start by creating one or more assets, which are 3-D models of the objects that appear in the game. This is usually done outside of Unity, using Tinkercad, for example. These 3-D models are imported into a Unity project, and they can be placed in different positions to create a scene in the game. Once the models are imported into Unity, the developer can define the behavior of the objects using a programming language such as C++, JavaScript, or Boo. It is this programming (or scripting, as Unity calls it) that allows objects in the game to move and respond to other objects and players.

Although the Unity engine is very complex, it fosters a low floor and high ceiling (Resnick et al., 2009). In other words, beginners should be able to cross an easy threshold to create a working program (low floor), and the tool should be complex enough to meet the needs of advanced students (high ceiling). In Unity, beginners can build their first game almost immediately. For instance, there are predefined models available so that the first game can start with many realistic models, such as cars, spaceships, people (and monsters), and so on. Moreover,

there are many built-in behaviors that can be used, such as one that maps the players' input to the way the camera moves around the scene. The key is to start with existing 3-D models and behaviors and gradually introduce custom models and behaviors into a game.

For instance, fourth- and fifth-graders may create a scene in a lush, tropical forest that supports aircraft or even spaceships in a nearby airfield. All of this can be created using available Unity models. Thus, students need only worry about placing these objects in a scene in the beginning. Then they can add a built-in 3-D movement behavior to the camera to fly around their scene and see it from different perspectives (e.g., landscape and bird's eye views). As they gain skills, they will be able to introduce their own models (e.g., build their own airplanes or spaceships.) Sixth- and seventh-graders can introduce more complex behavior, for example, by using the four forces of flight (i.e., lift, gravity, thrust, and drag) to create a more realistic impression of a flight. The important fact is that students can do this incrementally. Beginners can rely on 3-D models and programmed behaviors that are already available in Unity, while more advanced students can add their own models and programs to an existing Unity project. The Bessie Coleman Project extends the work of a prior project conducted in collaboration with the NASA Goddard Space Flight Center (GSFC) called Space Links.

Space Links: Integrating Space Science and Mathematics

Space Links came about as a result of my experience as a classroom teacher in Maryland. As a classroom teacher, I participated in the Maryland Governor's Academy in 1995. The Academy was a three-week summer program housed at Towson State University in Baltimore. The program provided middle school mathematics and science teachers with opportunities to network with one another and to develop innovative lesson plans to implement in their classrooms. The Academy was also my entree into the Lockheed Martin Graduate Fellows Program

(LMGFP). As a participant in the LMGFP, I was afforded the opportunity to work at the NASA GSFC in Greenbelt, Maryland, for eight weeks during the summer of 1996 as a teacher intern. The major outcomes of the internship were learning how to conduct research and the development of an integrated science and mathematics unit about the Sun, which I implemented with sixth-grade students in Prince George's County Public Schools during the 1996–1997 academic year. Because of my NASA experience, I sought to expose preservice teachers at Temple University to a similar experience.

Funded by the Space Telescope Science Institute (STScI) from 2002 to 2004, the Space Links program targeted female and minority preservice teachers. A major component of the program was to provide preservice teachers with an opportunity to work alongside a NASA scientist to learn firsthand what scientists do. Professional mentors were established because they can inspire others to set new goals and explore new vistas for career choices. Fostering an enthusiasm for science and mathematics is essential in encouraging students to investigate careers in these fields.

Research shows that poor preparation in science and mathematics during elementary and secondary school is one of the main reasons for the underrepresentation of female and minority students in STEM fields (Campbell, 1989). Thus, studies that examine preservice teachers' self-efficacy and instruction in science and mathematics are warranted.

Methodology

Mixed methods were used to collect and analyze data in the Space Link study. Qualitative data were collected to analyze preservice teachers' self-efficacy and teaching practices. In the qualitative tradition, the case study method was used to examine the self-efficacy, pedagogy, and beliefs of women and minorities. The case study design is useful in studying "special people, particular problems, or unique situations in great depth, and where one can identify cases rich in information" (Patton, 1990,

p. 54). Interventions included professional development, a community-based internship, curriculum support during student teaching, and a NASA externship.

Participants and Setting

Lillie, Melva, Cecilia, and Summer (pseudonyms) were selected by project staff to participate in the ongoing SUNBEAMS (Students United Becoming Enthusiastic about Mathematics and Science) program at NASA GSFC. Melva and Cecilia identified as African-American, and Lillie and Summer identified as White. The SUNBEAMS program allowed these preservice teachers to work firsthand with a scientist or engineer at NASA GSFC from July to mid-August 2003. The preservice teachers were among 15 teachers selected to participate in SUNBEAMS. Ten teachers from the District of Columbia Public Schools and one new-hire from Prince George's County Public Schools also participated in the program. The Space Links preservice teachers immersed themselves in the research that each scientist or engineer was working on and then developed innovative science curriculum to use with students. Lillie spent time with a scientist who worked on the Earth Observing System Satellite-Aura Project, which measured atmospheric levels of carbon dioxide and ozone. Melva worked with a physicist on the Mars Exploration Rover Mission, which centered on robotic vehicles (i.e., Spirit and Opportunity) designed to detect water, soil, and rock on the surface of Mars. Cecilia worked with an electrical engineer on the Messenger Mercury Laser Autometer Project. An astrophysicist who worked on the Multi-Wavelength Milky Way Project mentored Summer. Because they participated in the NASA externship, these participants were selected for further study.

Results

The results of this study are presented in two parts. First, descriptive quantitative data are presented to share the study's influence on the preservice teachers' efficacy and space science

teaching. Second, qualitative interview data are presented to determine how the interventions influenced focal participants' self-efficacy, attitudes toward science and math, use of STEM curriculum, and classroom practices.

TEACHER EFFICACY

Participants in the Space Links study completed the Science Teaching Efficacy Belief Instrument (STEBI-B) (Enochs & Riggs, 1990), which was administered on a pre-post basis to learn how preservice teachers' self-efficacy in science teaching changed during the study. The STEBI-B consisted of a 23-item survey that contained two subscales: Personal Science Teaching Efficacy (PSTE) and Science Teaching Outcome Expectancy (STOE). Cronbach's alpha coefficients for the PSTE and the STOE scales were 0.90 and 0.76, respectively. The survey used a five-point Likert scale to measure written responses—13 positive and 10 negative. In the case of positive responses, the point values were: Strongly Agree = 5, Agree = 4, Uncertain = 3, Disagree = 2, and Strongly Disagree = 1. In the case of negative responses, the point values were reversed. Scores on the PSTE ranged from 13 to 65 and indicated belief in one's personal ability to teach science. Scores on the STOE ranged from 10 to 50 and indicated expectations for students as an outcome of science teaching. Comparative data showed that five out of seven preservice teachers' self-efficacy increased after participating in the Space Links study (see Table 6.1). Average PSTE scores did not change, but STOE scores increased slightly from 36.71 to 38.43. While these results were not what the researchers expected, Melva and Cecelia improved on both the PSTE and STOE subscales.

SCIENCE INSTRUCTION

In order to evaluate Space Links participants' science instruction, they were observed during student teaching. Cecilia and Summer were observed during the spring semester of 2003, and Lillie and Melva were observed during the spring semester of 2004. Each of their lessons is briefly described below.

Table 6.1 Comparison of Pre- and Post-STEBI-B Scores: (n=7)

Participant ID	Pre-PSTE Scores	Post-PSTE Scores	Net Change (PSTE)	Pre-STOE Scores	Post-STOE Scores	Net Change (STOE)
4761	56	57	+1	46	47	+1
1761	56	53	-3	35	34	-1
Melva	36	39	+3	27	32	+5
Cecilia	51	54	+3	35	39	+4
1616	57	52	-5	42	42	0
0345	44	44	0	37	42	+5
9931	43	44	+1	35	33	-2
Mean	M= 49.00	M= 49.00		M= 36.71	M= 38.43	
(Std. Dev.)	(SD= 8.12)	(SD= 6.63)		(SD= 14.08)	(SD= 5.62)	

Cecilia taught the “Air Show” lesson from the *Mission Mathematics* curriculum (NCTM, 1997) to a class of 25 linguistically and ethnically diverse third-grade students. In this lesson, students designed their own airplane and then conducted four trials to collect and analyze data. The trials consisted of obtaining the following data for each plane: (a) distance, or how far the airplane flew, (b) accuracy, or how well the airplane landed on a target, (c) acrobatics, or how many times the airplane flipped during flight, and (d) duration, or how long the plane stayed in the air. The mathematics content standards were data analysis and statistics.

Summer implemented a project-based lesson with a class of 19 urban seventh-graders who were told to investigate one of the nine planets in the solar system. Mathematical connections in the lesson included number sense, estimation, geometry, and spatial sense. Students found each planet’s distance from the Sun, average temperature, patterns of rotation and revolution, and shape. It is worth noting that, since the delivery of this lesson, clearer definitions of what constitutes a planet have emerged. According to the International Astronomical Union (IAU), “a ‘planet’ is a celestial body that (a) is in orbit around the sun, (b) has sufficient mass for its self-gravity, ... and (c) has cleared the neighborhood around its orbit” (Flam, 2006, p. A10). Thus, a debate began about whether or not to reclassify Pluto as a dwarf planet. At the time of this writing, Pluto is still considered a planet because it has a moon and orbits around the Sun.

Lillie developed a lesson on galaxies and implemented it with 21 eighth-graders attending a suburban middle school. Lillie downloaded several images of galaxies from the Internet and copied and laminated them to make sets for the students to work with. Students worked in pairs and discussed the characteristics of each galaxy in order to classify it by type. Students learned that galaxies were categorized by their shape: elliptical, spiral, or irregular. The mathematical connection was geometry and spatial sense.

Melva taught the “Scrumptious Veggie Shuttle” lesson, which also came from the *Mission Mathematics* curriculum (NCTM, 1997), to 25 kindergarten students in an urban classroom. Materials needed to teach this lesson included bread (Orbiter), carrots (external fuel tank), and celery (solid rocket boosters). Cheese spread may be used in this lesson to stick the parts of the shuttle onto the Orbiter. Prior to making the shuttle, Melva read a book about rockets to the students. Then students worked in small groups with parent helpers to make their shuttles. After making the shuttles, Melva and the students simulated a countdown. Thus, the mathematical connection was counting.

The Science Teacher Inquiry Rubric (STIR) was used to rate seven female participants’ inquiry-based space science lessons. The STIR ratings were based on a student-centered–teacher-centered continuum. We modified the rubric to score lessons as follows: 0=no evidence of scientific inquiry, 1=highly teacher-centered, 2=moderately teacher-centered, 3=moderately learner-centered, and 4=highly learner-centered. Video-tapes and transcripts were evaluated to rate the preservice teachers across six categories. Four of the preservice teachers taught in 2003 (Year 1), and three taught science lessons in 2004 (Year 2). However, only Lillie and Melva had the benefit of participating in the NASA externship prior to teaching their lesson. Thus, the other five preservice teachers functioned as a control group. The results are shown in Table 6.2.

Data were analyzed for patterns by ranking individual mean scores and comparing these scores with the group mean scores in each category. Lillie had the second highest rank, and Melva tied for the second lowest rank, which is consistent with her low STEBI-B score. As shown in Table 6.2, the overall average STIR score across all categories was 2.38, indicating that most of the instruction among this cohort was moderately teacher-centered. Space Links participants were strongest in Category 4: *Learners formulate conclusions and explanations*, but they were weakest in Category 5: *Learners evaluate their explanations in light of alternative*

Table 6.2 Comparison of STIR Data

Preservice Teacher ID* (Grade Taught)	Learners Engage in Scientifically Oriented Questions	Learners Plan/ Investigate to Gather Evidence	Learners Give Priority to Evidence to Draw Conclusions and Evaluate Explanations	Learners Formulate Conclusions and/or Explanations	Learners Evaluate Their Explanations in Light of Alternative Explanations	Learners Communicate and Justify Their Explanations	Average
Summer ^a (7th)	2	3	4	4	2	4	3.17
Lillie ^b (8th)	1	3	3	4	3	4	3.00
Cecilia ^c (3rd)	1	4	3	4	2	1	2.50
Nia ^c (5th)	2	2	3	4	1	2	2.33
Diane ^c (4th)	2	2	3	4	0	1	2.00
Melva ^b (K)	1	2	2	2	3	2	2.00
Wilma ^c (3rd)	3	2	3	1	0	1	1.67
Average	1.71	2.57	3.00	3.29	1.57	2.14	2.38

Notes

a NASA participant and student teacher before externship.

b NASA participant and student teacher after externship.

c Student teacher who did not participate in externship.

explanations. The Space Links cohort engaged students in activities that led them to understand scientific meaning and explanation, but in several instances these teachers did not provide students with multiple resources to draw alternative conclusions.

When the scores of the two preservice teachers—Lillie and Melva—who were exposed to the externship were compared with those who were not exposed to or taught before the externship, the data produced some interesting results. Lillie's mean score of 3.00 was above the mean, indicating that she was a moderately student-centered teacher. On the other hand, Melva's mean score of 2.00 was below the mean, indicating that she was moderately teacher-centered in her instruction. However, it should be noted that the two highest scores occurred with teachers of middle school students, and Melva was the only teacher of early-childhood students (K–2). Therefore, it is quite possible that the STIR is a more appropriate instrument for middle school science teachers. In addition, we should expect early-childhood teachers to provide more structure and direction when they teach science. Younger students are limited in their ability to hypothesize and explore their own research questions (Piaget, 1965). Teachers of very young children may be more likely to use direct instruction rather than inquiry-based instruction. Additional research is needed to validate this assumption.

Analysis of individual categories also revealed some interesting patterns. First, both Lillie and Melva had scores below the group mean of 1.71 in Category 1: *Learners engage in scientifically oriented questions.* This implies that their experience working with scientists during the externship may have encouraged them to focus on specific questions to explore rather than allow inquiry to shift or diverge into different directions. Indeed, one criticism of inquiry-based instruction has been its tendency to lead classroom discourse down unknown and sometimes unproductive paths (Ball, 1993; Jegede & Olajide, 1995; Lo & Wheatley, 1994). Yet, Lillie and Melva took risks by engaging students in hands-on activities that required some interaction and group work.

Another interesting pattern was that Lillie and Melva's individual scores (3.00) were higher than the group mean (1.57) in Category 5: *Learners evaluate their explanations in light of alternative explanations*. Lillie and Melva's work with scientists allowed them to provide learners with multiple resources that included NASA materials. Posters of galaxies and nebula were on the walls in Lillie's class. Melva read a storybook about rockets to help young children understand what rockets were and how they were used to fly into outer space. These data suggested that preservice teachers' work with scientists may have influenced them to provide students with evidence in order to draw conclusions. Additional research is needed to validate this claim.

While the results of the STIR are inclusive owing to the small sample size and lack of a control group, further study to compare inquiry-based instruction in formal and informal school settings is warranted. Perhaps prospective female teachers are less structured and more willing to engage students in inquiry in informal settings (Leonard, Boakes, & Oakley, 2005). In the meantime, it is worth noting that teachers of older students appeared to fare better on the instrument than teachers of younger students.

PRESERVICE TEACHER REFLECTIONS

Cecilia and Melva, along with four other participants, were interviewed by project staff at the end of the second year of the study. Portions of their interviews provided additional insight about how these teachers' pedagogy developed as a result of the Space Links program. Four of the 10 questions asked during the interview along with the responses are presented below:

- What was your personal attitude about math and science, and how did your attitude change over time?

Initially math was always my favorite subject, but science was something that I wasn't familiar with, so I wasn't very confident in teaching it, until I was able to see and integrate it. So

now, after, you know, going through, you know, the math ... Mission Mathematics book, and seeing the integration, it was a lot easier to incorporate them (math and science) together, instead of looking at them as separate entities.

(Cecilia)

At first, I was a bit apprehensive because math and science are not my strong suits, but as I worked with my team members I found myself becoming more and more confident.

(Melva)

- How do you feel that your knowledge of the subject or self-efficacy has changed?

Um, I'm a lot more confident in my teaching in math and science. I don't see science as, you know, the forsaken zone that most teachers don't want to enter when they come to the classroom. Now that I really feel that it is an integration with mathematics, I don't see it as a separate entity. So, I feel that, right there, makes me more confident in teaching it. Knowing, you know, the content as well.... I think preparation and reading up on the content beforehand makes me more confident in my teaching as well.

(Cecilia)

I think that I know more, and I definitely have more to work with when I finally teach. As far as my knowledge for instance, just telling you what I know, I'll be honest. I can't just tell you this is this and that is that, but I am more comfortable in working with the resources that I have, more so than I did before I entered the program. And I know more [because of] doing more teaching in those areas.

(Melva)

- How did the space science curriculum fit into your school curriculum?

Um, "The Air Show" combines so much, um.... It combined the vocabulary that we learned in math and that we did in the previous lesson, "Rescue Mission Game." It had to do with symmetry when they created their airplanes as far as the line of symmetry. We measured the time, um ... they had a chance to, um, measure as far as the accuracy. They had a chance to [write a] hypothesis and collect data and create averages with, you know, the data.

(Cecilia)

It was very interesting because at the school that I was at they already have different subject preps. So, they have science prep. I really didn't have to worry about doing a whole big unit, but I wanted to do it because I have no idea about the kind of school that I am going to be entering into. So, I wanted to have experience in actually creating my own unit. Like I said before, I don't like to teach one subject. I like to integrate all subjects in my teaching. So, I'll probably do language arts and fit in there a lesson where I would read a science book. Then I would add on different things from there.

(Melva)

- What are specific examples that you used in your student teaching experience to highlight Earth or space science in your classroom?

I had the posters, of course, in the classroom. And with each lesson, "Rescue Mission" and "The Air Show" and, you know, the Alka-Seltzer rockets ... it was not just something that we did that day, it was, you know, a buildup. I tried to make it a great big unit of all the space things we were going to do. And because the lessons were so in depth and detailed, you know, we spent more than one afternoon on any given lesson. And um, it was before I actually did my NASA Goddard experience, actually the month before we spent that time. So, I didn't have the resources that I have now to incorporate it, so I think

in my own teaching experience, I'll be able to do a lot more because I have a lot more resources and a lot more experience from the NASA experience than I did when I [was] student teaching.

(Cecilia)

I just actually finished my [last] week of [student] teaching. We talked about the life cycle of plants. We talked about the different parts of plants and how plants grow. As far as the rocket lesson, definitely rockets do not move by themselves. They use fuel. Fuel comes from the ground. It comes from the Earth.

(Melva)

ANALYSIS OF REFLECTIONS

Four themes emerged about science teaching in the teacher reflections. The first theme was integration of subject matter. Both Melva and Cecilia mentioned the importance of integration as opposed to teaching science content in isolation. This is important because there is ample evidence to suggest that a major problem with teaching subjects in isolation is the limited time allotted to teaching all subject matter, which leads to some subjects being squeezed out (Weiss, Banilowe, McMahon, and Smith, 2001). Furthermore, isolation of content causes a huge disconnect for students. Science and mathematics standards call for connections to be made to the real world. In the real world, science and mathematics are not disconnected; rather, they operate together to create phenomena that we interpret to be scientific or mathematical. For Cecilia, integration led to sense-making. Therefore, it was “easier to incorporate them (math and science) together” as integration led to increased efficacy in teaching science (Lehman, 1994). The second theme to emerge from the reflections was the importance of additional field experience. Melva became “more and more confident” as she worked with team members to deliver space science instruction when she taught informal science in the community-based setting. The third theme was the importance

of user-friendly and accessible resources. Both Cecilia and Melva were comfortable with the *Mission Mathematics* curriculum (NCTM, 1997), resources, and ideas that were provided. In particular, the curriculum was adaptable; Cecilia specifically mentioned how she prepared more than she could actually teach and how she carried science over to additional days. The fourth theme was an awareness of the placement or fit of science into the overall school curriculum. In fact, both Cecilia and Melva reflected on how space science supported their school curriculum. Cecilia incorporated science vocabulary during reading time, and Melva read books about science during language arts instruction. Also, both participants mentioned creating space science units and not simply teaching the lessons once just to impress the researchers. For example, Melva did not have to do a science unit at her school, but she chose to do one anyway because she believed it would benefit her later on when she became a teacher. Overall, these preservice teachers' reflections provide examples of BFT as race, gender, science identity, and mathematics identity intersect (Thomas et al., 2018). Finally, it appeared that the Space Links program helped build these participants' self-efficacy and enhanced their science instruction.

Discussion

Because of the small number of cases, all of the data were triangulated (i.e., STEBI-B scores, STIR ratings, and interviews) to learn how the Space Links program and the NASA externship impacted the self-efficacy and science instruction of female preservice teachers. Findings revealed that the externships had a positive impact on science lessons as a result of beginning teachers working alongside scientists. Cecilia, Lillie, and Melva extended themselves by gathering data or materials outside of the classroom to implement innovative lessons with students. Specifically, Cecilia gathered materials needed for students to make model airplanes and conducted different types of trials. Lillie took extra time to download and laminate photographs

of different galaxies. Melva purchased a book about rockets, and grocery items for students to make veggie shuttles. These behaviors matched those of individuals categorized as high-efficacy teachers (Czerniak & Schriver, 1994; Mellado, 1998). In fact, many beginning teachers have difficulty deviating from the textbook and prescribed curriculum (Fullan, 2000). Yet, these novice teachers made science accessible and thinking visible while helping students to learn from each other and develop science process skills (Linn & Hsi, 2000).

Implications

The lessons learned from the project findings have important implications for teacher educators. One clear implication is that multiple and varied kinds of experiences better prepare, improve, and facilitate preservice teachers' science and mathematics instruction with diverse students and communities. This implication leads me to believe that, with more intensive and thoughtful planning and collaboration with community-based sites and supervisors of student teachers, scientists, and preservice teachers, Space Links and similar programs can be an important addition to the array of teacher approaches aimed at increasing female and minority representation in STEM careers. Finally, the nexus of culturally specific pedagogy in science and mathematics instruction offers a potential ray hope for administrators and teachers, who are mandated to increase the test scores of underachieving students. Anchoring mathematics and science instruction to the students' cultures and historical backgrounds has the potential to increase student knowledge and retention in both subjects.

Chapter 6 Discussion Questions

1. There is evidence that typical classroom discourse may be counterproductive to female participation in mathematics. What strategies can teachers use to enhance female students' discourse in mathematics classrooms?

2. There is a trend that female and underrepresented students' enrollment in engineering programs is increasing. How can K-12 teachers adapt their instruction to continue this trend?
3. Results of the Space Links Study revealed early-childhood teachers engaged students in science inquiry at lower levels. What strategies can be used by early-childhood teachers to provide young learners with more opportunities to engage in science inquiry?
4. Evidence suggests that single-sex classrooms may benefit female students' self-efficacy in mathematics. What can teachers in coeducational classrooms do to ensure girls have equitable mathematics instruction?
5. How can elementary and middle school teachers integrate science and mathematics with other content to improve performance outcomes among female students in STEM?

Note

1. www.imdb.com/title/tt4846340/goofs.

LEARNING MATHEMATICS FOR EMPOWERMENT IN LINGUISTICALLY AND CULTURALLY DIVERSE CLASSROOMS

Classrooms in the United States have become more diverse over the last decade. According to the Annie E. Casey Foundation's (2017b) data poll, 73 million children under the age of 18 reside in the U.S. Of that number, school-age children were identified as follows: 51% White, 25% Hispanic, 14% Black/African-American, 5% Asian, 4% two or more races, 1% American Indian/Alaska Native, and <0.5% Hawaiian/Pacific Islander. Furthermore, trends show the Hispanic population in the U.S. has grown substantially. In 2016, 25% of children under age 18 were identified as Hispanic, representing the largest minority group. However, it should be noted that students from Spanish-speaking countries may come from varied racial backgrounds. While language-minority students may be found in large urban school districts, their numbers are also increasing in small urban cities, towns, and suburban school districts, including the state of Wyoming. In fact, 14% of students in Wyoming were identified as Hispanic in 2016 (Annie E. Casey Foundation, 2017b).

In 2015, English language learners (ELLs) accounted for 9.4% or an estimated 4.6 million students in the U.S. (National Center for Education Statistics, 2018). In New York City alone, more than 180 languages are spoken at home by children attending public schools (Mass, 2015). Nieto (2002) contended that language diversity should be viewed "using the lens of educational equity" (p. 83). Yet, schools and colleges of education

have done little to prepare prospective teachers to teach linguistically diverse students (Lucas & Villegas, 2011; Russell, Leonard, Viesca, & Hamilton, 2015) and “accessing professional development (PD) and resources for teaching ELLs” is difficult (Takeuchi & Esmonde, 2011, p. 332). Delpit (1995), Gay (2000), and Nieto (2002) recommended reconceptualizing teacher education so that prospective teachers develop critical perspectives about their identities and use their own cultural awareness and reflection to raise consciousness and impart knowledge, skills, and values that will result in equitable classroom practices for all children.

Language Diversity and Professional Development

In recent years, language diversity has been addressed through professional development (Hadjioannou, Hutchinson, & Hockman, 2016; Russell, Leonard, Viesca, & Hamilton, 2015). Teaching English to speakers of other languages (TESOL) “asserts the need [for] teachers to have a solid knowledge of theory and research on second-language acquisition (SLA) and the ability to use this knowledge in supporting the language, literacy, and content-area learning of English language learners” (Hadjioannou et al., 2016, p. 3). To address this need, online and hybrid (web-based and face-to-face) professional development (PD) programs have been established (Hadjioannou et al., 2015; Russell et al., 2015). The Modular Design for English Language Learners (MODELL) instruction program was developed to prepare traditional classroom teachers to work more effectively with culturally and linguistically diverse children. Addressing distinct areas of the theory of language acquisition, cultural mindfulness, knowledge of state standards, and teaching strategies for ELLs, the MODELL program combined online PD with professional learning communities to help teachers improve their practices (Hadjioannou et al., 2016).

Thirty-four participants (16 elementary and 18 secondary teachers) took part in a study that measured changes in teachers’ practices. “Surveys of knowledge and reflective

writings revealed positive changes in the participants' ability and confidence in providing the kinds of learning environments that will significantly affect ELLs' language and literacy development" (Hadjioannou et al., 2016, p. 24). Yet, one year after completing the program, researchers found some incongruence between four focal participants' self-reports and the implementation of knowledge and teaching strategies. This finding implies that sustaining teacher practices that support ELLs is challenging. Thus, ongoing, long-term PD may be more effective than short-term PD.

In a second study, called eLearning Communities for Academic Language Learning in Math and Science (eCALLMS), online modules were developed to help teachers implement specific strategies related to mathematics and science content (Russell et al., 2015; Viesca, Hamilton, & Davidson et al., 2016). Pilot studies investigating the strengths and weaknesses of the modules revealed the importance of the following: (a) organizational structure, (b) holistic modes of processing information, (c) teacher-friendly resources, and (d) making connections to World-Class Instructional Design and Assessment (WIDA)¹ and Center for Research on Education, Diversity, and Excellence (CREDE)² standards. The modules provided teachers with the flexibility to complete online PD at their discretion while the content provided concrete examples for teaching specific mathematics and science content to ELLs. Teacher awareness of WIDA and CREDE standards, along with practical applications, helped them to support emergent bilingual students (Viesca et al., 2016). However, to impact student learning outcomes, eCALLMS researchers understood the need for long-term PD. While PD projects have attempted to address student learning in classrooms across the U.S., there is still a tremendous need to improve prospective teachers' knowledge of ELLs and the use of equitable teaching strategies in teacher education programs (Moschkovich, 2013).

Teacher Expectations

Many factors contribute to ethnically and linguistically diverse students' academic performance in school, including teacher expectations. Students who are perceived positively by teachers have advantages over those who are perceived negatively (Gay, 2000; Rist, 1970). Teacher beliefs about their students influence how they treat students, which impact how they will teach and how much students will learn (Gay, 2000). This phenomenon is an example of the self-fulfilling prophecy and has six attributes:

- Teachers expect specific achievement from specific students;
- Teachers behave toward students according to those expectations;
- Teachers' behaviors convey to students what is expected of them and are consistent over time;
- Students internalize teachers' expectations, and these expectations effect their self-concepts, achievement motivations, levels of aspiration, classroom conduct, and interactions with teachers;
- Over time students' behaviors become more and more attuned to what teachers expect; and
- Ultimately, students' academic achievement and other outcome measures are affected.

(Good & Brophy, as cited in Gay, 2000, p. 58)

The growing diversity of our nation's schools necessitates that reform at the teacher education level is crucial to the development of culturally competent teachers (Gay, 2000; Howard, 2003; Nieto, 2002).

In the United States, English is the language of power (Delpit, 1995; Nieto, 2002; Sheets, 2005). Therefore, in order to be successful in American society, it is necessary to learn the English language. However, the ability to speak more than one language should be viewed as an asset rather than a liability (Nieto, 2002;

Sheets, 2005). This position is also applicable to African-American students who come to school speaking Black English dialects. While it is important to recognize the importance of teaching and using Standard English to help African-American students utilize the language of power to succeed academically, it does not have to be done in a manner that is demeaning to the student and his/her culture (Delpit, 1995). "Teaching language minority students successfully means, above all, changing one's attitude towards the students, their languages and cultures, and their communities" (Nieto, 2002, p. 93).

In order to empower linguistically diverse students to achieve in any classroom, especially mathematics, Nieto (2002) compelled teachers to (a) understand how language is learned, (b) develop an additive perspective about bilingualism, and (c) consciously foster native language literacy. Each of these points will be addressed within the context of the mathematics classroom to identify culturally specific connections that can be made with multicultural children's literature. In addition, I suggest strategies and activities that teachers of mathematics may use to empower linguistically and culturally diverse students to learn mathematics within the contexts of culture and social justice. Finally, I reflect upon my own pedagogy and the influence I may have to change preservice teachers' perspectives on culturally and linguistically diverse students.

Understanding Language Acquisition

According to Cole (1992), no issue in culture and human development has received more scholarly attention than the interrelationship of culture, language, and development. In order for children to acquire language, "they must not only hear language but they must also participate in the activities that language helps to create" (Cole, 1992, p. 762). "The language or languages students speak categorizes them as members of distinctive linguistic, social, cultural, and ethnic groups" (Sheets, 2005, p. 108). Thus, language and culture are inextricably linked, as language is used to communicate and pass down

cultural values and beliefs (Nieto, 2002; Sheets, 2005). Moreover, language is the medium for expressing thought and is crucial to students' cognitive development (Vygotsky, 1986). In order to implement meaningful classroom practices to support ELLs' communication in English, teachers must have knowledge of second-language pedagogy (Sheets, 2005).

Two main types of language instruction have been prevalent in U.S. schools: English as a second language (ESL) and bilingual education programs (Nieto, 2002; Sheets, 2005). ESL teachers are trained to provide instruction in the content areas in English by using specific vocabulary and low-level reading strategies (Sheets, 2005). The goal of this type of program is to encourage assimilation among ELLs. Bilingual programs include transitional programs that function to teach students English at a fast pace. Yet, bilingual programs have been criticized for transitioning ELLs too quickly into mainstream programs (Nieto, 2002; Sheets, 2005). In maintenance bilingual programs, students' home languages and culture were respected, as students were allowed five to seven years to become literate in English (Sheets, 2005). In the two-way bilingual program, native English speakers were taught alongside ELLs from kindergarten through sixth grade. In this context, more time was devoted to English over the years. Moreover, the two-way bilingual program served a dual purpose—giving both ELLs and native-English-speaking children access to social and cultural advantages as they learned to speak, read, and write in two languages (Nieto, 2002; Sheets, 2005).

The findings of two quasi-experimental studies in mathematics and bilingual education are important to note. First, a study by Bacon, Kidd, and Seaburg (as cited in Demmert & Towner, 2003) examined whether or not eighth-grade Native American students who received bilingual instruction (English and Cherokee) differed in reading and mathematics achievement when compared to a control group that did not have bilingual education. In this study, ANCOVA results revealed children who received bilingual instruction scored higher on

reading and mathematics subtests compared to a control group. In a second study, Rosier and Holm (as cited in Demmert & Towner, 2003) studied the effects of initial arithmetic instruction for one cohort of students in Navajo and later in English compared to a control group that received arithmetic instruction in English much earlier. Findings showed that students in grades four and above who did not begin reading English until mid-second grade scored significantly higher than the control group on two standardized tests.

These studies highlight the difficulties faced by second-language learners (L2) in reading and mathematics. “Second-language learning, unlike first-language learning, takes place for different social, economic, political, and educational reasons and under different conditions” (Sheets, 2005, p. 114). Moreover, second-language acquisition is not an easy process, but generally takes five to seven years to develop fluency (Nieto, 2002). While more expensive than ESL, the maintenance bilingual program and two-way bilingual programs were more beneficial for ELLs. However, challenges to bilingual education and preferences for ESL programs create additional structural barriers for ELLs to actually learn English. Language-rich environments that value students’ first languages as well as English provide optimal conditions for students to practice speaking, listening, reading, and writing (Sheets, 2005). Thus, it is imperative for all teachers, not just ESL and bilingual teachers, to develop common knowledge about language diversity (Nieto, 2002; Viesca et al., 2016).

Nieto (2002) encouraged teacher candidates to learn a second language and acquire the following kinds of knowledge, capabilities, and experiences:

- Familiarity with first- and second-language acquisition;
- Awareness of the sociocultural and sociopolitical context of education for language-minority students;
- Awareness of the history of immigration in the U.S., with particular attention to language policies and practices throughout that history;

- Knowledge of the history and experiences of specific groups of people, especially those who are residents of the city, town, and state where they will be teaching;
- Ability to adapt curriculum for students whose first language is one other than English;
- Competence in pedagogical approaches suitable for culturally and linguistically heterogeneous classrooms;
- Experiences with teachers of diverse backgrounds and the ability to develop collaborative relationships with colleagues that promote learning for language-minority students; and
- Ability to communicate effectively with parents of diverse language, culture, and social class backgrounds.

(Nieto, 2002, p. 208)

By acquiring a broader knowledge base about linguistically and culturally diverse students, teachers engage in the process of becoming more caring and culturally competent individuals (Gay, 2000).

Teacher educators can engage teacher candidates in discussions about language, ethnicity, race, and gender diversity by using films and books to stimulate thought. Films such as *Lean on Me* (Avildsen, 1989), *Stand and Deliver* (Menéndez, 1988), and *Mona Lisa Smile* (Newell, 2003) are recommended. Scholarly books that may be used to engage preservice teachers in dialogue about diversity are *Mathematics Education at Highly Effective Schools That Serve the Poor* (Kitchen, Depree, Celedón-Pattichis, & Brinkerhoff, 2007), *Savage Inequalities* (Kozol, 1991), *The Dreamkeepers* (Ladson-Billings, 2009), and *Made in America: Immigrant Students in our Public Schools* (Olsen, 1997). By incorporating critical reflection of self and cultural identity in teacher education programs, teacher educators can encourage beginning teachers to deconstruct negative beliefs and stereotypes and reconstruct positive beliefs and values about linguistically and ethnically diverse students (Gay, 2000).

Developing Additive Perspectives

English language learners experience a great deal of conflict when the cultural values of the home and school do not mesh (De La Cruz, 1999; Sheets, 2005). For example, programs such as English-Only put ELLs at risk of language loss, as noted by Sheets (2005), who contended that language loss among immigrants has taken place at an alarming rate. To prevent language loss, bilingual education programs are crucial. As cited earlier, studies on bilingual students show that there are advantages to bilingual education (Bacon, Kidd, & Seaburg, as cited in Demmert & Towner, 2003; Rosier & Holm, as cited in Demmert & Towner, 2003; Thomas & Collier, as cited in Nieto, 2002). Specifically, language-minority students who received bilingual education scored at or above the 50th percentile rank on standardized tests, compared to ESL students, who scored between the 10th and 18th percentile ranks (Nieto, 2002). “Teachers need to support the language that students bring to school, provide them input from an additional code, and give them the opportunity to use the new code in a non-threatening, real communicative context” (Delpit, 1995, p. 53).

In the mathematics classroom, Delpit’s assertion can be realized in a number of ways. Early-childhood teachers can show the additive value of different languages by including the word names of the counting numbers (usually one to 10) in languages such as Spanish, Swahili, and Chinese, to instill student pride (Takeuchi & Esmonde, 2011). Older students may develop story problems using numeral scripts from different systems (i.e., Egyptian, Mayan, etc.). Such lessons, as demonstrated in the Kay Tolliver series of videos (FASE, 1998), help students to improve their understanding of the base 10 number system while celebrating the mathematical contributions of diverse people.

Fostering Language Literacy in the Mathematics Classroom

In an intensive study of one teacher’s work with third-grade Latinx students, Hufferd-Ackles, Fuson, and Sherin (2004) developed a framework that can be used to help teachers

establish language literacy through mathematics discourse. The case study took place in a Catholic school located in a working-class neighborhood in the Midwest. It described the growth of one teacher, Ms. Martinez, who began the year using a more traditional form of mathematics instruction and the changes that took place as she and her 25 students interacted in a math-talk learning community (Hufferd-Ackles et al., 2004). The main principles in the framework included questioning and explaining mathematical thinking. Using a developmental trajectory that consisted of four levels (Levels 0 to 3), the researchers examined changes over time in Ms. Martinez's classroom.

Results of the study found that Ms. Martinez's use of questioning techniques grew from Level 0 to Level 3 over the course of the year as discourse patterns shifted from the teacher as the primary source of student questioning to students asking questions of their peers. Another change in questioning patterns was less emphasis on "questioning to find answers to a focus on questioning to uncover the mathematical thinking behind the answers" (Hufferd-Ackles et al., 2004, p. 92). Student explanations of mathematical thinking also grew over time as short exchanges that focused on answers only (Level 0) became more elaborate as students became accustomed to communicating their thinking. Student explanations reached Level 2 in such cases, but students still required prompts, probing, and assistance to clarify their thoughts (Hufferd-Ackles et al., 2004). In order to move to the highest level (Level 3), students had to learn to take on more responsibility in the classroom. However, shifts in power and authority are not easy for students and teachers who are not accustomed to such practices (Bernhard & Freire, 1999; Lee, 2003).

Children's literature that incorporates multicultural aspects of mathematics may be used to foster language literacy in the mathematics classrooms. Texts such as *Moja Means One: Swahili Counting Book* (Feelings, 1971), *Two Ways to Count to Ten: A Liberian Folktale* (Dee, 1988), and *The Village of Round and Square Houses* (Grifalconi, 1986) are suggested. The content of the

counting books is fairly obvious. In the text *The Village of Round and Square Houses*, traditions in an African village are described: women lived in round houses, but men lived in square ones. Students can learn a great deal about measurement, area, and perimeter while building replicas of village houses in the classroom.

Research has shown that multicultural children's literature influences reading development and engagement (Pentimonti, Zucker, & Justice, 2011). Consequently, at two universities in the Rocky Mountain region, I used specific strategies to embed culture and language into my mathematics education courses (Han & Leonard, 2017; Leonard, Moore, & Brooks, 2014). In these courses, readings and activities addressed issues of language and cultural diversity. Students read articles about culturally relevant teaching in Mexican-American classrooms (Gutstein et al., 1997) and assessment pieces about how ELLs solved mathematics problems (Solano-Flores & Trumbull, 2003). Prospective teachers examined multicultural children's literature, such as *Grandfather Tang's Story* (Tompert, 1997), *One Grain of Rice* (Demi, 1997), *The Spider Weaver* (Musgrove, 2001), and *The Three Little Javelinas* (Lowell, 1992).

Grandfather Tang's Story is a folktale about two foxes that are able to transform themselves into different animals as they play a game of hide and seek. Teachers can reinforce students' spatial and visual skills by allowing them to use tangrams to create the animals while the story is being read. *One Grain of Rice* tells the story of a peasant girl, Rani, who gained favor with a raja. The raja promised to deliver rice to Rani for 30 days, beginning with one grain of rice and doubling the amount each day. The story helps children to learn about another culture as well as the rapid growth of exponential functions. Also, teachers can use the spread of communicable diseases to engage older students in graphing calculator activities (Dossey, Giordano, McCrone, & Weir, 2002). *The Spider Weaver* is a folktale about two men from the Ashanti village of Bonwire in Ghana who discover intricate designs made by a spider. Using designs found in the

spider's web, the men got the idea to weave Kente cloth for the people in the village. Straws and string or yarn may be used to create weblike geometric designs to connect this text to mathematics. *The Three Little Javelinas* is the Spanish version of the three little pigs. In this story, the three pigs used critical thinking to outsmart the predatory wolf. This text can be used to create story problems for students to solve.

In one study (Leonard, Moore, & Brooks, 2014), the teacher-researchers found the decisions prospective teachers made in selecting multicultural literature influenced their ability to engage students in cultural and math activities. Chappell and Thompson (2000) categorized multicultural texts as follows:

culturally contextual (culturally specific to one race or ethnic group), culturally amenable (not specific to a particular culture or race although the characters may be of a specific race or ethnic background) or culturally influenced (neither culturally contextual, nor culturally amenable).

(pp. 135–136)

In addition, the teacher-researchers rated the texts for practical importance or value of mathematics content (i.e., mathematically robust, mathematically related, or mathematically peripheral) (Koellner, Wallace, & Swackhamer, 2009). The focus on content is critical for teaching important mathematics concepts and vocabulary to ethnically and linguistically diverse students. Table 7.1 shows the multicultural literature choices of four focal preservice teachers in the aforementioned study (Leonard et al., 2014).

The results of this study revealed the importance of choosing multicultural literature to provide rich stories of children's culture as well as robust mathematics. Students can learn important language and vocabulary from the texts while also learning about their culture, if appropriate texts are chosen. Thus, teachers should attend to cultural elements, as well as mathematics content (or concepts), that draw upon

Table 7.1 Analysis of Multicultural Texts

<i>Teacher Candidate</i>	<i>Math Topic/Grade Level</i>	<i>Title of Text</i>	<i>Cultural Complexity</i>	<i>Mathematics Level</i>
PT#1	Measurement/Fifth grade	<i>One grain of rice</i> (Demi, 1997)	Culturally Contextual	Robust
PT#2	Money/First grade	<i>Rows and Piles of Coins</i> (Mollet, 1999)	Culturally Amenable	Robust
PT#3	Number/Third grade	<i>Aunt Harriet's Underground Railroad in the Sky</i> (Ringgold, 1992)	Culturally Contextual	Related
PT#4	Measurement/Third grade	<i>Inch by Inch</i> (Lionni, 1988)	Culturally Influenced	Peripheral

WIDA and CREDE standards. Incorporating literary experiences into mathematics lessons may also be gender-equitable, as some studies have shown that boys often lag in reading while girls lag in mathematics during their elementary years (Robinson & Lubienski, 2011).

Multicultural literature may also be used to engage linguistically and culturally diverse students in mathematical discourse. Texts that are related to historical events or contemporary life include *Sadako* (Coerr, 1993), *First Day in Grapes* (Pérez, 2002), *A Migrant Child's Dream: Farm Worker Adventures of Cholo, Vato, and Pano* (Silverman, Strawser, Strohauer, & Manzano, 2001), and *Harvesting Hope* (Krull, 2003). *Sadako* is a story about a Japanese girl's battle with leukemia as a result of exposure to the atomic bomb during World War II. Origami activities can be developed after reading the text. Also, critical discussion about the aftermath of war can be facilitated with older students. *First Day in Grapes* is a story about an immigrant boy named Chico. Because his parents were migrant farm workers, the author depicts Chico's life as that of a transient student in California. In third grade, Chico is confronted by a couple of bullies but uses his knowledge of mathematics to outsmart them and win their respect. A similar story is told about migrant farm life in *A Migrant Child's Dream: Farm Worker Adventures of Cholo, Vato, and Pano*. The story of Pano and his two dogs, Cholo and Vato, is available in English and Spanish (Silverman et al., 2001). *Harvesting Hope* is the story of the life of political activist Cesar Chavez and his historic walk from Delano, California, to Sacramento, California, on behalf of migrant farm workers who suffered from backbreaking work and low wages. In protest, Chavez organized a movement (see Figure 7.1) that became known as *Viva La Causa!* Numerous word problems relating to this aspect of Chavez's life may be developed to accompany this movement. Examples of these problems are noted below.

- Cesar Chavez organized the National Farm Workers Association to help fight for the rights of migrant farm

Figure 7.1 Cesar Chavez Organizes the National Farm Workers Association.

workers. In 1965, Cesar and his followers organized a 250-mile march from Delano, California, to the state capitol in Sacramento. It took 17 days for the marchers to reach Stockton, California. It is about 200 miles from Delano to Stockton. Find the average number of miles the people had walked so far.

- Using the Internet, determine how much further it takes to walk from Stockton to Sacramento. If the people walked the same average number of miles it took to get from Delano to Stockton to get from Stockton to Sacramento, how many more days did it take to get to Sacramento?
- It takes about four hours to drive by car from Delano, California, to Sacramento, California. How much longer did it take Chavez and his followers to walk from Delano to Sacramento than to ride by car?

- Chavez's movement on behalf of migrant farm workers was nonviolent. To bring attention to *La Causa*, Chavez went on hunger strikes, refusing to eat food for many days. In 1993, Chavez went on a 36-day hunger strike. How many weeks did this hunger strike last?
- After helping to improve the wages and working conditions of migrant workers who harvested grapes, Chavez helped to organize a strike on behalf of lettuce workers in California. If they worked 12 hours a day, how many hours did the lettuce workers strike in a typical work week?

Teaching Mathematics for Cultural Relevance and Social Justice

Several studies that focus on children's cultural heritage have been conducted in mathematics (Brenner, 1998; Gutstein, 2003; Gutstein et al., 1997; Lipka et al., 2005; Leonard, Buss, et al., 2016). Gutstein et al. (1997) described one study of culturally relevant teaching (CRT) in a Mexican-American school community. The purpose of the study was to develop a three-part model of CRT. CRT allows students to see their values, culture, or history embedded in content and/or learning experiences. Moreover, it empowers teachers and students to change society, challenging the status quo (Ladson-Billings, 1994, 2009). The three components of the Gutstein et al. study (1997) consisted of (a) building on students' cultural and experiential knowledge, (b) developing tools of critical mathematical thinking, and (c) developing orientations to students' culture and experience.

Teachers in the study used the context of social activism, a form of culture that defines social and political relationships (Hollins, 1996), to make connections to mathematics. Gutstein et al. (1997) found that CRT existed in practice and was consistent with the goals described in the *Professional Standards for Teaching Mathematics* (NCTM, 1991). However, in order to understand what CRT meant in Mexican-American classrooms, Gutstein et al. (1997) examined teachers' beliefs and educational practices as they related to the following:

- The role of culture in curriculum and pedagogy;
- Notions of cultural competence, bilingualism, and biculturalism;
- Perspectives on families and community;
- Relationships of students viewing knowledge critically to their role in society; and
- Conceptions of knowledge and the role of the teacher in knowledge construction.

(p. 717)

In order to build on students' knowledge, teachers needed to find out what students knew as a starting point from which to scaffold (Gutstein et al., 1997). Some teachers in the study viewed students' informal mathematical knowledge as a way of integrating student culture into the curriculum. For example, in one class, students studied the names and meanings of mathematical concepts in both Spanish and English (Gutstein et al., 1997). Moreover, the teachers cultivated a learning environment where positive orientations toward students' culture and experience were allowed to thrive, which encouraged the development of personal and social agency among Mexican-American students. However, the teachers in this study did not simply approach critical thinking about mathematics from the standpoint of helping students to learn math. Instead, their approaches empowered students as they learned how to question authority and promote democratic practices in the classroom (Gutstein et al., 1997). As this study demonstrates, it is not enough to teach mathematics and science literacy for literacy's sake; linking the content to issues of social justice and civil rights has been found to increase the participation of underserved and underrepresented students in mathematics classrooms (Gutstein, 2003; Leonard & Hill, 2008).

Learning mathematics within a social justice context allows students to develop sociopolitical consciousness, or *conscientização* (Freire, as cited in Gutstein, 2003), which is a necessary tool to fight for equity and social justice (Gutstein, 2003). Teaching for social justice allows students to develop a sense of

personal and social agency and positive social and cultural identities that validate their language and culture (Gutstein, 2003; Martin, 2000).

In a second study, Gutstein (2003) conducted teacher-research on his class of Latinx seventh- and eighth-graders, highlighting the difficulties and successes of his efforts to get students to think critically about mathematics and to use their mathematical knowledge to address issues of social justice. This study took place in an urban school where the vast majority of students were Mexican-American. Ninety-eight percent of the students were poor by federal subsidized lunch standards. Fifty percent were born as first-generation U.S. citizens and the other 50% were immigrants. All of the students, except one, were bilingual in Spanish and English.

In Gutstein's classroom, mathematics became the vehicle for questioning or examining imbalances of power, such as inequitable resources, disparate opportunities, and discrimination based on race, class, gender, and/or language. Some of the issues students investigated included SAT data, housing data, and international wealth. Two students reported the following analyses to the class:

In the U.S. Bill Gates holds more money than anybody else, but if you divide the wealth by population, Bill would probably have an average amount of money and a homeless [person] would have an average amount of wealth.

(Gutstein, 2003, p. 50)

Our family makes somewhere in the neighborhood of \$40,000. I heard that Michael Jordan makes about \$1,000 for every minute he plays. So that means that in 40 minutes he makes our whole family's earnings. While my family works year round for that money.

(Gutstein, 2003, p. 50)

In addition to learning mathematics for social justice, the students in Gutstein's class also developed mathematical power,

which was demonstrated by their success on tests, quizzes, projects, and assignments. Some students invented their own algorithms for solving word problems and were able to communicate their mathematical thinking and rationale to the class. Most importantly, all students passed their eighth-grade standardized assessments and were promoted to ninth grade. These data show that a culturally based curriculum that is connected to social justice not only increases opportunities to learn but also makes it possible to improve urban students' mathematical achievement (Gutstein, 2003).

The challenge we now face is how to create a curriculum filled with responsible social and political issues that will help students understand the complexity of such problems, help them develop and understand the role of mathematics in their resolution, and allow them, at the same time, to develop mathematical power.

(Romberg, as cited in Gutstein, 2003, p. 44)

Novice teachers in my courses also realized the importance of teaching for social justice. The following excerpt from a mathematics teacher in a methods course that I taught in 2013 summarizes how social justice themes can be used to teach mathematics:

Using math for a purpose is a reoccurring theme this semester. The living wages ideas we explored were a good example.... It costs us more for people to live in poverty than to not live in poverty. I liked bringing this back "home" by discussing where we have our most "wealth" and jobs. This could be from a national, state, and then local perspective. Mathematics is a tool and showing students how to use it is our task.

(White female teacher)

Reflections on Classroom Practices

After teaching mathematics methods courses for more than 20 years, I found that beginning a course with the teachers' mathematics experiences helped them to understand how powerful

and enduring early experiences are. Consequently, I used pre-service and beginning teachers' experiences to discuss the importance of equitable mathematics teaching. By making connections to their own schooling, novice teachers were receptive to embracing culturally responsive pedagogy and teaching mathematics for social justice.

TEACHERS' REFLECTIONS ON PRIOR MATHEMATICS EXPERIENCE

In 2017, I taught a middle-level mathematics methods course at the University of Wyoming. Vignettes of two White females' reflections of prior mathematics experiences are as follows:

Vignette 7.1

I do not have a ton of really specific math memories, but my pleasant math memories ended after fifth grade. My first vivid memory was playing around the world with flash cards in third grade. We were memorizing our times tables, and my teacher offered small prizes for those of us that "won" the around the world game. I remember practicing the flash cards in the kitchen with my mom and then being successful in class because I had a good memory and could spit [the facts] out pretty quickly. I do not remember learning anything conceptual about how multiplication works; I just remember the facts.... I started to dislike math in middle school, but by the time I got into high school, I hated it. I did not have a conceptual understanding of what I was doing with math, and the formulas/calculations became harder to memorize.

Vignette 7.2

When thinking back to my early memories of mathematics instruction and experiences, I realize that most of my memories stem from middle and high school. I do not recall what my math instruction was like as an elementary student. As a matter of fact, I do not recollect much of my elementary schooling at all. I attribute this to moving frequently and switching schools throughout my elementary years. In middle school, high school, and even college, I remember often feeling lost or "behind" my peers. I think I was a bit slower to catch on because I needed to know why it worked. I was a "why" student. I recall that some of my teachers didn't seem to know why, or if they did, they were not able to explain it in a way that made sense to me.

The two vignettes emphasize the importance of sense-making and developing conceptual understanding when teaching mathematics. They show that focusing on math facts and procedures without context or meaning limited the mathematics growth and development of these two females. The first woman grew up believing that all she needed to do was memorize facts and formulas to solve mathematics problems. When that did not work, she became frustrated and began to dislike mathematics. The second woman revealed the importance of curriculum continuity and assessment. Like this woman, through no fault of their own, migrant students move from school to school several times before they graduate from high school. However, the mathematics curriculum differs across school districts and educational systems in different states, thereby presenting, at times, an insurmountable challenge to the continuity of teaching and learning (Li & Lappan, 2014). While teaching standards, such as the Common Core State Standards (CCSS), have made mathematics content more consistent, teachers should be able to assess where new students are in their mathematical understanding and provide individualized instruction when needed.

Culture in the Mathematics Classroom Project

The National Science Foundation has sponsored several research studies to develop preservice and beginning teachers' development of CRT. As a researcher in a study based at the University of Northern Colorado, I taught a course at the University of Wyoming called Culture in the Mathematics Classroom (CIMC) in spring 2014. The purpose of the course was to examine issues related to the role of culture in the mathematics classroom and to explore ways to integrate culture into mathematics instruction with the goal of developing children's internal motivation. The course began with the development of essential knowledge by discussing the role of culture in learning mathematics. Additionally, tenets of CRT and teaching mathematics for social justice were developed. The course also fostered understandings of students' communities as cultural assets

while allowing them to examine approaches to building upon cultural resources and developing knowledge about strategies and techniques for connecting classrooms practices to students' backgrounds and learning needs. After reading articles related to building these specific outcomes (i.e., Howard & Terry, 2011; McGee & Martin, 2009; Nasir, Hand, & Taylor, 2008), students participated in literature circles to discuss texts such as *Beats, Rhymes, and Classroom Life: Hip-Hop Pedagogy and the Politics of Identity* (Hill, 2009); *Multiplication is for White People* (Delpit, 2012); *Classroom Diversity: Connecting Curriculum to Students' Lives* (McIntyre, Rosebery, & Gonzaléz, 2001); and *Reading and Writing the World with Mathematics* (Gutstein, 2006).

In addition to written assignments and class discussions, 10 student participants (three males and seven females) also completed a community engagement project and pre-post surveys on CRT (Siwatu, 2007). Each of these data sources are presented as evidence of teacher learning and teacher change. The constant-comparison method (Strauss & Corbin, 1990) was used to analyze their reflections on these assignments.

REFLECTIONS ON TEACHERS' WRITTEN ASSIGNMENT

Two reflection papers with critiques on peer-reviewed articles related to culture or cultural relevance were required in the course. Three focal teachers' reflection papers were randomly selected for analysis on the Howard and Terry (2011) article. Excerpts of their reflection papers, written near the beginning of the course, are presented below.

Vignette 7.3

As I reflected on the call for radical distribution of resources, I began to think that it doesn't matter if you redistribute the resources. Teachers are supposedly the most important resource. Redistribute the teachers you have and nothing changes. There was not a single African-American student in my math master's [education] classes last summer. The math department at my school is made up of 16 teachers, 15 of

them are White and one of them is Hispanic. There is very little diversity to redistribute. That makes me rethink the potential existence of racist schooling practices. In Leonard's book, *Culturally Specific Pedagogy in the Mathematics Classroom* (2008), she lists five aspects of power. The fifth struck me the hardest, "those with power are frequently least aware of – or least willing to acknowledge – its existence" (p. 15). That must be me. I am as white and as middle class as they come, and the educational system worked great for me. And now I am beginning to feel the need for me to be in this CIMC course. (White male)

Vignette 7.4

If you look at who decides our curriculum, standardized tests, and pretty much everything else in education, you find middle- to upper-class white males making the majority of these decisions. I feel that sometimes our freedoms to make our class relevant are hindered by our administration/legislation forcing us to follow a set curriculum. I see the obvious reasons for having a curriculum; I, however, often feel they really just want us to teach to the test. I spend a huge majority of my time trying to make my lesson cover the standards in a way that prepares them for the test as well as have meaningful real-world relevancy. (White female)

Vignette 7.5

Teaching to students at all levels and of all different cultures, I have to find a common ground where all of my students are successful. I found that three concepts (i.e., rigor, relevance, and previous experience of successful programs) are what I bring into my classroom every day. When my students first come to my classroom, they think because I am such a young teacher it is going to be an easy class and they won't have to do much. They find out that day they are mistaken. I always try to make my lessons include constant student thinking and encourage them to question why things work the way they do. My main goal this school year has been to get kids talking, and already I can tell students are doing more of the thinking and learning from each other instead of from me. I also try to make my lessons culturally relevant by bringing in things that are happening in their world. For example, when we were working on exponential word problems, I made the problems about cell phone usage, the number of homeless animals after the flood that happened in [the community], and the number of Black Friday shoppers at Wal-Mart. Connecting these problems to relevant topics in their life made them see where exponential functions are found in the world around them and made them interested in what we were doing. (White female)

As Vignette 7.3 shows, one focal teacher realized that lack of diversity in the teacher workforce influenced classroom practices and student outcomes. However, he realized that his privilege as a White middle-class citizen afforded him opportunities that other students did not have, which led to understanding his need for the course and his participation in it. In Vignette 7.4, a second teacher understood how curriculum dictated what teachers teach and students learn. She reflected that administrative decisions and curriculum that reflected European-American culture limited the use of inclusive cultural practices (Aikenhead, 2017). In Vignette 7.5, the focal teacher provided examples of how she used real-world examples in mathematics instruction. While the examples she referenced show unique ways to present algebraic concepts, only one example draws upon culture (i.e., Black Friday shopping). In particular, it is only a cursory example of holiday shopping in American culture (Lemons-Smith, 2013). Such examples do not reveal deep understanding about diverse students' culture.

THE COMMUNITY ENGAGEMENT PROJECT

To move the teachers in the course from reading and reflecting on their teaching practices to understanding their students and realizing community assets, each teacher was required to complete a community engagement project. The projects were varied and flexible, allowing students to draw upon the richness of their specific communities. Excerpts from the same three focal teachers are presented and analyzed below.

Vignette 7.6

When I asked one of my students "What is the best thing about your neighborhood" she replied, "It is gated and secure." In most communities, this would mean that she lives in a wealthy part of town. In this case, she meant that she lives on a military base. I interviewed six students about their experiences as military children. All six have lived in at least four different cities with nine being the most. All six have lived on at least three different military bases. All six have

attended at least five different schools. When I interviewed the students about living on [the base] many started off with what “village” they lived in. I came to realize that the residential areas are arranged in villages based on soldier rank. Intrigued by the blatant segregation of soldiers and their families, I wanted to map out the different neighborhoods by rank. Just as I suspected would be the case, officer housing is segregated from enlisted housing. Furthermore, the online lists of amenities were starkly different. Enlisted amenities included two-bedroom multiplex homes with ceiling fans and washer/dryer hookups. Officer amenities included four bedroom homes equipped with porches, patios, garages, fenced backyards, sprinkler systems, and more. Is there room for social justice pedagogy here? Is it okay to question the norms of the military at a military school? Is there anything unfair about dividing up a community of soldiers by rank when all are equally willing to give their lives for their country? These questions reflect my new perspective as an educator seeking culturally relevant pedagogical inquiries. (White male)

Vignette 7.7

Doing this project turned out to be a really amazing experience for me. Not only did I get to see how different members within my community see things the same as me but also differently. Often times being a teacher, I get caught up having a one-track mindset that centers everything around the school. However, after talking with the small business owners and parents, I was reminded that our community is so much more. This project also confirmed my expectation that the school would itself be considered a main asset to our community. We provide the facilities for many community activities. We also provide a place for the community members to come together to show support for each other, from sporting events, to science fairs, to art shows. This project has really excited me ... how I can use the ideas, concerns, and thoughts from my interviewees and apply them to my classroom. The economy, small business sector, financial support, and many other ideas got me thinking of math projects I could do that involve getting out in our community. It is an opportunity to show the students how they can and will apply what they learn in school to life outside the classroom. I can connect the math to what it means for my students to be participants, donators, spenders, and possible small business owners in the future. (White female)

Vignette 7.8

For my community engagement project, I decided to walk the path that our track team runs every day for practice. This is a two-mile path that takes the students in a rectangle around our school. As I walked north leaving our high school, I came to the lunch hangout spot for students who do not have their license. The next part of my walk was mostly housing developments. Most of the houses looked similar, were rectangular in shape, and were painted a natural color. The sidewalks were filled with small groups of middle school students riding their bikes or walking home together from school. About halfway through my walk, I reached [a park]. This park has big soccer balls and footballs made of concrete. I thought these would be a perfect experiment for a geometry class. They could measure the circumference of the soccer balls and from there calculate the volume and then the weight. As I approached the school, there were lots of people outside of their apartment complex playing tennis and basketball. There were also several Somali students waiting for the city bus to take them home. From this community walk and interviewing several community members, I learned several things. I think the number one value our community has is family. There are families walking home together from school in the afternoons or high school students driving to pick up their siblings when they are out of school. (White female)

ANALYSIS OF THE COMMUNITY ENGAGEMENT PROJECT

Each of these three focal teachers revealed the importance of community in terms of housing, schools, and businesses in a written reflection of the community engagement project. In terms of housing, the first teacher discovered that discrimination existed among military families by rank. Those with higher rank and status enjoyed superior options in terms of housing and amenities. While these differences may have been put into place to reflect time and years of service, the focal teacher raised critical questions that implied his thinking about culture and privilege evolved throughout the course. However, the third teacher, while emphasizing the similarity of the homes in community and the tight family niche, neglected to acknowledge the Somalian students waiting on the city bus. Instead of riding bikes and being transported by high school siblings who were privileged with cars, the Somalians took the bus to get to

school and back each day. She learned nothing about the community that Somalian students lived in. This oversight implied that the community engagement project was one of convenience for some teachers in the CIMC course. The third teacher simply observed those who lived closest to the school and chose not to venture further out to include students who may not have had access to the resources she described. Thus, the opportunity to learn about a linguistically and culturally diverse group of students was missed. The second focal teacher interviewed two parents and two students. While her reflection focused on parent interviews, she learned from the parents and was able to view the community's resources in terms of economic development. In this way, she was able to draw upon community assets in a purposeful way.

CULTURALLY RESPONSIVE TEACHING SURVEYS

Based on Bandura's (1997) efficacy scales, Siwatu (2007) developed a survey that measured teachers' sense of efficacy related to CRT. The teacher beliefs scale, known as the Culturally Responsive Teaching Self-Efficacy Scale (CRTSE), contained 40 items. The student outcomes scale, known as the Culturally Responsive Teaching Outcome Expectancy Scale (CRTOE), consisted of 26 items. Ratings for both scales ranged from 0 to 100. Beginning teachers of mathematics enrolled in the CIMC course took the survey on a pre-post basis. While the number of participants were too few for quantitative analysis, descriptive data revealed trends and patterns as a result of taking the CIMC course (see Table 7.2).

Table 7.2 Results of Pre-Post Culturally Responsive Teaching Scores

<i>Efficacy Scale</i>	<i>Mean</i>	<i>Std. Dev.</i>
Pre-CRTSE ($n=10$)	75.9	14.5
Post-CRTSE ($n=9$)	75.3	11.7
Pre-CRTOE ($n=10$)	80.9	12.9
Post-CRTOE ($n=9$)	85.3	10.0

Survey results show this cohort of 10 students’ CRTSE scores remained constant and did not change as a result of taking the CIMC course: Pre-CRTSE ($n=10$) $M=75.9$ ($SD=14.5$); post-CRSTE ($n=9$) $M=75.3$ ($SD=11.7$). However, CRTOE scores increased by 4.39 points from pretest to posttest: Pre-CRTOE ($n=10$) $M=80.9$ ($SD=12.9$); post-CRTOE ($n=9$) $M=85.3$ ($SD=10.0$). Thus, this cohort exhibited greater change in overall outcome expectancy than personal efficacy. When survey items were disaggregated, the data revealed interesting results. Table 7.3 shows the results of efficacy beliefs and outcome expectancy-related items specific to teaching ELLs as a subgroup of students.

The CRSTE items related to ELLs revealed this cohort of teachers’ efficacy score was weakest on item #18. This item exposed these teachers’ ambivalence when it came to greeting

Table 7.3 Contrasting Pre-Post Culturally Responsive Teaching Efficacy Items on ELLs

<i>Item #</i>	<i>Pretest Score (n = 10)</i>	<i>Posttest Score (n = 9)</i>	<i>Gain Score</i>
CRTSE items			
#18 Greet ELLs for accomplishments using a phrase in their native language	49.0	51.1	2.1
#30 Model classroom tasks to enhance ELLs’ understanding of classroom tasks	64.5	53.3	(11.2)
#31 Communicate with parents of ELLs regarding their child’s achievement	89.0	85.0	(4.0)
CRTOE items			
#10 Providing ELLs with visual aids will enhance their understanding of assignments	90.5	93.3	2.8
#19 Simplifying language used during the presentation will enhance ELLs’ comprehension of the lesson	83.0	86.0	3.0
#21 Encouraging students to use their native language will help them to maintain their cultural identity	68.0	80.1	12.1

students in their native language. Nevertheless, pre-post scores on this item improved slightly after taking the CIMC course. CRTSE results indicated that these teachers may not have understood the importance of modeling tasks and communicating with parents on ELLs' academic success. Specifically, this cohort's efficacy score on item #30, which referenced modeling classroom tasks to improve ELLs' understanding, had the greatest decline from pre to post, and communication with parents, item #31, also showed a decline, though it was rated highest of the three items. However, it is unclear why the scores on these items declined. This finding, along with the small sample size and missing data (i.e., one teacher did not complete the post-test), suggests that these results should be interpreted with caution. Furthermore, the implication is that PD that focuses on academic learning for ELLs is crucial (Russell et al., 2015; Viesca et al., 2016).

The CRTOE items revealed this cohort of teachers' outcome expectancy scores improved from pretest to posttest. The greatest increase was on item #21: encouraging students to use their native language will help them to maintain their cultural identity. Interestingly, of the three CRTOE items, these teachers had the highest score ($M_{\text{post}}=93.3$) for the use of visual aids (item #10) to enhance ELLs' learning. Recall that the same teachers rated modeling to enhance ELLs' understanding of classroom tasks on the CRTSE 40 points lower ($M_{\text{post}}=53.3$). Finally, scores increased on item #19 from pre-post, indicating that teachers understood that using simplified language enhanced ELLs' comprehension of lessons. As with the CRTSE, the small sample size and missing data suggest that these results be interpreted with caution. Nevertheless, the results provide additional evidence to support the overall increase in CRTOE scores from pre to post. Still, research is needed in similar courses that include interviews or focus group sessions to understand the survey results.

Summary

In order to improve mathematics instruction in linguistically and culturally diverse classrooms, teachers must develop additive perspectives about bilingualism and culture to create safe classroom environments for ELLs and students of color to learn (Civil 2016; Nieto, 2002). Teachers can foster safe environments by greeting linguistically diverse students in their native languages and viewing the language they bring to school as additional code to support the learning of new code.

Teachers should become familiar with their students' culture and understand their values and beliefs in order to develop appropriate culturally specific examples to enhance learning in the mathematics classroom (Aikenhead, 2017). Furthermore, teachers should use simplified language to enhance linguistically and culturally diverse students' comprehension in mathematics lessons, model tasks to promote deeper understanding of mathematics, and communicate with parents regularly to report students' progress. Such practices are embedded in culturally relevant pedagogies and funds of knowledge approaches to promote equitable mathematics instruction and should be embraced by teachers of linguistically and culturally diverse students.

Chapter 7 Discussion Questions

1. How might teachers use students' prior mathematics experiences as a scaffold to engage them in deeper conceptual understandings of mathematics content and cultural relevance?
2. What multicultural children's books are currently available to teach mathematics concepts that are also culturally contextual or culturally amenable?
3. What effective teaching strategies can be used to help teachers deliver quality instruction to ELLs? How can these strategies be sustained over time?
4. What incentives can be offered to help teachers learn more about their students' communities and to use community-based assets for learning?

5. What can teacher educators do to encourage preservice and beginning teachers to use culturally specific teaching strategies and to communicate more effectively with the parents of ELLs and culturally diverse students?

Notes

1. www.wida.us/standards/eld.aspx.
2. <http://manoa.hawaii.edu/coe/crede>.

BLACK LIVES MATTER

A Context for Teaching Mathematics for Social Justice

Mathematics educators and scholars suggest using real-world problems to engage underrepresented children and youth in mathematics (Gutstein & Peterson, 2013; Leonard et al., 2010; Leonard & Evans, 2012). Issues related to gendered, racial, and/or social experiences provide opportunities to teach mathematics for empowerment (Leonard, 2009). For example, data and history may be combined to advocate for justice. From #OscarsSoWhite to #BlackLivesMatter (#BLM) to #NeverAgain, there are myriad contexts that can be used to teach mathematics for social justice. Teaching mathematics for social justice (TMfSJ) could begin with the notion of schooling and education itself.

The research presented in this chapter begins with an acknowledgment of the educational debt owed to Black and other disenfranchised Americans. The educational debt is followed by a historical overview of the voting rights era and its relevance to the current political landscape. Policies such as *Broken Windows*, *Stop-and-Frisk*, and the assault on Black bodies (i.e., Trayvon Martin, Rekia Boyd, Eric Garner, Michael Brown, Tanisha Anderson, and many others) are discussed as an introduction to an examination of the #BLM movement. Lastly, this chapter closes with a treatise on African-American firsts in mathematics and science (Journal of Blacks in Higher Education [JBHE], 2018) for without these achievements, America would not be America. Black millennials stand on the shoulders and the contributions of these great Americans who made a

difference in local, national, and global communities. Using the framework of culturally specific pedagogy, suggestions for TMfSJ will be interwoven within these contexts.

The Educational Debt

While president of the American Educational Research Association, Dr. Gloria Ladson-Billings (2006) presented research on the educational debt owed to Black and Indigenous people from historical, economic, sociological, and moral perspectives. The educational debt, much like the national debt, accumulates across time (Ladson-Billings, 2006). Beginning with the Emancipation Proclamation on January 1, 1863, and ending with the Hurricane Katrina tragedy in 2005, Ladson-Billings revealed how under-education has had a deleterious impact on multiple generations of Black and Indigenous families. Rather than recounting all of the factors impacting the lack of educational opportunity in this chapter, the educational debt is discussed from legal and historical perspectives. Discrimination lawsuits heard by the U.S. Supreme Court (e.g., *Brown v. Topeka Board of Education*) form the basis of the legal perspective. My ancestry is used as the historical context to understand the impact of disparate educational opportunities in the rural South. While Blacks had separate issues in the North with de facto segregation, that discussion is beyond the scope of this chapter.

In 1896, the *Plessy v. Ferguson* case institutionalized separate education for Black and White students in the U.S. for nearly 60 years. Although *Brown v. Board* ended de jure segregation in 1954, unfair lending practices and housing discrimination were deterrents to racial integration and, as a result, neighborhood schools remained (then and now) highly segregated by race and class (Chang, 2016; Rothstein, 2017; Taylor, 2016). Furthermore, since the 1970s, zero-tolerance policies have negatively impacted African-American students with suspensions and expulsions that have been linked to the school-to-prison pipeline (Chang, 2016; Taylor, 2016). Black boys are suspended

three times more often than White boys (Losen & Skiba, 2010), and Black girls are suspended six times more often than White girls (Morris, 2016). It is these systemic issues of segregation, discrimination, and inordinately punitive measures that contribute to unequal educational opportunities for African-American children (Davis, 2016; Ladson-Billings, 2017; Taylor, 2016).

From an educational perspective, this point is illustrated by tracing my ancestry, which I learned from DNA¹ testing is 75.6% West African, 21.8% European, 1.6% South and Southeast Asian, and 1% Other. Some of my ancestors of African descent were slaves and then sharecroppers in rural Mississippi, having been brought there from Alabama (fourth great-grandmother, Mrs. A, b. 1800), Georgia (third great-grandfather, Mr. S, b. 1805), Virginia (third great-grandfather, Mr. L, b. 1825), and South Carolina (fourth great-grandfather, Mr. W, b. 1801). However, I discovered that 1850 and 1860 U.S. Census records showed that one family of ancestors lived on 12 acres in Alabama as free Blacks. Slaves were not generally listed by individual name on the same census record as Whites until 1870. It is interesting to note the term *Mulatto* was used in the 1870 Census as the racial identification of several ancestors, who were owned by European slaveholders (and their descendants) that fought in the Revolutionary War. Thus, those who fought for freedom and liberty denied it to most of my African-American ancestors in spite of the fact that some of these ancestors were also their progeny. Genealogy research revealed that five generations of my maternal African-American ancestors lived in Oktibbeha County, Mississippi. Beginning with my maternal grandmother, Lou Ellen (pseudonym), these generations are shown in Figure 8.1 below.

Census records further revealed that none of Lou Ellen's great-grandparents could read or write. Their illiteracy was not surprising given they were born prior to 1865 and were most likely slaves on small farms or larger plantations in Oktibbeha County, Mississippi. The laws in Mississippi and other states

Figure 8.1 Hamilton Ancestry.

throughout the South, prohibited slaves from learning to read and write (JBHE, 2018; Ladson-Billings, 2006). In the next generation, two of Lou Ellen's grandparents could read, and two could read and write. One generation removed from slavery, Lou Ellen's parents had meager educational opportunities. Her parents could read, but only her mother could write. Lou Ellen and her two sisters attended a segregated elementary school in their community in Oktibbeha County. They were the first in the maternal line to complete elementary school through seventh grade, though they were unable to matriculate beyond that point. In the rural South, there were few high schools for Blacks in their own communities, which limited their opportunities to pursue higher education (Siddle-Walker, 2000).

In terms of work, most of my ancestors worked in agriculture until the early to mid-twentieth century when a phenomenon known as the great migration occurred (Wilkerson, 2010). Between 1916 and 1970, six million Blacks moved from the rural South to the industrialized North (Morris & Monroe, 2009). Several of my family members, including two uncles,

migrated from Mississippi to Missouri in the 1930s. One uncle was employed in the steel industry after learning a trade. Census records revealed the second uncle attended high school through the tenth grade. He later became a successful businessman and purchased his own home. When my grandmother, Lou Ellen, migrated to Missouri in the 1940s, she worked for that uncle until she could receive additional job training (Leonard, Walker, Cloud, & Joseph, 2017). As a result of my ancestors' determination to leave the South and move to the Midwest in search of a better life, my siblings and I were the first to receive a K–12 education outside of the rural South. Yet, we attended de facto segregated schools in Missouri.

To put our lives in context, a 110-year timeline (see Table 8.1) shows significant educational events and other achievements for Blacks in America (from 1870 to 1980) alongside annotations for my maternal ancestors, including my brother and me. From this timeline, one can see the steady progress Blacks have made in educational attainment as well as their contributions to American society. Although 2,000 Blacks had attained college degrees in 1900, this was only 0.0002% of the 8.8 million Blacks living in America at the time (U.S. Department of Commerce, 1993). Thus, the educational debt owed to Blacks who lived in the South with limited access to public high schools in the 1930s and 1940s is enormous. This is also true for those who were denied access to public universities until the 1960s.

Historically Black Colleges and Universities (HBCUs), like Alcorn State University and Rusk University, were the primary means for obtaining a college education for most Blacks in Mississippi prior to *Brown v. Board* in 1954. According to my mother, who lived in Starkville, Mississippi, until 1956, "Blacks were not allowed to step foot on the grounds at Mississippi State University." Fortunate to be born after the *Brown v. Board* ruling, I was the first female in my immediate family to graduate from high school and the first to graduate from college in 1981. My younger brother was the first male to receive a bachelor's

degree in engineering in 1982. Yet, every relative who was a sharecropper mattered. They cherished their children and provided stable family units. Without their tenacity, strong educational values, and financial and emotional support, I would not have earned a PhD in curriculum and instruction with a focus on mathematics education from the University of Maryland in 1997. The foregoing legal and historical analyses illustrate Ladson-Billings's construct of the educational debt and provide evidence that lack of educational opportunity, rather than race, class, or culture, adversely influences academic success (Ladson-Billings, 2017).

As I observed when I taught in public schools, tracing one's ancestry is a culturally specific activity that middle school students are interested in and willing to research (Leonard, 2004). From a mathematics perspective, a family tree illustrates a natural pattern of base two. As the family tree grows beyond direct ancestors to include uncles, aunts, and cousins, the number of family members increases exponentially. Thus, a connection to algebra can easily be made with ancestry. In addition to building a family tree, students may collect data on educational attainment, occupation, age of marriage, and number of children. Furthermore, a timeline that aligns with the birth of students' ancestors to historical events in America puts their lives in perspective. Thus, students can learn how educational opportunity and historical events impacted their lives.

Voting Rights

According to the documentary *Eyes on the Prize: America's Civil Rights Years* (Hampton, 2010), the right to vote was the ultimate symbol of freedom for Blacks in America. Voting records on the paternal side of my family revealed a former slave registered to vote in 1867 in the state of Alabama. Yet, exercising the right to vote in the South was particularly challenging due to poll taxes, literacy tests, and other forms of intimidation and violence. According to a letter² written by Booker T. Washington to W. E. B. DuBois on January 27, 1904, Blacks in Alabama were

Table 8.1 Chronology of Significant Educational Events and Other Achievements of Blacks in America: Decades View 1870 to 1980

<i>Decade</i>	<i>Selected Events for Blacks in Higher Education¹</i>	<i>Birth of Author's Ancestors</i>
1870s	Twenty-two HBCUs in existence; Richard Theodore Greener first Black student to graduate from Harvard; James Webster first Black student admitted to West Point	Great-great-grandparents are sharecroppers in Mississippi
1880s	Forty-five HBCUs in existence, Spelman College (first HBCU for women) and Tuskegee Institute founded, 1881	Great-grandfather Mr. J. W. born
1890s	Sixty-four HBCUs in existence; Ida Gray first Black woman to earn a degree in dentistry from University of Michigan, 1890; W. E. B. DuBois first Black to earn a Ph.D. in history from Harvard, 1895; <i>Plessy v. Ferguson</i> —U.S. Supreme Court established separate but equal doctrine, 1896	Great-grandmother Mrs. W born
1900s	Seventy-eight HBCUs in existence; 2,000 Blacks earned college degrees, 390 from predominantly White institutions	
1910s	Julian Herman Lewis first Black Ph.D. in physiology, University of Chicago, 1915; St. Elmo Brady first Black doctorate in Chemistry, University of Illinois, 1916	Great-great uncle Mann Hamilton is lynched in 1912 Grandmother born in this decade (completed grade seven)
1920s	Eva B. Dykes (Radcliffe College), Sadie T. Mossell Alexander (University of Pennsylvania) and Georgiana R. Simpson (University of Chicago) first Black women to earn doctorates	
1930s	One hundred seventeen HBCUs in existence, 1932; George Maceo Jones first Black Ph.D. in civil engineering, University of Michigan, 1934; Maryland Court of Appeals rules University of Maryland Law School must admit Blacks, 1936	Mother born in this decade (completed grade 10); uncles migrate to Missouri

1940s	Marguerite Thomas Williams first Black Ph.D. in geology, Catholic University, 1942; Adelaide Cromwell first Black faculty member at highly selective liberal arts college (Smith College); W. Allison Davis first Black tenured professor, University of Chicago, 1947	Grandmother migrates to Missouri
1950s	Joseph T. Gier, engineering professor at UCLA, second Black faculty member tenured at PWI, 1952; Howard Thurmann first Black dean at PWI (Boston University), 1953; <i>Brown v. Topeka Board of Education</i> , 1954; Autherine Lucy first Black admitted to University of Alabama, 1956 (suspended and then expelled)	Mother migrates to Missouri; author born in Missouri during this decade
1960s	Four North Carolina A&T Black students hold sit-ins at lunch counters at F. W. Woolworth in Greensboro, 1960; Charlayne Holmes and James Hunter first Black students at the University of Georgia, 1961; James Meredith first Black graduate from the University of Mississippi, 1963; Vivian Malone first Black graduate from University of Alabama, 1965	Author attends de facto segregated school in Missouri
1970s	Black students at Jackson State University in Mississippi protest racial injustice (two deaths and 12 injuries), 1970; Eileen J. Southern first Black woman tenured as professor at Harvard, 1975; <i>Regents of the University of California v. Bakke</i> ruled on race and college admission, 1978; Sir Arthur Lewis, Black economics professor at Princeton, wins first Nobel Prize in economics, 1979	Author graduates from high school and attends Boston University
1980s	Federal government sues the state of Alabama in an effort to desegregate the system of higher education, 1983. Sylvia A. Boone becomes the first Black woman to become a tenured professor at Yale University, 1988	Author graduates with BA in Education, St. Louis University; Author's brother graduates with BS in chemical engineering, Washington University in St. Louis

Note

1 Source: Archives, Journal of Blacks in Higher Education (2018).

admonished to pay the poll tax by the February 1 deadline in order to vote. According to the Smithsonian Institute, the poll tax was highly effective in preventing Blacks from voting, as illustrated by the decline in the number of Blacks registered to vote in Louisiana from 130,000 in 1896 to 1,342 in 1904. A receipt from the Smithsonian archives revealed that the poll tax was \$2.50 (see Figure 8.2), while wages for farm labor were approximately \$11.76 per month in Alabama in 1895.³ Thus, the poll tax was roughly equivalent to one week's work for a sharecropper in Alabama. This unjust and unconstitutional hindrance effectively supported a hegemonic and racist system of bigotry and discrimination that disenfranchised and subjugated Black people in America. Remarkably, Booker T. Washington, who communicated regularly with Theodore Roosevelt from 1901 to 1917 and received a \$600,000 grant (worth \$14,724,772 in January 2018) from Andrew Carnegie in 1915,⁴ was out of touch when he suggested that Blacks simply pay the tax.

Selma, Alabama, became the major focal point in the struggle for voting rights in the South. In 1965, less than 1% of Blacks in Selma (Dallas County, Alabama) were registered to vote even though they made up more than half the population. Dr. Martin Luther King Jr. and the Student Nonviolent

No. 838 Birmingham, Ala. 4/9 1896

Received of J. M. Giville (Col.) (White.)

the sum of \$2.50 Dollars

in full of amount of Poll Tax for the year 1895.

Poll Tax,	2.50
Assessor's Fee,	.50
Collector's Fee,	.50

P. T. C.

Figure 8.2 Sample Poll Tax Receipt 1895.⁵

Coordinating Committee (SNCC), which was founded by Ella Baker, sponsored events that brought national attention to the voting rights issue in Selma. As a result, five marches took place in Dallas County, Alabama, that changed the course of history and illustrated the power of solidarity and nonviolent civil disobedience. The first march, on January 22, 1965, included 105 local school teachers who protested the arrest of a prominent citizen in Selma. When police refused to arrest the teachers, they marched to Brown Chapel African Methodist Episcopal (AME) Church, which became the epicenter of the movement. A second march took place at night in the nearby town of Marion on February 26, 1965. During the march, Jimmy Lee Jackson, a deacon in the Baptist church and civil rights activist, was shot and killed by an Alabama state trooper. In response to his death, the community planned to march from Selma to the state capitol in Montgomery. This march, which began at Brown Chapel AME on March 7, 1965, became known as Bloody Sunday. As more than 600 peaceful marchers descended across the Edmond Pettus Bridge, state troopers attacked them with tear gas, billy clubs, and whips. Mrs. Amelia Boynton and Mr. John Lewis (who is currently a U.S. representative from Georgia) were among the injured as a result of this attack on Black citizens. The scene was televised nationwide, effectively expanding the movement from voting rights to human rights.

After Bloody Sunday, SNCC wanted to march again the following Tuesday. More than 450 clergy came to Selma to participate in the next march, on March 9, 1965, which grew to more than 2,000 participants. As Rev. Ralph Abernathy prayed for direction on the Pettus Bridge, Dr. King and others turned around and went back to Brown Chapel because they feared there would be additional violence. However, on March 21, 1965, a final march was sanctioned by a judge and supported by federalized troops. Participants included not only Martin Luther King, Coretta Scott King, Andrew Young, Ralph Abernathy, and John Lewis but also actor Harry Belafonte, singers Joan Baez and Tony Bennett, and thousands of working-class Blacks and

sympathetic Whites. The event peaked with 25,000 marchers from Selma to Montgomery. Though lives were lost, including Rev. James Reeb and Ms. Viola Luizzo, the efforts in Selma were not in vain. Five months later, 9,000 Blacks registered to vote in Alabama after the Voting Rights Act was signed by President Lyndon B. Johnson on August 6, 1965.

On March 7, 2015, thousands returned to Selma to commemorate the passage of 50 years since the signing of the Voting Rights Act in 1965 and to remember the heroism and courage of those who participated in the movement. Speeches from dignitaries, including President Barack Obama, took place on the Pettus Bridge. Ten days later, I took a trip to Tuskegee University to discuss a future National Science Foundation project with colleagues in the College of Engineering. While I was in the area, I visited Selma and Montgomery. Selma was relatively quiet. There were few signs—except for a church marquee announcing the name of a prominent minister as a guest speaker—that there had been a huge rally in Selma the week before. The historic Brown Chapel AME Church sat in the center of an urban housing project. Most notably, despite the attention that had been given to their struggle, the economic conditions of Blacks in Selma appeared relatively unchanged in the 50 years since the historic march. More recently, new ways of disenfranchising voters have emerged.

Since the historic election in 2008, where more than 64% of Blacks cast their vote for President Barack Obama, the harsh reality is that “5.8 million Americans are prevented from voting because of a prior felony conviction, including more than 2 million formerly incarcerated African Americans” (Taylor, 2016, p. 16). In addition to incarceration, voter suppression efforts began in 2012 as a backlash to Obama’s election. Requirements, such as voter identification, were instituted to suppress the vote in poor communities and communities of color. While judges blocked voter suppression laws in Pennsylvania and South Carolina before the 2012 election, voter identification requirements remained in effect in Kansas, Indiana,

New Hampshire, Tennessee, and Georgia (Bronner, 2012). According to the Brennan Law Center:

*In the first analysis of its kind in 2018, the Brennan Center's Voting Laws Roundup shows that lawmakers in eight states have introduced at least 16 bills making it harder to vote, and 35 restrictive bills in 14 states have carried over from previous legislative sessions. If passed, the laws would increase restrictions on voter registration and limit early and absentee voting opportunities, among other changes.*⁶

In addition to voter suppression, Republican-controlled legislatures in several states, including Pennsylvania, Maryland, and Wisconsin, used 2010 Census data to revamp voting districts, which resulted in gerrymandering to elect more Republicans to state and national offices (Associated Press, 2018). In January 2018, the Pennsylvania Supreme Court ruled the state's congressional map unconstitutional (Associated Press, 2018). The decision was upheld by the U.S. Supreme Court. Despite America's long and bloody history on voting rights, suppression continues to impact persons of color (Austin, Cardwell, Kennedy, & Spencer, 2016).

Yet, the power of the vote was illuminated in the 2017 state election in Virginia, which resulted in a tie that literally led to a lottery-style drawing to decide who won (Simpson, 2018). Furthermore, Black female voters helped to elect an Alabama Democratic candidate, Doug Jones, to the U.S. Senate in a special election in 2017 to replace Attorney General Jeff Sessions (Fausset & Robertson, 2017). These and other examples show that the importance of the voting process cannot be understated, as literally every vote counts.

The history of voting rights in the United States provides a strong context for teaching mathematics concepts. Mathematics lessons can be blended with social studies to help K–12 students learn and understand our voting history. Stevens and Stevens (2016) developed a mathematics lesson about the

electoral process. They used M&Ms and Skittles to help high school students understand data and statistics through candy elections. Such activities can be used to not only help students understand elections but the voting process as well.

Black Lives Matter

The tragic death of Trayvon Martin in February 2012 left Black America numb. Trayvon was an unarmed 17-year-old boy,⁷ who seemingly did nothing to provoke the encounter with George Zimmerman, who pursued him even after police told him not to do so. Subsequently, a trial based on what many people considered an open-and-shut case turned into a circus in which the victim was characterized as the aggressor. There were three decisions the jury could have reached—guilty of second-degree murder (the actual charge), guilty of manslaughter, or not guilty. Many people expected at least a manslaughter conviction. In the case of Trayvon Martin, justice was not served, as the jury returned a verdict of “not guilty” against George Zimmerman. In response to that verdict, three women—Patrisse Cullors, Opal Tometi, and Alicia Garza—created the hashtag #BlackLivesMatter (Taylor, 2016). After the grand jury in St. Louis County, Missouri, decided not to indict Darren Wilson on November 24, 2014, for the death of Michael Brown in Ferguson, Missouri, the hashtag became a movement (Chang, 2016; Taylor, 2016). With the deaths of Tamir Rice in Cleveland and Eric Garner in Staten Island, patience with the criminal justice system ran out, and anger that had been simmering for years erupted into a national outcry over the blatant inequities of the U.S. judicial system.

Although state violence in the form of police shootings has been a fact of life for Black America, the image of Michael Brown, a young, unarmed Black man shot multiple times, even as his hands were raised, and his body left in the street could not be reconciled. Within a few months, “thousands of college, high school, and even middle school students began organizing and participating in die-ins, walkouts, marches, and other forms

of public protest” (Taylor, 2016, p. 173). Congressional aides protested in Washington, DC, too. In December 2014, there was a protest and die-in at the University of Wyoming, where I worked. I listened to student and faculty speeches and then marched with about 100 others and participated in a die-in. However, our work did not stop there.

Although I was living and working in Wyoming, the death of Michael Brown near my hometown of St. Louis was surreal. The expletives allegedly uttered by Officer Darren Wilson to Michael Brown and his friend to get out of the street were familiar as I recalled my own negative encounters with St. Louis police officers when I was a teenager in the 1970s. In response, I called on three female colleagues who met with me to address diversity issues at the University of Wyoming. As a result of this meeting, a grassroots organization called the Committee on Women and People of Color (CoWPoC) was formed. This group met with university administrators and Department of Justice staff in Denver, Colorado, to initiate the hiring of a chief diversity officer. In addition, the committee—which consisted of faculty, staff, and students—sponsored several events, including distinguished speaker events and banquets to recognize teaching, research, and service among diverse faculty, staff, students, and community members.

#BLM is not simply about police brutality. It uses the decentralized leadership and local chapter organizing methods of the 2011 Occupy movement to speak to all issues related to human dignity while asserting the value of Black life (Taylor, 2016). The issues of racial profiling, health and wellness, water quality, and equal housing are among the issues included in their platform. These issues, like those discussed previously, can provide a potent backdrop for teaching mathematics for cultural relevance and social justice.

Racial Profiling

Teachers of mathematics can build student awareness of #BLM by using data collected on traffic stops as well as policies like

Broken Windows and *Stop-and-Frisk*. *Broken Windows*, or “order maintenance policing,” began as a law enforcement policy in New York City in the late 1990s (Hill, 2016, p. 41). This policy focused on petty crimes, which law enforcement officers believed would lead to large-scale crimes (Hill, 2016). *Stop-and-Frisk* tactics (ruled unconstitutional in 2013) were used to stop, question, and frisk individuals suspected of a crime. In New York City, there were more than 4.4 million stops from 2004 to 2012, but those who were stopped most often were Black (50%) and Latinx (30%) (Hill, 2016). *Stop-and-Frisk* was also used in Los Angeles, California, with even greater frequency.

Himmelstein (2013) developed a mathematics lesson that used *Stop-and-Frisk* as the basis for learning about central tendency. Students compared stops in different boroughs in New York City and created histograms and box-and-whiskers plots to examine the number and the percentage of stops for different racial groups in proportion to their representation within the general population. Such mathematics exercises provide high school students with the opportunity to engage in quantitative as well as qualitative data as they match data to their personal experiences in culturally specific ways. Notably, the data revealed that Black and Latinx citizens had the highest number of stops, but White and Latinx citizens had the highest percentage of stops in 2010.

Similarly, Gutstein (2013) presented the mathematics lesson “*Driving While Black or Brown*” to his middle school students in Chicago, Illinois. Based on demographics for Chicago, students used probability with colored cubes to explore what the percentage of traffic stops should be for people of four different ethnic backgrounds (African-American, White, Latinx, and Asian). Students then compared the actual number and percentage of traffic stops by ethnicity. Teachers in other towns and cities may encourage students to collect similar forms of data. Findings, such as those in Ferguson, revealed that 95% of traffic stops involved Black drivers (Hill, 2016). These data can be used as evidence of racial profiling.

In August 2014, I was pulled over by local police on a residential street in Laramie, Wyoming. The White policeman, who was wearing a bodycam, stated I was speeding and that he clocked me going 11 miles over the speed limit. I replied, "I do not think I was going that fast." The officer went to his car to check my license and insurance. When he returned, he asked if I was from Laramie. I replied, "I live right around the corner, and I believe you pulled me over because of my race." Surprised by my response, he denied racial profiling and stated he was giving me a ticket for speeding, but I had a discount for wearing my seatbelt. I responded, "I will see you in court!" Two months later there was a court hearing. To prepare for the hearing, I recalled that I had a receipt from the local Walmart for cleaning items. The receipt showed the time I left the store, and the ticket showed the time I was pulled over. The elapsed time was about 10 minutes, which was four minutes longer than the six minutes MapQuest determined it would take me to get home. I used this evidence to challenge the ticket. The district attorney objected to this evidence, stating that we could not be sure Walmart cash registers kept the correct time. However, the rate problem itself was flawed (Wu, 2014).

Like most textbook mathematics problem, the rate problem described above assumed I was traveling at a constant speed rather than an average speed. Even if I had been traveling slower initially on the route home from Walmart, I could have in fact been speeding on the portion of the route where I was stopped by the policeman. Furthermore, the time it took to make a left turn out of the Walmart parking lot and the number of red lights encountered were variables that ticked the time away. Nevertheless, using the rate problem ($\text{rate} = \text{distance} / \text{time}$) was an effective argument because it caused the judge and the district attorney to think more deeply about my racial profiling claim.

The officer used video from his dashcam and data from the radar gun as evidence of speeding. I pointed out that the video also showed the officer raising the radar gun after I passed him

in my car. I asked the officer if he pulled me over because I was Black or because I was speeding. The district attorney, of course, objected to this question. I rephrased by asking the officer if he pulled me over because he saw *me* driving or because *I was speeding*. Of course, the response was the latter, but the judge, who was a woman, gave some thought to my argument. However, because there was no proof that the radar gun had malfunctioned, the judge ruled in favor of the officer and upheld the fine. Nevertheless, the judge stopped the proceedings and did not hear the next case until she had spoken with the officer. I believe she warned the officer about racial profiling. Subsequently, while I had the right to appeal the judge's decision, I decided to pay the fine to move on with my life.

In May 2015, however, I was absolved of liability for a parking violation. I was fined for parking in a handicapped space even though I had a temporary handicapped decal that was issued by the University of Wyoming. The officer had just placed the ticket on my windshield when I returned to my car after attending a meeting. Hobbling with an orthopedic shoe, I asked the officer why I was ticketed. The White male officer said the parking space was reserved for handicapped decals issued by the state but not the university. My disadvantage was not knowing the difference between the types of handicapped signs on the campus. My argument in this particular instance was sound, however, because there was no way of knowing which handicapped signs applied to my decal. The order for dismissal of the citation read: "dismissed as it is in the best interests of justice."

The foregoing mathematics lessons and personal accounts may be used to engage students in problem solving, reasoning, and logic to make mathematical arguments (Gutstein, 2013; Himmelstein, 2013). Students in middle and high school should be encouraged by these examples to consider how they might use mathematics for social justice to resist racial profiling and other forms of state oppression.

“I Can’t Breathe!”

In addition to racial profiling, #BLM brought state violence and public health to the forefront of American consciousness with protests over the death of Eric Garner in Staten Island, New York, in July 2014. Mr. Garner was confronted by two White police officers, Justin Damico and Daniel Pantaleo, for selling loose cigarettes (Hill, 2016). When he refused to comply with their instructions, he was put in a choke hold and thrown to the concrete sidewalk with his head pinned to the ground (Hill, 2016). Cell phone footage revealed that Eric Garner repeated the phrase “I can’t breathe!” 11 times before losing consciousness. For #BLM, his death (as well as the death of his daughter in December 2017) threatened the right to thrive (Austin, Cardwell, Kennedy, & Spencer, 2016). Thus, public health and attention to environmental hazards that inhibit air quality become a basis for TMfSJ.

Prior to the #BLM, Akom (2011) linked educational outcomes to community health issues, specifically those related to the presence of lead and asbestos in housing units and the presence of polychlorinated biphenyl (PCB)—a toxic organic pollutant—in poor communities. He examined the relationships between race, space, place, and waste in what he called eco-apartheid. Akom (2011) concluded that “health disparities have led to the disproportionate exposure of Black people/people of color to the effects of concentrated poverty,” and he linked environmental hazards (i.e., lead and asbestos) to “depressed academic performance” (p. 833). Akom inspired youth to study these links by using the Geographic Information System (GIS) and ground-trooping (i.e., collecting evidence on the ground) to obtain data on biohazards in an effort to increase community awareness and advocate for environmental justice. Data can also be collected on the Air Quality Index (AQI) in specific communities. The Environmental Protection Agency (EPA) has a website that students can use to assess real-time AQI data by zip code.⁸ For example, the site showed that

Camden County, New Jersey, had a moderate air quality rating of 58 at 12:00am on January 29, 2018. Thus, teaching mathematics for environmental justice can motivate students to learn while providing them with lifelong skills that have a direct bearing on community health.

Flint Water Crisis

Public health is dependent upon clean water and healthy food supplies. The predominantly Black community of Flint, Michigan, with more than 40% of its residents living in poverty, suffered exposure to massive amounts of lead from old lead pipes that contaminated the drinking water in August 2014 (Hill, 2016, Oosting, 2016). The toxic levels of lead that thousands of children in Flint were exposed to is incalculable, revealing to the nation and the world the injustices that poor urban communities continue to endure (Hill, 2016). Michigan State University (MSU) colleagues implemented a mathematics program in Flint to address some of the educational inequities that exist there. The Access, Agency, and Allies in Mathematical Systems (A3IMS) project used a practice-based model of professional development that focused on creating systemic reforms through collaborative communities in which mathematics teacher educators, mathematics teachers, and students worked together to support opportunities to learn (Larnell et al., 2016). Teachers, with the help of graduate students at MSU, used the Flint water crisis to develop a mathematics lesson for second-grade students to determine the amount of bottled water the class needed each day (Plumb, Roberts-Caudle, Harper, & Jones, 2017). Rather than shying away from topics like these, the lesson revealed that young children have the capacity to investigate and learn from real-world complexities, such as water quality, that impact their lives (Plumb et al., 2017).

Housing Inequality

In 1968, the Fair Housing Act was passed to end discrimination against African-Americans and other underrepresented groups

in housing, but ongoing residential segregation, which has an impact on the racial demographics of neighborhood schools, persists (Rothstein, 2017). Investigations into housing practices revealed “restrictive covenants on real estate and the proliferation of community-destroying interstate highways to create geographic barriers between whites and blacks” contributed to school segregation (Ladson-Billings, 2017, p. 83). Housing developments (i.e., Levittown, New York) favored working-class White veterans who were able to accumulate wealth through homeownership over time (Ladson-Billings, 2017; Rothstein, 2017), while subprime loans eliminated wealth for many Black homeowners during the 2007 economic downturn (Taylor, 2016). For example, in Levittown, New York, homes that originally sold for \$6,000 in the 1950s were worth more than \$500,000 in 2017. In comparison, the New Jersey townhome that I purchased in July 2003 for \$212,500 was worth \$167,200⁹ in July 2018. Negative equity and foreclosures erased most of the wealth that Black families accumulated in their homes during the 2007 housing market bust (Taylor, 2016). These lower values have also had an impact on school funding, which continues to be supported by residential property taxes (Ladson-Billings, 2006). Lower property taxes mean lower revenue for school improvements and teacher salaries. Lower revenues limit the school district’s ability to provide adequate curricular resources and to recruit and retain high-quality teachers. Thus, a cyclical pattern (i.e., segregated housing, inexperienced teachers, failing schools, etc.) is created that contributes to structural inequities and educational disparities (Ladson-Billings, 2017).

Mathematics lessons that investigate instances of race-based discrimination in home buying, such as *“Home Buying While Brown or Black”* (Gutstein, 2013), have examined data on mortgages. In one lesson on fractions and percentages, middle school students discovered that African-Americans in Chicago were five times more likely to be rejected for mortgages than Whites, and Hispanics were three times more likely to be

rejected for mortgages than Whites. Middle school students (Gutstein, 2013), as well as teacher candidates (White, Crespo, & Civil, 2016), have debated whether such practices are racist. To address their concerns, additional mortgage data in myriad communities across different populations are needed to assess the impact of mortgage lending practices at different periods throughout U.S. history.

As the Levittown example revealed, families can accumulate wealth through home buying. Yet, declining property values, foreclosures, gentrification, and other factors have limited the accumulation of wealth for many Black and Brown families (Taylor, 2016). Studying these patterns, as well as learning about mortgages and interest rates, provides middle and high school students with opportunities to learn mathematics for empowerment.

Black Firsts in Science and Mathematics

#BlackLivesMatter is a movement of grassroots activists that want to promote life and wellness in the Black community. Thus, any discussion of the movement is incomplete without the acknowledgment of Black men and women throughout history who have made significant contributions to society at large. In 2009, the U.S. Department of Education reported that 4.5 million African-Americans living today have earned undergraduate degrees and 100,000 (i.e., 0.026% of the population) have earned doctoral degrees. In 2010, the National Science Foundation reported that 2,221 African-Americans had earned doctorates, which was more than any single previous year. Furthermore, African-Americans continue to break barriers. Like the women in *Hidden Figures* (Shetterly, 2016), there are numerous African-Americans in the fields of science, technology, engineering, mathematics (collectively referred to as STEM disciplines), medicine, and education. Yet, many of their accomplishments and successes have been overlooked or obscured by the passage of time. Learning about Black firsts reinforces the concept that teaching is a

political act (Ladson-Billings, 2009). The stories of six men and women who were first or early to make a difference in some of these fields are recounted below.

St. Elmo Brady (1884–1966)

Born in Louisville, Kentucky, Dr. Brady was a graduate of Fisk University in Nashville, Tennessee, and the first African-American to earn a doctorate in chemistry (University of Illinois) in 1916.¹⁰ He worked with Dr. George Washington Carver at Tuskegee Institute in Alabama and headed chemistry departments at Howard University (Washington, DC) and Fisk University. He contributed to research on the chemistry of polynuclear hydrocarbons and organic medicinals at Fisk University where he retired in 1952. He also established a chemistry department at Tugaloo College in Mississippi after he retired from Fisk.

Martha Euphemia Lofton Haynes (1890–1980)

Born in Washington, DC, Euphemia Lofton Haynes was a graduate of Smith College (Massachusetts) and in 1943 the first African-American woman to receive a PhD (Catholic University of America, Washington, DC) in mathematics. She was an educator who taught in the Washington, DC, public schools for 47 years. She taught mathematics at Armstrong High School and Dunbar High School, where she also served as chair of the Mathematics Department.¹¹ After retiring from the school system in 1959, Dr. Haynes established the mathematics department at Miner's Teacher College (renamed the University of the District of Columbia).

Bessie Blount (1914–2009)

Born in Hickory (i.e., Chesapeake), Virginia, Mrs. Bessie Blount Griffin was a physical therapist who patented two inventions to help disabled WWII veterans who were amputees—the feeding tube and the disposable emesis basin. The Veterans Administration was not interested in her inventions. As a result, the feeding tube patent was donated to France and used in French

hospitals, and the patent for the basin was sold to Belgium, where it is still used in hospitals today.¹² Later, when she was about 55 years old, Bessie Blount went into law enforcement and became a forensic scientist. In 1977, she became the first African-American woman at Scotland Yard in England.¹³

Ed Dwight (1933–)

Ed Dwight was selected by the Kennedy administration as the first African-American astronaut candidate in the U.S. Born in Kansas City, Kansas, he graduated with a degree in aeronautical engineering from Arizona State University. Mr. Dwight served as an Air Force test pilot, achieving the rank of captain.¹⁴ Today, Mr. Dwight lives in Denver, Colorado, and is renowned as a sculptor. He was honored with a lifetime achievement award at the University of Wyoming in 2015.

Jessie Eugene Russell (1948–)

Born in Nashville, Tennessee, Mr. Russell majored in electrical engineering and graduated from Tennessee State University in 1972. He is known as the father of the cell phone. Having worked for Bell Laboratories, Mr. Russell patented and continues to invent technology related to broadband wireless networks, technologies and services, commonly known as 4G.¹⁵ Presently, Mr. Russell is the chairman and CEO of incNETWORKS in New Jersey.

Aprille Ericsson-Jackson (1963–)

Born in Brooklyn, New York, in 1995 Dr. Ericsson-Jackson became the first African-American woman to earn a doctoral degree in mechanical engineering (Howard University). After completing a master's degree at Howard in 1991 and a bachelor's degree in aeronautical/astronautical engineering from the Massachusetts Institute of Technology in 1986 (Goad, 2016), she began a career as an engineer at NASA Goddard (Maryland) in 1992. Dr. Ericsson-Jackson is also the first African-American woman at this agency with a doctoral degree in mechanical engineering.

Summary

While the #BLM movement began as a reaction to state violence against people of color, it has grown to be so much more. Quality of life in health, housing, education, and labor have become focal points in #BLM. Data provide evidence for conducting research on myriad topics that middle and high school students will eagerly engage in during mathematics classes. They would be surprised to learn that on March 2, 1955, in Montgomery, Alabama, a 15-year-old student named Claudette Colvin was the first African-American to be arrested for refusing to give her bus seat to a White woman. Although her story is obscure, she was a pivotal witness in *Browder v. Gayle* in 1956 (Hoose, 2009). In examining the history of topics from voting rights to the election process and from wages to mortgages, the sky is the limit for what underrepresented students can learn about empowerment and the struggle for social justice using mathematics as the basis. However, teachers should be sensitive to marginalized students' emotional and psychological well-being when discussing social justice topics, and teachers should be flexible in regard to the choice of topics to ensure that students have a safe space to voice their opinions and concerns.

African-Americans are brilliant, as the snapshots of scholars listed above have shown (Leonard & Martin, 2013). African-Americans have made numerous contributions to social and scientific communities that include original American music (e.g., gospel, blues, and hip-hop) and notable STEM contributions. K–12 teachers who wish to teach mathematics for social justice (TMfSJ) can shed light on these achievements as they engage in culturally specific pedagogy.

Chapter 8 Discussion Questions

1. What arguments can teachers use to justify the importance of teaching mathematics for social justice to K–12 students?

2. What strategies can teachers use when students (i.e., Gutstein's mathematics classroom in Chicago) fail to see discrimination in housing or some other set of data?
3. How can teachers help students realize that #BLM does not mean that other life is not valued?
4. Given that teaching is a political act, how might teachers support students' efforts to engage in social activism?

Notes

1. DNA results obtained from 23andme.
2. Fisk University, John Hope and Aurelia E. Franklin Library, Special Collections, St. Elmo Brady Collection.
3. Miscellaneous Series Bulletin, Volume, 7; Volume 9–23 (U.S. Printing 1893).
4. Fisk University, John Hope and Aurelia E. Franklin Library, Special Collections, St. Elmo Brady Collection.
5. Division of Political History, National Museum of American History, Smithsonian Institution.
6. www.commondreams.org/newswire/2018/01/22/new-analysis-voter-suppression-laws-concern-2018-though-many-states-looking.
7. The notion that he was a child is significant since there is evidence that Black children are often pathologized and tried as adults in the criminal justice system.
8. https://airnow.gov/index.cfm?action=airnow.local_city&zipcode=08081&submit=Go.
9. Data obtained from Zillow.com.
10. <https://chemistry.illinois.edu/node/193>.
11. www.biography.com/people/euphemia-lofton-haynes-21465777.
12. <https://americacomesalive.com/2016/02/11/bessie-blount-griffin-physical-therapist-and-inventor>.
13. www.myblackhistory.net/Bessie_Blount.htm.
14. https://en.wikipedia.org/wiki/Ed_Dwight.
15. <http://blackinhistory.tumblr.com/post/76170627429/jesse-eugene-russell-#.WnToboJG2t9>.

RACE AND ACHIEVEMENT IN MATHEMATICS

A Historical Perspective

The underachievement of students of color, African-American students in particular, has a long history and continues to give credence to a great deal of research. From a theory of lower intelligence, such as that proposed in the *Bell Curve* (Herrnstein & Murray, 1994), to cultural deficit theory (Coleman, 1987; Jensen, 1969), some have tried to explain achievement differences among students of color in negative terms. Others have examined social conditions such as poverty (Knapp, 1995; Kozol, 1995), inequitable school funding (Imazeki & Reschovsky, 2006; Kozol, 1991), and low teacher expectations (Irvine, 1991; Rist, 1970) as factors that contribute to underachievement. In addition, Black scholars like Boykin and Toms (1985) have described the influence of cultural differences on Blacks' enculturation and assimilation in school. More recently, it has been argued that some African-American students are disengaged because of sociohistorical, community, school, and individual factors (Martin, 2000, 2003; Ogbu, 2003). Needless to say, underachievement among students of color is complex and undeniably rooted in a system of inadequate schooling (Ladson-Billings, 2006; Evans & Leonard, 2013).

After slavery was abolished in 1863, public schools were established to educate Blacks throughout the South (Du Bois, 1995). However, these *sharecropper* schools were inferior in terms of facilities and resources (Du Bois, 1995; Moses & Cobb, 2001). When the *Plessy v. Ferguson* case was brought forth to challenge segregation, the U.S. Supreme Court ruled in 1896 that *separate*

but equal accommodations were constitutional. For 58 years, this ruling was applied to segregate Blacks from Whites in housing, schooling, churches, transportation, and most public places. Accordingly, during that time period, most Blacks and Whites did not attend school together. It was not until the 1954 ruling of *Brown v. Board of Education* that de facto segregation in schools was ruled unconstitutional.

The impact of *Brown v. Board* has been characterized in two waves or time periods (Tillman, 2004). During the first wave (1954–1963), attempts to integrate schools in the South were met with strong resistance by Whites (Fine, 2004). In 1957, the governor of Arkansas used the National Guard to block the Little Rock Nine from attending high school. In response, President Eisenhower sent federal troops to enforce court-ordered integration. In 1958, nine schools in four Virginia counties closed to avoid desegregation (Fine, 2004). Furthermore, Black schools were forced to close and Black administrators and teachers lost their jobs in droves (Tillman, 2004). While many people are familiar with the Little Rock Nine, few are knowledgeable of the Clinton 12 (see Figure 9.1). These 12 students courageously integrated the White high school in Clinton,

Figure 9.1 Clinton 12 Historical Marker.¹

Tennessee, in 1956, which was one year before the Little Rock Nine integrated the schools in Little Rock, Arkansas.

The Clinton 12

When the Supreme Court passed the law to desegregate schools in May 1955, the school board in Clinton, Tennessee, worked during the summer to comply with the law. Twelve Black students (Bobby Cain, Jo Ann Crozier Allen Boyce,² Minnie Anne Dickey Jones, Gail Ann Epps Upton, Ronald Gordon Hayden, William Latham, Alvah J. McSwain Lambert, Maurice Soles, Robert Thacker, Anna Theresser Caldwell, Regina Turner Smith, and Alfred Williams) had previously been bused 18 miles away to a segregated high school in Knoxville, Tennessee. In 1950, Alvah McSwain's mother filed a lawsuit seeking the right for Blacks to attend school in Clinton, but a judge ruled in 1952 to maintain segregation. The McSwain lawsuit became part of the *Brown v. Board* litigation. After the landmark *Brown v. Board* decision was made by the Supreme Court, Black students attended Clinton High School for the first time on August 26, 1956. A documentary of the Clinton 12, narrated by actor James Earl Jones to commemorate the fiftieth anniversary, was produced in 2006. The story—as told by the Clinton 12, several White students, teachers, and administrators—revealed that the school year began without incident. However, John Kasper, an outsider and member of the Ku Klux Klan, came to Clinton and formed the Anderson County White Citizens Council to protest desegregating the schools in Clinton. Media coverage brought attention to the issue, and within a few weeks thousands of segregationists flocked to the town square to protest. As a result, the Clinton 12 were harassed and threatened daily as they walked to school. In fact, the harassment and threats extended to the entire Black community in the form of bomb threats and gun violence. Governor Frank G. Clement dispatched the Tennessee National Guard to maintain peace.

The walk to school for the Clinton 12 became more volatile as tensions rose in December 1956 over a local election, where

several segregationists were running for office. Rev. Paul Turner, a White Baptist minister, walked the Clinton 12 to school on election day. He was brutally attacked by a mob after the children entered the school. The following Sunday, despite his wounds, he preached against violence and community decay. As a result of turmoil and calls for peace, the people of Clinton defeated the segregationists at the polls. In May 1957, Bobby Cain was the first Black student to graduate from Clinton High School. However, he did not participate in the graduation exercises because he was assaulted prior to the ceremony.

One year later, perpetrators bombed the high school on October 5, 1958. Nearby, Oakridge Elementary School was renovated for temporary use until the high school in Clinton was rebuilt. The Rev. Billy Graham spoke on the high school football field in Clinton in 1959 to raise funds for the new high school. According to Mr. Cleo Ellis, curator of the Green McAdoo Cultural Center, Graham had the police take down ropes that were erected to separate people by race on the football field. A friend of Rev. Dr. Martin Luther King, Graham often preached, “There is no excuse, ever, for bigotry and intolerance and prejudice” and “we are to love as God loves us” (Shellnutt, 2018, n.p.).

One of the Clinton 12, William Latham, decided not to continue after the bombing. Instead, he entered the military and later received his GED. However, the rest of the Black students persevered and graduated with their respective classes. Their once-segregated elementary school is now the Green McAdoo Cultural Center. These courageous students, as well as the Little Rock Nine and others, put the *Brown* decision to the test and helped to bring an end to de facto segregation in America’s schools (Fine, 2004). However, according to Mr. Ellis, there were still racial tensions in Clinton during the 1960s, and many Black families moved away because of violent threats.

Desegregation and School Busing

During the second wave (1964–present), reaction to *Brown v. Board* took on a different form. In response to the law, southern

school districts published gaps in the test scores of Black and White students to justify their opposition to desegregation (Ogbu, 2003). The reaction of some Whites in the South and the North was *White flight*. Urban public schools began to lose White students as White families moved to the suburbs or sent their children to private or religious schools (Fine, 2004). Instead of dismantling racial injustice and creating a system that provided quality education for advantaged and disadvantaged students alike, Black children were bused to White schools as a means to achieve racial integration (Fine, 2004).

Harmon (2002) described the experiences of gifted African-American students who were bused to predominantly White schools in the Midwest during this time period. Two fourth-grade and four fifth-grade students were interviewed about their experiences. The African-American students who were bused from urban Tacoma Elementary School to suburban Rocky Creek Elementary School, which was predominantly White, stated they were called names and harassed by White students on the bus as they rode to and from school. Moreover, these students reported disparate treatment by some teachers at Rocky Creek, stating "*They won't teach us*" (Harmon, 2002, p. 71).

The African-Americans who participated in Harmon's study claimed they were placed in low-ability groups and given less challenging work compared to White students. African-American students also reported that teachers at Rocky Creek did not explain concepts in a manner that they could understand. Moreover, these students claimed teachers did not attempt to teach concepts in a culturally responsive way, nor did they use visual or tactile methods of teaching during instruction (Harmon, 2002). African-American students were simply told what to do and expected to sit still and follow directions. Conversely, while the predominantly African-American school in their home community certainly had fewer resources and less modern facilities, the teachers cared for, accepted, and supported the children within a safe learning environment (Harmon, 2002). Likewise, the elders, who were students when

the *Brown* decision was handed down, reported their all-Black schools, while underfunded, were “culture-rich, academically rigorous, and family-strong” (Fine, 2004, p. 504).

Such experiences lead one to ask: *Were there any benefits to busing as a means of desegregation?* One of the longest continuous voluntary school desegregation programs took place in Boston, Massachusetts (Schofield, 2001). The Metropolitan Council for Educational Opportunity (METCO)—the longest-running voluntary school desegregation program in the country—began in 1966. METCO facilitated the enrollment of African-American students from Boston schools in 32 suburban communities (Schofield, 2001). Susan Eaton (2001), author of *The Other Boston Busing Story*, interviewed 65 adults about their experiences in the METCO program. Like the students at Rocky Creek, METCO students relived feelings of alienation and invisibility when they were interviewed about their experiences (Schofield, 2001). However, some participants stated that the METCO experience was valuable because it provided them with the opportunity to become familiar with “the world of power and privilege in the suburbs, which enabled them to overcome their fears of such settings and to make informed decisions” (Schofield, 2001, p. 386). In other words, these students were able to learn the dominant discourses, which allow one to have greater access to people, power, prestige, money, and status (Gee, 1989).

Resegregation and Inequitable School Funding

Today, many urban schools are just as segregated as they were prior to *Brown v. Board* (Fine, 2004; Tillman, 2004). In fact, more than 60 years later, the majority of African-American children still attend racially and economically segregated schools (Leonard, Walker, Cloud, & Joseph, 2017). Public schools have been resegregated along racial and social class lines because the neighborhoods that feed students to local schools remain highly segregated (Chang, 2016; Ogbu, 2003). Moreover, local and state policies that rely mostly on the use of property taxes

to fund schools result in disparate funding for property-poor schools (Kozol, 1991; Ladson-Billings, 2006). More than 50 years after Dr. King's *I Have a Dream* speech, parents of poor African-American students have limited school choice, and their children, who attend segregated schools, are grossly underserved (Kozol, 2005).

Litigation such as *Edgewood v. Kirby* (1989) revealed the consequences of inequitable school funding on the education of poor students in San Antonio, Texas (Imazeki & Reschovsky, 2006; Kozol, 1991). As a result, attention was focused on providing students with equal access to an *adequate* education. However, exactly what *adequate* meant remained the subject of debate and further litigation. Imazeki and Reschovsky (2006) examined the school funding issue in Texas to determine the impact of state funding policies on student achievement.

Texas reformed its formula for funding schools in the 1990s with a plan that was dubbed "Robin Hood" (Imazeki & Reschovsky, 2006). In essence, less money was given to property-rich school districts, while more money was given to property-poor districts. Despite great strides to improve funding for Texas school districts, underfunded districts remain and are more likely to be large urban districts that consist of poor, minority, and limited English proficient students. Furthermore, even if funding were equal, data show that it costs more than average to improve achievement in the lowest-performing districts. "It is impossible to expect both equal outcomes *and* equal dollar allocations" (Imazeki & Reschovsky, 2006, p. 31). In November 2005, the Texas Supreme Court ruled in *Neeley v. West Orange-Cove* that the funding system in Texas was unconstitutional (Imazeki & Reschovsky, 2006).

The Pedagogy of Poverty

Although school funding is an important factor in the education of poor and minority students, what happens in urban classrooms is even more critical. No Child Left Behind (NCLB, 2001) legislation spawned a great deal of rhetoric about highly

qualified teachers and the importance of teacher quality on student achievement. However, policymakers and researchers were divided over exactly what *highly qualified* meant and how to produce teachers who met the standards of NCLB (Viadero, 2005), which underscored the importance of teachers' practice and subject matter knowledge. Students in high-poverty schools are more likely to be taught by teachers who do not have sufficient knowledge of the subjects they teach (Haycock, 2001). This is a critical observation, as teacher practices in urban classrooms, where the majority of students of color are, have a direct impact on student achievement in general and mathematics achievement in particular.

Haberman (1991) identified the following teacher practices, which he characterized as a basic urban style of teaching:

- Giving information
- Asking questions
- Giving directions
- Making assignments
- Monitoring seatwork
- Reviewing assignments
- Giving tests
- Reviewing tests
- Assigning homework
- Settling disputes
- Punishing noncompliance
- Marking papers, and
- Giving grades

(p. 290)

If these practices are viewed separately, Haberman (1991) admitted they may not be deleterious. However, taken together and performed systematically to the exclusion of other activities, such as cooperative learning, inquiry-based instruction, and project-based learning, they constitute what Haberman (1991) called the *pedagogy of poverty*. Such practices do not lead

to higher academic achievement, and they stagnate the learning of above-average and gifted students (Haberman, 1991; Harmon, 2002). Also, teachers who engage in reform-based practices may experience resistance from the students themselves, who may become accustomed to routine procedures and conceptualize learning as engagement in text-based activities (Haberman, 1991; Martin, 2000; Ogbu, 2003). Thus, parents and students must accept reform-based teaching in order for it to be effective in mathematics classrooms.

Yet, the *achievement gap* continues to spark a great deal of debate. Cognitive, cultural, sociohistorical, community (i.e., peers, parents and others), and institutional factors (i.e., school finance, school choice, roles of administrators and teachers) are reasons cited for underachievement among students of color (Boykin & Toms, 1985; Kozol, 1991; Martin, 2000; Ogbu, 2003). However, few research studies examine what parents and students themselves have to say about underachievement (Martin, 2000; Ogbu, 2003; Taylor, 2004).

The next section of this chapter synthesizes data and findings from two research studies that examine the perspectives of students and parents on underachievement in general. That section is then followed by data and findings from another research study on the perspectives of parents and students on underachievement in mathematics.

Perspectives on the Achievement Gap

While few researchers have conducted investigations that report what African-American students and parents think about the achievement gap (Ford, 1993; Martin, 2000; Ogbu, 2003), former teacher, administrator, and executive of two large urban school districts Kay Lovelace Taylor (2004) presented a thoughtful treatise on the national achievement gap. She acknowledged that African-Americans perform below other ethnic groups on national assessments in reading and mathematics. Taylor (2004) took an interesting approach, posing the following question to high school students, graduate students,

parents, and educators across the country: *What do you think is the number one reason African American children do not score as high as other ethnic groups?* (p. 2).

Taylor analyzed how high school students, parents, and teachers responded to her question, noting both differences and similarities in their responses. As a result of these interviews, five barriers to academic success emerged: (a) student behaviors, (b) lack of parent and family support, (c) teacher behaviors, (d) school culture, and (e) community and environmental issues. Notably, graduate students responded that students, teachers, and parents were to blame in part for the achievement gap. Teachers in the study were less willing to critically examine their role in the achievement gap and generally blamed parents and students for underachievement. Because student and parent perceptions are underreported in the literature, I have chosen to focus on Taylor's analysis of student and parent interviews.

African-American students "identified themselves as a part of the problem and the solution to poor academic achievement" (Taylor, 2004, p. 23). African-American students identified lack of motivation, lack of focus, poor study habits, and simply not applying themselves as factors that contributed to their underachievement. Furthermore, peer pressure caused some students not to ask for directions or help in class even when they needed it from the teacher. Moreover, these high school students believed their parents were too lax because they did not ask about homework, help with homework, or inquire about their grades. In addition, students faulted some teachers for giving unchallenging work and others for covering material at too fast a pace. Finally, students admitted they received mixed messages about school from their community. Certain community elements sent students the message that achieving in school was synonymous with "acting White," while underachieving was considered "cool" (Taylor, 2004, p. 30).

The "acting White" concept is not new. Ogbu (1987 & 2003) suggested that internalization of the belief that Blacks are less

intelligent than Whites translated to the belief that White students should succeed academically but Black students should not. As a result of internalized oppression (Ogbu, 2003), low teacher expectations (Harmon, 2002), and the disconnect between African-American culture and school culture (Banks, 2001; Diller, 1999), some African-American students have come to believe that doing well in school is synonymous with Whiteness (Martin, 2000). The belief becomes even more of a dilemma when average, above-average, and gifted African-American students receive too little administrative and teacher support when they are harassed by underachieving peers (Martin, 2000).

Surprisingly, Taylor (2004) also found that African-American parents held themselves responsible for their children's underachievement. Parents noted lack of communication with their children as one problem. Some parents also stated they were ambivalent about helping their children with homework because they did not understand the subject matter or they had reading difficulties. Furthermore, several parents mentioned they were often too tired to help their children after getting home from work and simply resigned the education of their children over to teachers (Williams & Leonard, 2004). In general, parents felt society's low expectation of African-American children was a huge part of the problem and believed lower expectations caused their children to have low self-esteem. Coupled with inadequate school resources and low teacher expectations, many of the parents who were interviewed were simply overwhelmed.

One parent shared his/her emotions after a parent conference: "You feel like you are failing in school all over again, even though you are there to talk about your child" (Taylor, 2004, p. 45). This comment is not only poignant but also very telling. Schools, by and large, have been failing to educate generations of African-American students (Du Bois, 1995). If the school has failed to educate the parent, how can the parent help the child? Moreover, how can either the parent or the child trust the

educational system to do its job when it has failed so miserably in the past? This failure perpetuates a cycle of underachievement that is extremely difficult to break.

In a second study, Ogbu (2003) examined academic disengagement among African-American students attending school in an affluent Ohio suburb. While parents of students in Shaker Heights were more likely to be involved in their children's education and to help them with homework, Ogbu (2003) found that African-American students, as a whole, were still not performing to their potential. School practices such as low teacher expectations, leveling, and disproportionate representations of Blacks in special education reinforced the belief that Black students were not capable of high academic achievement. Furthermore, the perception that Black students who perform well are "exceptional" continues to reinforce the stereotype that being Black and smart is abnormal (Ogbu, 2003, p. 85). Additionally, several reasons were given by students for the "low-effort syndrome" described in the study (Ogbu, 2003, p. 17). They included: (a) lack of motivation, (b) norm of minimum effort (i.e., doing as little as possible to get by), (c) peer pressure, (d) poor study habits, (e) poor teachers, and (f) boring or uninteresting courses.

Although the socioeconomic status of the students interviewed by Taylor (2004) and Ogbu (2003) was different, student perceptions about low academic achievement overlap in both studies: lack of motivation, poor study habits, peer pressure, and the belief that underachieving was considered "cool" and achieving was considered "acting White." These perceptions revealed the complexity of underachievement among African-American students. While one may be motivated by extrinsic rewards and study habits can be taught, how does one change African-American students' beliefs about academic success, especially in mathematics? Beliefs about achievement in general and mathematics achievement in particular, though influenced by external forces such as peers and community values, are intrinsic rather than extrinsic (Becker & Luthar,

2002; Ford, 1993; Martin, 2000). Therefore, an examination of African-American students' mathematics identity and mathematics socialization adds to the discussion about African-American achievement.

Mathematics Socialization and Identity among African-American Students

Martin (2000) conducted a qualitative study on African-American students' achievement and persistence in mathematics in Oakland, California. He used a multilevel framework to describe and analyze mathematics socialization and identity. By examining mathematics socialization and identity, Martin believed new understandings about success and failure among African-American students in mathematics would help the research community to understand low achievement. Like Taylor (2004), Martin wanted to know why African-American students, as a group, were underachieving in mathematics. Martin (2000) asked the following question:

Why is it that despite increased demands for those who possess mathematics-related skills and knowledge, significant advances in educational theory, and calls for higher educational standards, African-Americans continue to experience their mathematics educations in ways that place them at or near the bottom on all measures of achievement and persistence?

(p. 9)

After interviewing four parents, Martin found that socioeconomic and educational experiences caused two participants to diminish the value of mathematical knowledge in their own and their children's lives. In the other two cases, parental experiences were a motivating factor to revisit obtaining mathematical knowledge for their own benefit, as well as their children's benefit. One African-American male interviewee provided an alarming perception of mathematics education:

I only indulged myself in my studies to the degree that I was satisfied that I could do math up to multiplication and division of fractions and decimals and that was good enough for me for what I was going to do. I wasn't going to be doing any math. To be a laborer, all it's going to require is to run a piece of machinery.

(Martin, 2000, p. 42)

We don't have no industry out there and the industry that is out there, they're not targeting the Black community and saying, "If you go and get more math, then I can guarantee you this."

(Martin, 2000, p. 45)

I have hopes. My expectation is that [my son] will graduate from high school. If he doesn't, it's no big deal.... My expectation for him is to probably be no worse than I was. Just to pass.

(Martin, 2000, p. 46)

Certainly, the norm of minimum effort and the low-expectation syndrome described by Ogbu (2003) is evident in response to this parent's effort in school and his hopes for his son. However, the data also suggest that past discrimination and racism continue to have an impact on families, as parental attitudes and values are often passed on to their children. The comment about industry providing incentives is an interesting one. While there is a need for domestic and international diversity, outsourcing jobs overseas does not send the Black community a message that African-Americans will be recruited to fill the high-tech jobs that largely go unfilled (Moses & Cobb, 2001). Moses and Cobb (2001) argued that a culture of literacy in mathematics needs to operate in the African-American community to the same extent literacy in reading does. But how to create that culture and provide support for African-American students who choose to achieve and persist in mathematics without guaranteed employment is another dilemma.

Knowledge is power and mathematical literacy opens the door of opportunity. The job outlook for 2018 reveals that more than

51% of all STEM jobs will require knowledge of computer science (Bureau of Labor Statistics, 2016). These jobs require knowledge of mathematics and technology. Employees in high-tech fields can earn 82% more than workers in other fields (Moses & Cobb, 2001). Therefore, industry needs to target diverse populations living in the U.S. with the incentives to motivate them to achieve in mathematics and compete for the high-tech jobs that are available. Mathematics literacy and mathematics achievement lead to higher education and economic empowerment.

Danny Martin (2000) conducted a case study at Hillside School (a pseudonym) in Oakland. The impetus for studying successful African-American students' mathematics achievement was the paucity of such studies in the research literature (Brown & Boshamer, 2000; Leonard, Davis, & Sidler, 2005; Malloy & Jones, 1998; Martin, 2000). Martin observed middle school teachers and students in three mathematics classrooms. The teachers were diverse in terms of ethnicity and gender. Two were identified as persons of color, and one was female. The curriculum used at the school during the time of the study was the *Algebra Project*. The reform-based curriculum included activities that required students to discuss, draw diagrams, and participate in cooperative learning.

Martin (2000) found that sometimes students did well and were highly engaged in the activities. However, on other occasions, students were off-task, stating that they were bored and apparently uninterested in the curriculum and materials. The comments of two students offer some insight:

math is basically where you're adding things, and subtraction, and dividing. I don't think that in math you're drawing pictures. That's for art. (Carl, seventh grade)

(Martin, 2000, p. 103)

I like doing work out of the math book. I like doing math. I don't like writing. (Sheneka, seventh grade)

(Martin, 2000, p. 103)

Despite the use of a reform-based curriculum, some students do not recognize it as mathematics. This dilemma points to the need for systematic curriculum reform at the elementary level (K–6) (Li & Lappan, 2014). Unless all teachers of mathematics engage in reform-based activities, it will be difficult to change student conceptions of mathematics. Student achievement in mathematics does not occur within a vacuum. Curriculum, teacher behaviors, and teacher and student conceptions about mathematics must be in sync for significant change to occur.

In addition to making classroom observations, Martin interviewed 35 middle school students. However, seven target students were selected for further study. Five of these students were female and two were male. Of this number, two were in seventh grade, three were in eighth grade, and two were in ninth grade. Their GPAs ranged from 3.33 to 4.0 during the year of the study. Some of the interesting themes and patterns that emerged across these interviews revealed startling facts about the students' mathematics socialization and identity.

In terms of mathematics socialization, all of the students believed learning mathematics was important and necessary to achieving their life goals. These views were illustrated in the students' responses to interview questions about learning math:

If I want to be a doctor or an engineer. It'd be good to already have [math] under your belt. (Annette, eighth grade)

(Martin, 2000, p. 144)

[Math] gets you into college. If you don't know it, you aren't going to be able to get a good job like computers or something. So, I feel I have to take it. (Melody, ninth grade)

(Martin, 2000, p. 155)

Jobs. You cannot go anywhere or do anything in this world without using math. (Jasmine, seventh grade)

(Martin, 2000, p. 160)

These students not only realized that knowing mathematics would help them gain access to higher education but also acknowledged that mathematics was extremely important in careers like medicine, engineering, and computer science. One student even realized that mathematics literacy was important to one's existence and survival. Such perspectives caused these students to excel and persist in mathematics.

It is important to note, however, that while all of these students were high achievers, their experiences and perceptions about the school and their peers were not uniform. Lisa (eighth grade) and Paulette (ninth grade) described themselves as hardworking and intelligent. However, Annette (eighth grade) was competitive and wanted to be the best. Terrell (eighth grade) worked hard because he wanted to succeed, but he kept his grades up to continue playing hockey. Melody (ninth grade) and Carl (seventh grade) always liked school, but Melody was motivated because she wanted a better life. Jasmine (seventh grade) was outgoing and confident in math but found her math class boring and unchallenging.

Other differences among these students were their perceptions about the school and underachieving students. In general, the girls were much more critical of the school and the students than the two males. Paulette believed the school was violent, and Melody would not recommend it to anyone. Lisa believed most of the students did not care about school, and Melody thought the kids were rowdy. Jasmine simply said, "They're bad" (Martin, 2000, p. 158). However, Carl was the most positive about the school, stating, "I would describe it as good" (Martin, 2000, p. 162). Terrell admitted that the school had a bad reputation but claimed, "The school is better than what people say it is" (Martin, 2000, p. 147). Carl and Terrell were critical of student behaviors but not the students themselves.

The children, I think they need better behavior. (Carl, seventh grade)

(Martin, 2000, p. 162)

A lot of them care but it's just that a lot of them don't have that will to want to do it. (Terrell, eighth grade)

(Martin, 2000, p. 147)

Terrell's response shows his neutrality despite being criticized by some of his peers because he played hockey, which some claimed was a White sport. In fact, all seven of the target students reported that they experienced differential treatment by their peers. For example, high-achieving students at the school in Oakland were often called geeks and nerds. Consequently, some of these students handled this situation by limiting their associations to other high-achieving students.

While all of their stories are different, these students demonstrated strength of character, resilience, and individual agency (Martin, 2000). Their dreams and aspirations were more powerful than negative peer pressure. Lisa's motivation was not only personal; she also wanted to become successful in order to show others that African-Americans are intelligent. Moreover, she wanted to give back to the community by becoming a teacher to show the next generation what they could become by her example. These student's comments suggest that development of mathematics socialization and identity are critical to success in mathematics.

Links to Everyday Mathematics

In order to help African-American children develop mathematics socialization and identity, they must realize that mathematics may be found in many aspects of African-American life and culture. Examples of mathematics and culture can be found in art, for instance. Mathematics and art can be integrated to help children observe different geometric patterns found in artifacts such as sculptures, paintings, prints, and posters (Chappell & Thompson, 2000). Students can use patterns and shapes to create their own tessellations, which are artistic patterns often found in tile and mosaics. Such activities are not only fun but also helpful to students in developing

and valuing their artistic talent while understanding the importance of mathematics.

Furthermore, nail salons, beauty shops, and barbershops are stable businesses that many students of color can identify with. Mathematics can be seen in patterns on sculptured nails, in hair braiding, and designer haircuts, respectively. The patterns and designs that are formed on sculptured nails and in hair styles can be examined from a geometric perspective. The lists of prices found at the aforementioned business establishments provide teachers and parents with sources for developing culturally relevant mathematics problems for children to solve. For example, natural hair salons such as Duafe in Philadelphia offer a menu of ethnic hair styles: cornrows, coils, palm rolls, flatbraids, two-strand twists, and locks. Teachers and parents can pose problems that compare the costs of maintaining particular hairstyles over time or determine the percentage of a monthly budget spent on haircare.

Mathematics can also be learned by participating in gaming (Leonard, this volume), chess (Thomas-El, 2003), and sports. Digital game playing has also been used successfully in mathematics classrooms to teach problem solving (Chang, Wu, Weng, & Sung, 2012) and can be used to support the development of “strategic thinking, planning, communication, application of numbers, negotiating skills, group decision-making, and data-handling” (Li, 2010, p. 429). Furthermore, the game of chess has become more popular with students of color. Chess requires the knowledge of the hierarchical roles of bishops, rooks, and knights as well as logic to win. Finally, sports such as track and field can also be used to help children learn mathematics. Students learn the value of decimals as they experience how tenths and hundredths of a second make the difference in winning or losing a race.

Conclusions and Recommendations

After giving considerable thought to the work of Ladson-Billings (2006, 2017), Martin (2000), Ogbu (2003), Taylor

(2004), and others, I believe two factors perpetuate underachievement among students of color: generational underachievement and institutional barriers to academic success. Generational underachievement is grounded in past discrimination and economic constraints. As a result of racial discrimination, Blacks living in the South received an inferior education that often culminated at the seventh or eighth grade (Du Bois, 1995; Moses & Cobb, 2001; Leonard, Walker, Cloud, & Joseph, 2017). Also, the cycles of underachievement and poverty for many African-American and Hispanic families were tied to an agrarian lifestyle in the South and southwestern U.S. In many African-American and Hispanic families, children did not enroll in school until after the harvest (Borden & Kroeger, 2001; Krull, 2003; Pérez, 2002). Moreover, some children had to attend several different schools because the family had to migrate from one farming community to another (Krull, 2003; Pérez, 2002). Such economic constraints had a definite impact on families. As a result, it has taken some families several generations to produce their first college graduate and to break the cycle of poverty.

For some students, poverty and negative school experiences have been limiting and debilitating, but, for others, it has been a source of inspiration (Martin, 2000). In my immediate family, which is six generations removed from slavery, my mother dropped out of high school in the tenth grade. She was a single parent and had working-class jobs. Given the demographic variables associated with my childhood and upbringing in St. Louis, many researchers and policymakers would not have predicted my academic success. Other variables, such as learning for the intrinsic value of learning, spiritual connectedness, motivation to exceed others' expectations, and family values, contributed to my academic success.

Interestingly, in 2018 I am still witnessing first-generation college graduates among students of color. Particularly for some working-class African-American and Hispanic families, it has taken more than a century to produce one college graduate.

The legacy continues by maintaining strong educational values in the family, community, and social institutions. The key to maintaining academic success after the cycle of underachievement has been broken is to shatter notions that equate academic success to “acting White” (Martin, 2000; Ogbu, 2003; Taylor, 2004). A legacy of high academic performance must become the norm, especially among first-generation African-American and Hispanic college graduates. In my own family, there is a second generation of college graduates, as I have passed the legacy of academic success on to my two daughters. If we are able to pass the legacy on to a third generation, the cycles of poverty and underachievement may be broken for good. Similarly, in order to shatter the notion that academic success is “not cool” or unattainable, all children of color need to be exposed to successful role models who look like them. Success breeds success.

In the African-American community, positive role models may be found in Black sororities and fraternities such as Sigma Gamma Rho and Kappa Alpha Psi. In addition to these organizations, the Black church has been a pillar in the African-American community for generations, helping to instill strong education and family values in the lives of African-American children. For example, Rev. Dr. Zan Wesley Holmes Jr. established the pastor’s report card review at St. Luke “Community” United Methodist Church in Dallas, Texas, when my children were growing up there. The program had a profound impact on my daughters long after we relocated to the East Coast. They continued to send Pastor Holmes (now retired) copies of their report cards even when they were in college. From daycare centers to GED programs, the Black church has supplemented education for children and adults for decades. In my role as principal investigator of several community-based research studies, mathematics and science programs were implemented in several churches in Philadelphia, Pennsylvania, and Denver, Colorado. Funded by the National Science Foundation and the Office of Urban Ministries of the United Methodist Church,

more than 200 children were impacted by these community-based projects. The Black church provides role models to promote the development of mathematics identity and socialization among African-American students.

One of the greatest challenges to establishing a legacy of achievement is the American system of education itself. Institutional barriers such as apartheid schools must be dismantled (Kozol, 2005). First, we must ensure that students of color and poor students gain access to the best schools in their community without regard to geographical boundaries (Kozol, 1991). Ideally, these schools should not be segregated in terms of race, ethnicity, language, and achievement variables. Second, the neediest students should have the most talented and culturally responsive teachers. Third, the curriculum, technology, and other resources available to these students should be world-class.

Creating and maintaining a legacy of achievement requires a major overhaul of the current educational system and a substantial investment of capital—human, cultural, and social (Dance, 2002). Human capital refers to “the knowledge, skills, educational training, and other capabilities acquired by individuals that enhance economic productivity” (Dance, 2002, p. 72). Cultural capital may be interpreted as “the heritage or acquired linguistic codes, disposition, tastes, modes of thinking, and other types of knowledge or competences deemed legitimate by the dominant group or groups in society” (Dance, 2002, p. 74). Social capital is defined as the “resources that result from social relationships among individuals, families, communal groups, [and] social networks” (Dance, 2002, p. 72). I believe that significant investment in these types of capital will help students become more successful in school and society in general.

In order to improve achievement and course-taking patterns among students of color in mathematics, curriculum must be meaningful and relevant to their lives, taught in interesting and sometimes nontraditional ways, valued in the community, and recognized as a means to economic success. When teachers incorporate the cultural identities that diverse students bring to

school into the classroom, they create opportunities not only to learn important content but also to appreciate students' rich cultural heritage by confronting notions that academic success is a White endeavor.

The bicultural identities of African-American, Asian-American, Native American, and Latinx students can be used as a springboard to engage these populations in culturally specific mathematics (Brenner, 1998; Gutstein, et al., 1997; Ladson-Billings, 1994; Lipka, et al., 2005). From the cradle to the schoolhouse door, from the pulpit to the pew, entire communities must be involved in helping to build mathematics identity among students of color, sending them the message that it is "cool" to be literate in mathematics. While these recommendations are not a panacea, changing society's perceptions about who is expected to succeed, providing an infrastructure for all students to maximize their potential, and embracing the culture of all students are an auspicious beginning.

Chapter 9 Discussion Questions

1. What factors may have led to the story of the Little Rock Nine being more familiar than the story of the Clinton 12?
2. What factors led to the failure of voluntary (and mandatory) busing to achieve racial desegregation in public schools?
3. What can be done to achieve equitable education for all students, regardless of the type of school they attend?
4. How can teachers help students to better use human, material, and electronic resources to obtain a quality education?
5. What everyday activities and instructional strategies can teachers use to engage students of color in culturally specific pedagogy?

Notes

1. Historical marker photographed by Jacqueline Leonard in Clinton, Tennessee.
2. Grandmother of Cameron Boyce, actor known for *Descendants* (2015).

APPENDIX A

Computational Thinking Rubric

Table A.1

<i>CT components</i>	<i>Emerging (1)</i>	<i>Moderate (2)</i>	<i>Substantive (3)</i>
Formulating Problems	If/then statements unclear in terms of problem goals (e.g., “Can pigs fly?”)	If/then statements create conditions that allow agent to move through program using a single condition (e.g., “If you see a ghost, move left”)	If then statements are more complex and agent moves to more than one set of criteria (e.g., “If you see a ghost and a scarecrow, move to the left and/or up”)
Abstraction	Agent and background resemble tutorial in <i>Frogger</i> game	Agent or background is nontraditional and created by the student	Agent and background are nontraditional and created by the student
Logical Thinking	If/then statements do not follow logical path (e.g., agent is stuck and cannot move through the program)	If/then statements follow logical path with some complexity (e.g., agent moves through the program but there are no real challenges)	If then statements follow logical path with more complexity (e.g., agent moves through program but can run into danger)
Using Algorithms	No evidence of algorithmic use (i.e., game cannot keep score)	Some evidence of algorithm use (i.e., the game can keep score)	Evidence of algorithm use and final score: (i.e., the games keep score and say “you won”)

continued

Table A.1 continued

<i>CT components</i>	<i>Emerging (1)</i>	<i>Moderate (2)</i>	<i>Substantive (3)</i>
Analyzing and Implementing Solutions	No evidence of the ability to debug the program	Some evidence of debugging	Strong evidence of debugging at higher levels
Generalizing and Problem Transfer	Game resembles <i>Frogger</i> example	Game has some evidence of <i>Frogger</i> but some differences	Game is not similar to <i>Frogger</i> at all and shows creative in regard to use of knowledge transfer
Use of culture or off-the-shelf games	No evidence of culture or inclusion of any elements from off-the-shelf games	Some elements of culture or similarities to current off-the-shelf games	Substantial modeling or similarities to off-the-shelf games with improvements and/or modifications

APPENDIX B

Scratch Dance Party Tutorial¹

The Scratch interface is split into four main sections: Main Window, Sprite Window, Scripts Area, and Block Area. The Main Window is where the results of your block sequence are shown. The Sprite window displays the selectable sprites in your project. The Block Window is where you select from various blocks for your project, and the Scripts Area is where you build your project.

1. Click and Drag a MOVE block into the Scripts Area.
Double-clicking the number in the middle of the block

will allow you to change the amount of steps the cat will take.

2. In the Block Window, click on “Sound” to bring up the sound block options. Click and drag a PLAY DRUM block, and snap it under the MOVE block.

3. Add another MOVE block. Click inside the block and add a minus sign before the number so that the cat will move backwards. Add another PLAY DRUM block. Click the arrow next to the “1” and choose any drum from the dropdown menu.
4. In the Block Window click “Control” and drag out a REPEAT block. Snap it around the entire block stack
5. In the Block Window click “Looks” and drag out a “SAY ____ FOR __SECS” block. In the text box, type whatever words you desire your cat to say. Snap this block to the top of the stack. Your cat will say whatever phrase you typed in the text box before it begins to move.

6. In the Block Window, click “Events”. Drag out a WHEN (GREEN FLAG) CLICKED block and snap it to the top of the stack. This will allow you to start your event by simply clicking the green flag in the top right corner of the Main Window.

7. Click on the “Looks” tab in the Block Window. Drag out a CHANGE COLOR EFFECT block.
8. We need to make the color change interactive somehow. To do this we will use a WHEN (KEY) PRESSED block. In the Block Window choose the “Events” tab. Drag out a WHEN (KEY) PRESSED block and snap it to the top of the CHANGE COLOR EFFECT block.
9. Now we have to add a backdrop to our stage. On the left side of the Sprites Window there are four buttons. The first button will allow you to choose a new backdrop from the library. Click this button and find “Spotlight Stage” in the selection window that pops up.

10. Lastly, we need to add a song for the dance party. In the scripts area, select the “Sound” tab. Click the “Upload from File” button and choose a song which you have downloaded. You now have a full dance party! Enjoy.

Note

1. Lesson developed by Peter A. C. Hill.

APPENDIX C

Knex Data Collection Sheet¹

Name of Engineers

Name of Car

Variables: tire size, number of spins

You may only test 1 variable at a time.

Each design must be tested 3 times.

Predictions:

We predict that the optimal number of spins is

We predict that the optimal tire is size

Table C.1

Distance Traveled in Centimeters

<i>Design Type</i>	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Average</i>	<i>Did you improve your design?</i>
Original Design					Original design
Modification #1					Y/N
Modification #2					Y/N
Modification #3					Y/N
Modification #4					Y/N

Note

1. Lesson developed by Tonya Busse.

APPENDIX D

Sculptris Bison Tutorial¹

This tutorial will use basic concepts from the 3D sculpting program, *Sculptris*, to replicate an American Bison. Before beginning the actual sculpting process, find a few photos of an American Bison on the Internet. These photos will be used as reference points during the sculpt. It is a good idea to find a “side” and “back” view.

Open Sculptris, and make sure all options are set to default (the most important option to have toggled is “Symmetry”).

- Using the **Grab (g)** tool, create the basic shape of the bison’s back, torso, and hind legs. Focus on making a “skeletal” structure to sculpt on. The shape doesn’t have to be perfectly aligned with the reference images because small adjustments will be made throughout the sculpt.

- Continue to focus on the torso and ribs. Broaden the bottom of the torso as to give definition to the stomach/chest area using the **Draw (d)** tool.
 - This is equivalent to adding skin on top of the skeleton.
- Lower the back (towards the hind legs), and slightly widen the hips.
- Pull down the front legs of the bison using the **Grab (g)** tool. Place a slight angular bend towards the ground to represent the hooves.

- Add an entire layer of skin to the bison (thick hide) using the **Draw (d)** tool. Focus design on creating a robust rib-cage and buttocks. Broaden the shoulders and hind legs.
- Start to define “hinge points” on the bison (peroneus, ulnaris)
 - Hinge points are the anatomical points where bends happen (equivalent to kneecaps, and elbows on humans)
- Switch focus to the front of the bison. Give the front legs more definition by rounding the shoulders. Heighten the trapezius muscles as well.

- Begin to build the foundation of the bison fur.

- Continue to define the torso of the bison by rounding, and smoothing the shoulders, hips, and any point where limbs connect.
- Lower the bottom of the torso (underbelly) to give the bison the look of a muscular gut.
- Thin the front legs as to create a reference point for where the fur connects to the bison's front legs
- Begin to thicken the top of the fur
- Continue to create connections between the fur and skin.
- Raise the spine area as well.
- Redefine the shoulder area now that the fur has been created.
- Begin to shape the head and frontal portion of the bison's fur.
- After the head is shaped use the **grab (g)** tool to pull out horns and shape the hooves
 - Make sure to create an indentation where the horns meet the head
- Make indentions where the eyes and nose are located
 - Create a brow and ridge line

- Continue to detail the hooves and horns.
- Add secondary details and finishing touches (hooves, musculatory underlines, nose ridges, etc.)

Note

1. Lesson developed by Peter A. C. Hill.

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