The Urban Review (2023) 55:133–172
https://doi.org/10.1007/s11256-022-00643-4

Embracing Culturally Relevant Education in Mathematics and Science: A Literature Review

Maria Kolovou[1]

Accepted: 23 August 2022 / Published online: 13 September 2022

Abstract

Culturally relevant education (CRE) approaches use minoritized populations' cultural capital to break the perennial cycle of these groups' underperformance. Yet, mathematics and science teachers do not feel confident in using CRE approaches. This literature review explores the practices and challenges that accompany CRE implementations in math and science classrooms aiming to inform mathematics and science teachers' preparation for equitable education. Practices were clustered in alignment with the CRE outcomes, namely cultural competence, academic achievement, and critical consciousness; further categories were inductively identified. Challenges were clustered in teachers' beliefs, lack of inclusive tools, and influence of institutional norms. Insights from the findings inform implications for preparing math and science teachers for equitable education.

Keywords Culturally relevant education · Math teaching · Science teaching · Cultural capital · Equity in education

Despite several reparatory attempts, education in the U.S. still fails to overcome achievement disparities stratified by race and social class (Entwisle, 2018; Lareau, 2015) and this tendency is intensified in math and science subjects (Han et al., 2016). Research on achievement disparities focuses mostly on urban settings, which serve high percentages of children from low-income families and minoritized racial-ethnic populations (Howard & Milner, 2021; Mattei & Aguilar, 2016; Milner, 2013). However, it is now understood that also the suburbs provide contexts for such studies, because low income, Black, Latinx, and Indigenous people increasingly live in the suburbs and endure racial implications also in these settings (Diamond et al., 2021; Posey-Maddox, 2017). According to Ladson-Billings (2006), the so-called achievement *gap* should be seen as an educational *debt*, which has been accumulating for decades, because of other *gaps* in education. Milner (2011) urges policy

✉ Maria Kolovou
mxk1058@miami.edu

[1] Department of Teaching and Learning, University of Miami, Miami, USA

makers and educators to identify and address these gaps, such as the teacher training and the teaching quality gaps (Milner, 2011).

Howard and Milner (2021) suggest that teachers who teach minoritized populations should understand not only the subject they teach and how to teach it, but also the racial and cultural background of their students. Valuing students' culture is particularly needed in math and science learning environments, in which the curriculum is Euro-centric and the perspectives of Indigenous, Latinx, and Black people's contributions to math and science are erased. When teachers integrate students' culture, students' academic achievement and cultural competence is enhanced (Brown & Crippen, 2017). Considering the history of oppression in the Science, Technology, Engineering, and Mathematics (STEM) areas, both outcomes (academic achievement *and* cultural competence) assist historically marginalized students' development.

The urge to centralize culture led to theories that focus on low-income and historically marginalized students' potential. which can be united under the umbrella-term, 'culturally relevant education' (CRE; Aronson & Laughter, 2016). In this paper, CRE encompasses pedagogies that use students' culture and prior knowledge to contextualize learning and teach for social justice. These include Cultural Relevant Pedagogy (CRP; Ladson-Billings, 1995), Cultural Responsive Teaching (CRT; Gay, 2002), Cultural Sustaining Pedagogy (CSP; Paris, 2012), and social justice education (science and math for social justice). Reviews illustrate examples of CRE (which was operationalized to include CRP and CRT) implementations that positively affected learning outcomes across all content areas (Aronson & Laughter, 2016; Morrison et al., 2008). Despite the promising results, such implementations remain relatively low and sporadic, partly because teachers feel unfamiliar or not confident with using CRE practices (Neri et al., 2019). Teachers' reluctance to implement CRE is intensified in math and science classrooms (Boutte & Kelly-Jackson, 2010), especially because teachers perceive math and science as "objective," and a-cultural subjects (Gutstein, 2003).

To address math and science teachers' reluctance to embrace CRE, this review examines CRE implementations in math and science K12 formal and informal educational settings. The purpose of this investigation is (a) to identify specific practices associated with positive CRE outcomes for students in math and science educational settings, (b) to identify challenges when applying CRE in math and science educational settings. In the context of this review, the term "practices" refers to teachers' identifiable actions that apply the theoretical principles of CRE. The review was guided by the questions:

1. Which specific practices have been associated with positive CRE outcomes for students in math and science educational settings?
2. What were the challenges of applying CRE in math and science educational settings?

In the following, after introducing how culture has been used in education and specifically in STEM learning settings, I highlight that teachers' preparation

should include knowledge about low-income and minoritized students' racial and cultural background. I continue with a summary of the three outcomes of CRE implementations, a brief overview of CRE implementations in STEM, and I conclude with CRE related challenges especially for math and science classrooms.

Conceptual Framework

Culture at the Center of Educational Efforts

Cultural anthropologists used the concept of culture-initially defined as a set of characteristics and knowledge about language, traditions, values, beliefs, religion, and art-to diffuse arguments about supposedly scientific hierarchical racial classifications and their racial implications (González et al., 2006). Race as a concept has been eventually assigned to biology, whereas culture now explains human behavior as conditioned by sociohistorical contexts rather than biological traits (González et al., 2006). Because race was expunged from social science, many argue that culture came to mistakenly stand for race (González, 2004). This might enforce assumptions that culture is a static set of rules of behavior in which all group members abide by, presuming coherence within groups which may not exist. To highlight its dynamic rather than static nature, in this paper, culture is defined as a "historically transmitted pattern of meanings embodied in symbols, a system of inherited conceptions expressed in symbolic forms by means of which … [humans] communicate, perpetuate, and develop their knowledge about and attitudes toward life" (Geertz, 1973, p. 91).

Although the concept of culture has the potential to affirm diversity, this has not always been the case in education. For example, cultural deficit models have emerged to explain the so-called achievement gap—in these models, low performance of poor and minoritized students is assigned to these groups' cultural practices associated with socialization and language patterns, which do not follow the schooling norms (see Valencia, 1997 for a historical overview about the evolution of deficit thinking). In the quest to move away from deficit paradigms and understand the sources of inequalities' reproduction, many scholars have drawn upon Bourdieu's conceptualization of cultural capital—defined as a set of values, attitudes, and knowledge, unique for different social groups, that parents pass on to their children (Bourdieu, 1986).

A strand of research on cultural capital dissolved pre-held illusions that education acts as a buffer for inequalities and expanded scholars' understandings about how education may, in fact, reproduce inequalities (Lareau, 2003, 2011, 2015). Collins (1979, 2014) asserted that cultural capital serves as a resource for any group that shares symbols, rituals, vocabularies, and styles, and that the more social connections that are formed between the members of a group, the more value its cultural capital holds. This perspective led researchers to move away from the perception of poor and minority students' cultural capital in terms of its deficiencies and towards explorations of its strengths. Yosso (2005) for example, identified six forms of cultural capital that students of color bring from their homes and communities, such as

the aspirational, social, and navigational capital. Yosso argued that schools should acknowledge the value that these capitals hold. For the purposes of this review, the use of the term "culture" encompasses the idea of culture being a form of capital, which holds strengths, and which is passed on from parents to children.

Valuing Non-Western Cultures in STEM Education

Valuing students' culture is particularly needed in math and science learning environments, in which the curriculum is Euro-centric and the perspectives of Indigenous, Latinx, and Black people's contributions to math and science are erased. Eurocentrism in science refers to assumptions that European-generated scientific practices and concepts are superior to the non-Western ones and that the history of science owns nothing or little to non-Western civilizations (Harding, 1994). In terms of science, the dominant Euro-centric curriculum still marginalizes the culture from non-Western civilizations. For example, Indigenous narratives about living in harmony with nature are absent from the science curriculum, although these narratives and the relevant knowledge can contribute to the sustainability of the environment (Glasson, 2010). Similarly, the Euro-centric curriculum invalidates the work of non-Westernized people (Cochran et al., 2020). The principles of scientific rationality that are taught in schools reflect Western cultures (Harding, 1994). It is not stressed enough that the questions that science asks, the ways these questions are framed, and the ways the answers are pursued still have deep political roots and implications (Kumashiro, 2001). Furthermore, the examples that science textbooks use to make science relevant to students are drawn from the dominant White culture. Cochran et al. (2020), for instance, invite people to reflect on what it means for diverse ethnical and racial groups of students to learn physics from examples that require familiarity with American football.

In terms of math, what is wrongly assumed is that the mathematics taught in schools is the only mathematics that exist in the world (Bishop, 1990). If we consider the richness of different counting systems, the different ways to record numbers, or the alternatives ways to conceive space, we recognize that mathematics is not a "uniform," phenomenon. Western mathematics not only is not culture-free, but it has been used throughout the history of colonization to impose the Western culture on Indigenous people (Kumashiro, 2001). But just as mathematics can be used as a colonizing tool, it can also be used as a tool to promote civil rights and social change. Works such as the *Algebra Project* by Moses and *mathematics for social change* implementations are notable examples (Gutierrez, 2005; Wahman, 2009).

Considering Culture and Race in Teaching

Howard and Milner (2021) highlight three areas of knowledge for preparing teachers for equitable education: (a) subject content knowledge, (b) pedagogical content knowledge, and (c) cultural and racial knowledge. Teachers' training programs often aim at the first two areas of knowledge, at the expense of the third. First, indeed, teachers should have deep knowledge of their subject. This is

especially true for math and science teachers whose level of content knowledge correlates positively to students' achievement (Howard & Milner, 2021). Second, teachers should know *how* to teach their subject. For this, not only depth, but also breadth of knowledge is needed, so that teachers can choose from a variety of pedagogical tools. Several scholars acknowledge that the areas of subject content knowledge and pedagogical content knowledge should not be treated as separate, and many professional development programs consider the dialectic relationship between these two domains (Howard & Milner, 2021).

For STEM education, when considering the subject content knowledge, it is important also to consider *content knowledge* constructed by non-Westernized people. What are the African and Indigenous cosmological and astronomical systems? What other counting systems exist, and how this knowledge can enrich mathematical thinking? How can science data, statistics, and numbers can be used to illustrate power dynamics in the world? Teachers should consider the impact of societal structures and historical oppression on historically marginalized communities. Teachers should realize that, over the history of math and science, certain racial and socioeconomic groups have been benefited and other have been oppressed (Harding, 1994). Yet just the knowledge of the oppressed history is not enough. White teachers might show guilt and anger about the Black people's tormented histories but fail to accept contemporary examples of oppression (McIntyre, 1997). It is important to uncover the power dynamics that still dominate in science and math classrooms (Cochran et al., 2020). Finally, teachers should know the cultural and racial background of the students they are going to teach (DuBois, 1999; Woodson, 1972). Figure 1 summarizes an adaptation of Howard and Milner's (2021) framework for preparing STEM teachers.

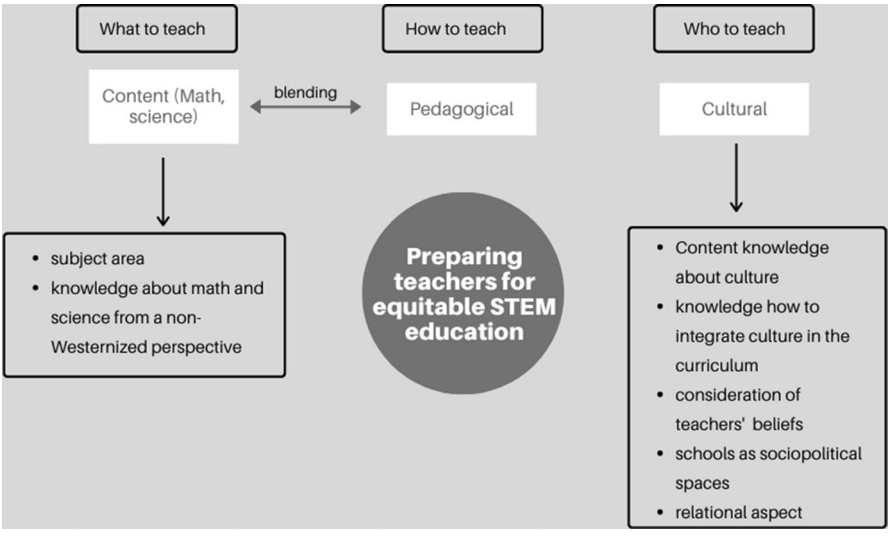

Fig. 1 Howard and Milner's (2021) adapted framework for preparing STEM teachers for urban education

CRE provides a good framework for exploring ways to understand students' cultural and racial background and it is explored further in the following section.

Culturally Relevant Education

The term CRE refers to practices and pedagogies that use minoritized students' culture and lived experiences as a starting point for teaching, with a focus on pursuing social justice (Neri et al., 2019). Aronson and Laughter (2016) used the term CRE to include closely related approaches that operate under the same tenets, but with a different focus. For example, Culturally Responsive Teaching (CRT) focuses on teachers' practices and what teachers should *do* to be culturally responsive, and Culturally Relevant Pedagogy (CRP) focuses on teachers' stances, "describing a posture a teacher might adopt that, when fully embodied, would determine planning, instruction, and assessment" (Aronson & Laughter, 2016, p. 167). Under the umbrella term, CRE, this paper incorporates also Culturally Sustaining Pedagogy (CSP) and social justice education (e.g., science and mathematics for social justice). CSP is an approach that explicitly highlights the need for schools to sustain a linguistic and cultural pluralism (Paris, 2012). Social justice education is based on Giroux's (1983) dialectic approach in which education should be politically and ethically transformative and Freire's (1970/2002) ideas that education should empower students to collaboratively investigate society and actively act to transform it—critically "read" the word; critically "interpret" the world; critically "rewrite" the world.

Ladson-Billings (1994) introduced two cornerstones important for all CRE implementations: (a) the empowerment of the collective in contrast to simply the individual, and (b) the establishment of a school culture of caring, not only for students' academic success, but for their overall well-being. These cornerstones are encapsulated in three educational outcomes: cultural competence, critical (or sociopolitical) consciousness, and academic achievement (Ladson-Billings, 1995). Teachers should address all three outcomes of CRE, and not choose one at the expense of the others (Ladson-Billings, 1995).

Cultural competence refers to helping students recognize and affirm their "cultural beliefs and practices while acquiring access to the wider culture, where they are likely to have a chance of improving their socioeconomic status and making informed decisions about the lives they wish to lead" (Ladson-Billings, 2006, p. 36). For students to recognize and affirm their culture, education should bridge students' school life with their home life (Paris & Alim, 2014). Teachers should affirm the funds of knowledge that students bring from home. Such funds can be considered as forms of capital that schools should strive to activate (Rios-Aguilar et al., 2011). Note again, that the idea of recognizing and affirming one's culture should not be seen as a static way of viewing the world or behaving in it. The concept of "funds of knowledge" is helpful for realizing that it is important to look at students' lived experiences which may or may not be coherent among groups. González et al. (2006) describe funds of knowledge of a community not as "a laundry list of immutable cultural traits, but rather [as] historically contingent, emergent within relations of power, and not necessarily equally distributed" (González et al., 2006, p. 25). To

foster cultural competence, teachers should use their students' diverse cultures as vehicles for learning and consider the funds of knowledge and unique lived experiences their students bring. Critical consciousness refers to empowering students to understand social inequalities and to act upon them (Ladson-Billings, 1995). Finally, regarding academic achievement, Ladson-Billings (2008) clarified that the term refers to authentic learning—real world learning, relevant to students' lives—and that it should not be mistaken with success in standardized test scores. To foster learning, teachers should hold high expectations for low-income and minoritized students' abilities (Ladson-Billings, 1995).

CRE Implementations in STEM

Several studies suggest that culturally relevant teaching improves achievement and cultural competence in math and science (Aronson & Laughter, 2016; literature review). Furthermore, practices that integrate minoritized students' cultural capital in STEM teaching, increase students' participation (and engagement) in STEM subjects (King & Pringle, 2019; Ortiz et al., 2019). Black girls' personal narratives, when respected and highlighted, increase involvement in STEM learning (King & Pringle, 2019) and enhance interest in STEM careers (Ellison et al., 2020). Furthermore, the ways that Black students perceive their Blackness (i..e., racial identity) in STEM learning environments affect their participation in STEM fields (Morton et al., 2019; Vincent-Ruz & Schunn, 2018).

Despite some promising results, CRE implementations in math and science remain relatively low and sporadic (Brown et al., 2019; Neri et al., 2019). Math and science teachers cannot find obvious connections between their subject areas and students' cultural and ethnic backgrounds (Boutte & Kelly-Jackson, 2010). Scholars have stressed that more effort is needed for preparing teachers to translate culturally relevant theory into practice, particularly for math and science subjects (Brown et al., 2019).

CRE-Related Challenges in STEM classrooms

Some factors act as barriers for integrating culture into teaching. In their framework for preparing teachers for equitable education, Howard and Milner (2021) highlight that knowledge about students' racial and cultural background presupposes reflection on teachers' deep-rooted beliefs. For example, White teachers hold an (often unconscious) belief about White race's supremacy—a belief that is translated to deficit perspectives about minoritized students' cultures and norms (Howard, 2016; McIntyre, 1997). The deficit perspective can be accentuated in math and science learning environments, in which the curriculum is Euro-centric and the perspectives of Indigenous, Latinx, and Black people's contributions to math and science are erased.

Another barrier for CRE is the ideology of colorblindness—not seeing race when teaching (Bonilla-Silva, 2006). Advocates of colorblind rhetoric argue for a moral preference that focuses on human similarities instead of differences. Studies suggest

that the preference to focus on human similarities instead of differences can be a hindrance to incorporate cultural experiences into STEM teaching. Hachfeld et al. (2015) studied the relationship between colorblindness and a willingness to adapt teaching of mathematics to culturally diverse populations. Colorblind beliefs were assessed through the Teacher Cultural Beliefs Scale (Hachfeld et al., 2011), and willingness to adapt teaching to culturally diverse populations was assessed through a 6-point disagree-agree response format. Analyzing results for 433 beginning teachers, the study showed that those who manifested a colorblind ideology, were reluctant to adapt their teaching to culturally diverse students. Similarly, Aragón et al. (2017) surveyed 1,179 STEM teachers who were taught inclusive teaching practices in a summer training program over a period of ten years. The study showed that teachers with colorblind ideologies reported lower use of inclusive teaching practices in the classroom than teachers with multicultural ideologies (Aragón et al., 2017).

Purpose of the Review

The current review used examples of math and science CRE implementations to illuminate: (a) the practices teachers used and (b) the challenges teachers faced, aiming to inform math and science teachers' professional development. The ultimate purpose is to assist future math and science practitioners for contextualizing their students' culture in teaching. The guiding questions were:

3. Which specific practices have been associated with positive CRE outcomes for students in math and science educational settings?
4. What were the challenges of applying CRE in math and science educational settings?

Methods

The literature search was carried out in the ERIC (EBSCO) database, following a multistep procedure. Initially, social justice education was not part of the CRE framework. The terms that were used initially were "culturally relevant pedagogy," "culturally sustaining pedagogy," "culturally responsive teaching," and "culturally relevant education," in combination with the terms "teaching science" and "teaching mathematics." The search generated 107 results for science and 6 results for math. After deduplication, the results were reduced to 86. Following this procedure, all abstracts were read and the articles that were not empirical studies in learning environments were excluded. For this review were included (a) K-12 education and teachers' professional development/training if they provided descriptions of classroom implementations, (b) both formal and non-formal learning settings.

This process generated 35 results. After reading the descriptions of the implementations, 22 qualitative papers were prioritized. These papers were chosen because they provided detailed information on (a) the context of the settings and the

teachers' background and (b) the practices that were used in the classroom. After reading the full texts of these articles, additional cited papers were identified, and three peer reviewed papers were added following the above-mentioned inclusion criteria.

For the analysis, both a deductive and an inductive approach was used. The three CRE outcomes served as a "start list" of codes (Miles & Huberman, 1994). The "methods" and "findings" sections of the reviewed studies were printed and skimmed, and the identified practices and challenges were coded in vivo (Charmaz, 2014) at the margins of the texts and were categorized as relevant to one of the tree outcomes.

The initial analysis showed that there was a limited number of studies that addressed the outcome of critical consciousness in STEM classrooms, a limitation emphasized in previous reviews (Aronson & Laughter, 2016). To enrich the findings about critical consciousness, the database research was expanded to include critical mathematics and critical science implementations. Critical mathematics and science implementations aim for a politically and ethically transformative education (Giroux, 1983; Gutstein, 2006). Such implementations were effective in addressing the outcome of critical consciousness and were also consistent with the other CRE outcomes, cultural competence and academic achievement. Two almost identical search strings were used, one for mathematics ("teaching" and "critical mathematics" or "mathematics for social change") and one for science ("teaching" and "critical science" or "science for social change"). The search provided 159 new papers, which were reduced to 7, following the above-mentioned inclusion criteria and scanning process. In total, this review examines 30 empirical papers and two book chapters (Brantlinger, 2005; Peterson, 2005). The examples in the chapters were not reported as empirical studies but provided details of critical mathematics implementations and students' opinions about these implementations (see Fig. 2 for an illustration of the reduction process and Appendix for a Table with the reviewed empirical studies). It is important to highlight that the purpose of this review was not to be extensive, but to provide a substantial number of papers that would provide detailed descriptions of how teachers implemented CRE.

The additional 7 studies were analyzed following the previously described analysis process. After the initial analysis, a detailed reading of all the printed texts followed. During this process, extensive notes were kept, and connections between codes led to groupings and finally to the emerging categories (Charmaz, 2014). The three tables presented in the "findings" section, illustrate (a) the "start list" codes in the first column, (b) the emerging categories in the second column, and (c) the groupings of the codes in the third column.

Findings

Practices and Challenges for Cultural Competence

Table 1 summarizes the practices and challenges associated with cultural competence in the reviewed studies. Regarding practices, two categories emerged: (a)

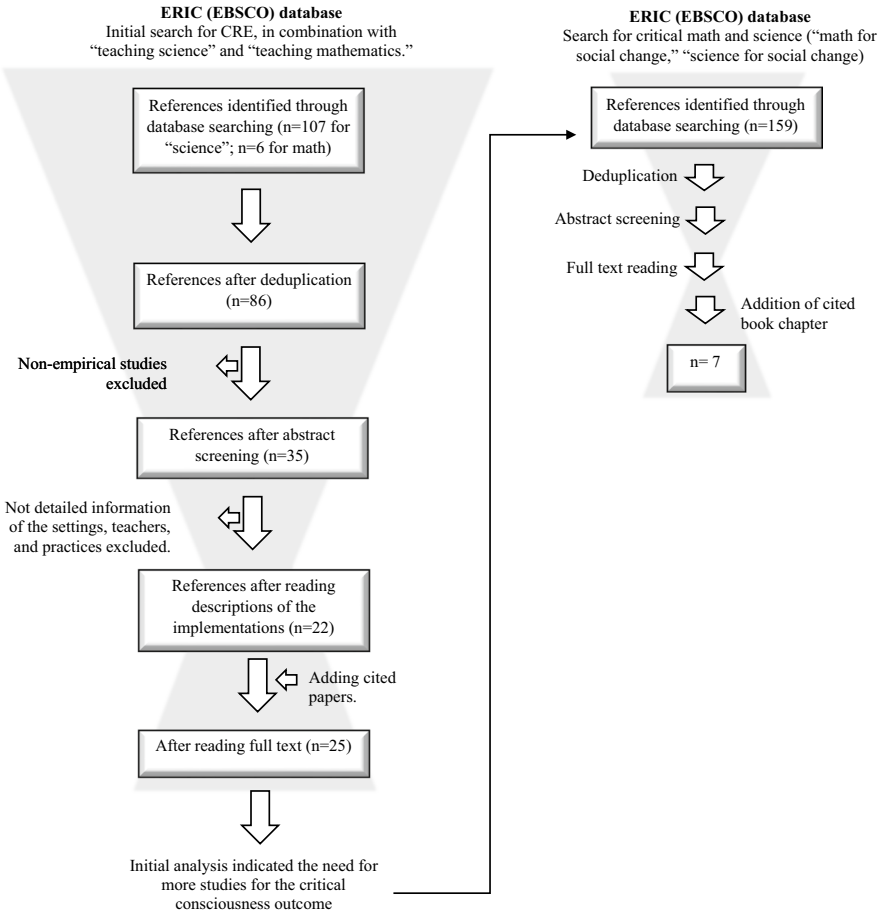

Fig. 2 Illustration of the reduction process for the selection of the articles

building stable, substantial relationships and (b) integrating students' ethnic and racial identities into teaching.

Building Teacher–Student Rapport

Cultural competence presupposes that the students feel comfortable in sharing their ethnic, racial, cultural, and personal identities. Most teachers in the reviewed studies aimed to establish a teacher–student rapport. Teacher–student rapport presupposed that (a) teachers cared for students' lives and respected students' identities and (b) students *perceived* teachers' care and respect (Basu & Barton, 2007; Hubert, 2014; Johnson, 2011; Laughter & Adams, 2012; Noddings, 2012; Tsurusaki et al., 2013). When teachers shared racial and/or cultural identities with students, teachers relied on their own experiences and knowledge

Table 1 Practices and challenges for achieving cultural competence

Cultural competence	Building teacher-student rapport	Teachers' practices: Showing awareness of students' difficulties (e.g., adopting students' first language or using expressive gestures if English was not students' first language) Encouraging discussions about students' lives and interests (e.g., brainstorming, reflections) Establishing habits (e.g., responding to the question of the day) Empowering students to draw from personal experiences to create and analyze data Interviewing students Attending students' out of school activities Acknowledging and respecting students' identities Confronting racial issues Creating partnerships with students, communities, and families Visiting students' neighborhoods and homes Challenges: Time and energy consuming Challenges with confronting racial issues (e.g., lack of tools) Challenges with visiting students' neighborhoods and homes (e.g., reinforcing stereotypic attitudes) Limitations of class size Some cultural choices might not be welcome if used by teachers of different race (e.g., use of Hip Hop in teaching)
	Integrating students' cultural and racial identities to teaching	Practices: Brainstorming, discussing, and reflecting with students Use of teachers' knowledge about students' identities Challenges: Teacher's colorblindness or biases Lack of tools, skills, or experience Curriculum and standardized evaluation restrictions

for communicating their care. Historically marginalized students tended to trust teachers of the same race (Adjapong & Emdin, 2015; Cahnmann & Remillard, 2002; Emdin et al., 2016; Kelly-Jackson & Jackson, 2011). When interviewed, some teachers reported that they drew inspiration on their cultural experiences. Due to her Puerto Rican ethnicity, a math teacher knew first-hand that her students were familiar with dominoes. This knowledge prompted her to integrate the use of dominoes into her math teaching (Cahnmann & Remillard, 2002). Due to an inherent trust, cultural choices were welcome by students when introduced by teachers of the same race. Hip hop songs in a science classroom might have estranged African American students if the teachers who introduced hip hop were not familiar with students' street code and the conventions of hip hop music (Emdin et al., 2016).

White teachers may need to work harder to earn historically marginalized students' trust. Although there may be no foolproof prescription to communicate a genuine concern and respect, White teachers recruited certain practices. Less encountered practices included adopting students' norms or language (e.g., teachers included Hispanic words and phrases in teaching; Johnson, 2011). Interviews with students revealed that, even if teachers did not adopt students' language, other practices that showed teachers' awareness of students' difficulties to comprehend English were also effective (e.g., speaking slowly, integrating pictures to teaching, non-verbal communication, such as use of gestures; Lewthwaite & McMillan, 2010). More typical practices included discussing students' personal experiences (e.g., habit of responding to the "question of the day"; Brown & Crippen, 2017). Discussions were encouraged through brainstorming (e.g., Basu & Barton, 2007) and student reflection practices (e.g., Buxton, 2010). Some teachers encouraged students to create and analyze data using their own experiences (e.g., food intake; Tsurusaki et al., 2013). A teacher in Brown and Crippen (2017) study interviewed students to learn more about themselves and their families. Teachers' encouragement prompted students' discussions about their personal interests (e.g., tuning drums; Seiler, 2001), neighborhood experiences (e.g., traumatic experiences with drunks; Tate, 1995), family concerns (e.g., mortgages, displacement; Gutstein, 2016), local issues (e.g., nearby river pollution; Bouillion & Gomez, 2001) and curiosities about universal problems (e.g., HIV-AIDS; Gutstein, 2016).

For students to engage in discussions about their experiences, teachers showed interest about their students' ethnic, racial, and cultural identities. Some teachers openly acknowledged different racial identities and directly confronted racial issues when emerged. In Milner's (2011) study, for example, whenever students highlighted the different racial backgrounds that separated them from their science teacher, the teacher openly discussed these differences. Other teachers avoided direct references to race and culture (Cahnmann & Remillard, 2002). Some teachers created partnerships with students, communities, and families (Bouillion & Gomez, 2001; Civil & Khan, 2001; Fusco, 2001; Milner, 2011). For instance, in a professional development program, teachers visited students' homes, so that they would be able to reflect on their students' everyday experiences in the classroom (Johnson, 2011). Such practices—similarly to open acknowledgement and direct confrontation of racial issues—led also to mixed results. For example, in Rubel's (2017) study,

teachers' community walks reproduced their previous stereotypic and deficit preconceptions about their students of color.

Teacher-student rapport flourished in after school and community-based programs (Basu & Barton, 2007; Calabrese Barton & Tan, 2018; Seiler, 2001; Tate, 1995). These programs established relaxed environments in which discussions were a norm. In a science after-school lunch group, students' narrations during lunch were used as prompts for scientific investigations (Seiler, 2001). Other after school programs allocated time for interactions that positively affected students' feelings about the instructors (Basu & Barton, 2007; Civil & Khan, 2001). Small classroom size might also have affected the quality of relationships built. The previously mentioned science lunch group, for example, consisted of only eight students (Seiler, 2001).

Communicating care and respect was not an easy endeavor, especially when teachers and students' race did not coincide. It entailed time, devotion, and effort. Milner (2011) detailed Mr. Hall's challenges to earn some of his students' trust. For example, he managed to build his relationship with a specific student only through his persistence and after attending the student's basketball practices. Milner (2011) characteristically notes: "Throughout my 2 years of study … I never saw, witnessed, or observed Mr. Hall taking a break" (p. 76). Similarly, the teachers in Johnson's (2011) study spent time getting to know their students and their communities. Teachers' background as described by some reviewed studies reveals teachers with a certain mindset—enthusiastic, devoted individuals, with commitment to the relational aspect of teaching (Aguirre & del Rosario Zavala, 2013; Lewthwaite & McMillan, 2010; Tate, 1995).

Integrating Students' Racial and Cultural Identities into Teaching

Knowledge about students' lives and experiences was a key starting point for integrating minority students' identities into teaching. As a next step, teachers connected this information to their curricula. Experienced teachers and teachers with strong content knowledge were likely to discover tight connections (Basu & Barton, 2007; Brantlinger, 2014; Brown & Crippen, 2017; Gutstein, 2016; Tate, 1995). Seiler's expertise and experience helped him to bridge discussions about tuning drums with a relevant subject topic (e.g., the frequency of vibration and the pitch of a sound; Seiler, 2001). Similarly, a teacher's knowledge about Hispanic cultures prompted learning because she used this information to teach how machines operate (Johnson, 2011).

Teachers who were provided with pedagogical tools for culturally responsive teaching showed a gradual confidence and effectiveness in designing inclusive lesson plans. Positive results were reported both for long (e.g., 3-year) and for shorter (e.g., 6-month) professional development programs. But even when teachers became comfortable with inclusion practices, they felt restricted by standardized evaluations (Brown & Crippen, 2017). It might not be a surprise that curriculum transformations took place in non-typical classroom settings—such as after-school and community-based programs—that were not restricted by curriculum or state policies (e.g., Basu & Barton, 2007; Calabrese Barton & Tan, 2018). Some scholars transformed the whole curriculum around themes generated by students. Gutstein (2016) created a

whole year curriculum for a 12th grade mathematics class in the Social Justice Public High School. The curriculum was co-created with the students based on personal relevant themes they discussed. Among the chosen themes were HIV-AIDS, criminalization, and displacement. Gutstein (2016) designed the math content—contextualized in the chosen themes—and let students decide the pace and the modifications of the units.

Practices and Challenges for Academic Achievement

Using Constructivist Practices to Support Learning

Teachers used constructivist practices to increase students' learning; such practices empower learners to actively construct knowledge (NRC, 1996). Seiler (2001) described the practice of debates, in which students built on their peers' ideas. Bouillion and Gomez (2001) exemplified the brainstorming and reflective practice "What do we think we know, what do we want to know, and what did we learn?" Other constructivist practices included general scaffolding activities (e.g., Gutstein, 2016), encouraging students to generate scientific questions (e.g., Tsurusaki et al., 2013), guided discourses (e.g., Johnson, 2011), open inquiries (e.g. Enyedy & Mukhopadhyay, 2007), action-based inquiries (e.g., Tate, 1995) and collaborative activities (e.g., Laughter & Adams, 2012). Close monitoring ensured the progress of the collaborative activities and of the discourse practices (Johnson, 2011; Laughter & Adams, 2012).

Shifting from the Authoritative Teacher to Teacher-as-Facilitator

Constructivist practices presuppose a shift from teacher's role as an expert, who knows all answers, to a facilitator, who supports students when needed (Freire, 1970/2002). Some scholars use the term "repositioning," to indicate that both students and teachers should acclimate with their new roles (Brown & Crippen, 2017). Teachers enlisted certain practices to convince students that their (students') thinking was valued. These practices included student-initiated research questions, student-initiated experiments, and open and action-based inquiries that required student-decision making (e.g., Buxton, 2010; Gutstein, 2003). Seiler (2001) used "student cross-talk uninterrupted by teacher talk" (p1010). Teachers in Brown and Crippen's (2017) study acknowledged collaborative learning strategies as catalytic for approaching a shift in teacher's authoritative role, a finding confirmed also by class observations (e.g., Kelly-Jackson & Jackson, 2011).

If teachers are not equipped with tools to address power shifts, they might experience the discouragement and frustration of not being able to handle time effectively so that to complete their curriculum, as observed in Dimick's study (2012). Cahnmann and Remillard (2002) highlighted a teacher's uneasiness to students' unanticipated questions and comments.

CRE professional development projects showed encouraging results when teachers were exposed to constructivist practices (Brown & Crippen, 2017; Johnson,

2011). These results included a gradual shift from teachers' authoritative role. A teacher, for example, changed his preference for one-right answer questions to open-ended questions and became more confident in engaging in investigations for which he didn't have the answers (Johnson, 2011).

Even in studies where teachers abandoned their authoritative self, teachers did not initiate student-centered lesson plans because they felt restricted by institutional norms (Brown & Crippen, 2017). Conversely, in after school and community-based programs, where there was more flexibility regarding curricula, teachers allocated "control" to students; this was most often translated in student-centered curricula (e.g., Basu & Barton, 2007; Gutstein, 2003; Seiler, 2001). A teacher characteristically saw herself as a "school bus driver," who goes where students live to pick them up and follows their directions for where they choose to go (Tate, 1995, p.172).

Communicating High Expectations to Advance Academic Excellence

Culturally responsive teachers should hold high expectations for students' abilities so that to push them toward academic excellence (Ladson-Billings, 1995). Still, oftentimes, teachers have low expectations for low-income and minoritized students' achievement (Ayers et al., 2008). Thus, it is important to identify the ways science and math teachers communicated their high expectations in the reviewed studies.

Teachers consistently made clear their high expectations and asked for better academic results (Milner, 2011). They supported completion of students' tasks by designing manageable and open-ended assignments (Lewthwaite & McMillan, 2010) and by enacting strict plans with consequences for students who didn't complete their work (Johnson, 2011). In some cases, teachers engaged their students in open inquiries that demanded sophisticated techniques. For these inquiries, teachers designed challenging (but accompanied with scaffolding practices) real-world problems, while they continuously monitored students' performance (Gutstein, 2003; Gutstein, 2016; Tate, 1995). Teachers avoided correcting students, but did not provide easy solutions; instead, they redirected students' thinking (Brown & Crippen, 2017; Tsurusaki et al., 2013). In many studies students mentioned that these classes were the most challenging and demanding they had attended (Calabrese Barton & Tan, 2018; Gutstein, 2003; Milner, 2011).

A possible threat to communicating high expectations is insinuated in Brown and Crippen's, (2017) study, in which teachers initially revealed some stereotypic beliefs about minority students' deficiencies. Teachers' claims were not based on their direct experiences, but on media, conversations, and books. These stereotypic beliefs seemed to gradually shift after teachers' reflexive stances on macro-level influence.

Evaluating CRE Implementations Through Alternative Assessments

Some researchers used standardized tests to assess students' learning (Enyedy & Mukhopadhyay, 2007; Gutstein, 2003; Rodriguez, 2015), but in most studies, teachers and researchers used alternative assessments. Alternative assessments included artifacts, such as newspaper articles (Tate, 1995), presentations (Calabrese Barton

& Tan, 2018; Gutstein, 2016; Seiler, 2001; Tate, 1995), STEM innovations (e.g., anti-bullying app, light-up umbrella, house alarm system; Calabrese Barton & Tan, 2018), and students' journals—in which students reflected either on the content knowledge (Johnson, 2011) or on social justice issues (Gutstein, 2003; Gutstein, 2016). Students' artifacts were evaluated through a variety of ways. For example, Bartell (2013) used students' presentations to triangulate findings about their learning. In the rubric she created, she analyzed students' types of claims (e.g., describing or comparing variables) and the evidence they used to support their claims (e.g., statistics, use of interactive map, stories, and individual data points). Some scholars and/or teachers evaluated quality of dialogue; (Brantlinger, 2014; Laughter & Adams, 2012) or used informal assessment points during scientific inquiries (Johnson, 2011). Some teachers implicated students in the evaluation process targeting their metacognitive skills. For example, Adjapong and Emdin (2015) empowered students to evaluate their own memorization and understanding of science concepts. In Brown and Crippen (2017) study, one teacher created a worksheet so that students could monitor their group communication level. Teachers interviewed in Johnson's (2011) study highlighted the conflict between CRE alternative assessments and high state tests on standardized curriculum.

To sum up, for fostering academic achievement, teachers used constructivist practices to support learning that presupposed a shift from the authoritative teacher to teacher-as-facilitator. Even when provided with training and constructivist tools, some teachers felt that constructivist practices and the shift from the authoritative teacher conflict with curriculum restrictions and institutional norms. To target academic excellence, teachers should communicate high expectations to their students. Teachers' stereotypic beliefs about poor and minoritized students' abilities was a possible threat for holding high expectations. Teachers used a range of alternative assessments for evaluating students' progress, although some teachers felt that alternative assessments conflicted with standardized curricula (see also Table 2).

Practices and Challenges for Achieving Critical Consciousness

Understanding injustices and acting upon them are interdependent processes as learners understand the world and reflect on their actions (Gutstein, 2016). Although understanding sociopolitical issues is a precondition to acting, these two processes do not progress linearly, but dialectically (Gutstein, 2016). Not all reviewed studies reached the second process, therefore, two categories emerged: (a) practices aimed for students' understanding about sociopolitical issues and (b) practices aimed for students to become actors of change (see also Table 3).

Practices Aimed for Students' Understanding about Sociopolitical Issues

Understanding an injustice and reflecting on its consequences is important for realizing how the world works (Gutstein, 2016). To this purpose, many teachers used reading materials as prompts for group discourse in the classroom (e.g., math problems, articles, extracts from books, and science fiction stories). Ensign (2003) used

Table 2 Practices and challenges for achieving academic achievement

Academic achievement	Using constructive practices to support learning	Practices Debates, guided discourses, brainstorming, reflecting (e.g., "What do we think we know, what do we want to know, and what did we learn?") Scaffolding Responsive strategies Encouraging students to formulate research questions Open and action-based inquiries Collaborative activities Challenges: Shifting from the authoritative teacher to teacher as facilitator Assessment challenges
	Shifting from the authoritative teacher to teacher as facilitator	Practices: Student-initiated research questions student-initiated experiments student crosstalk uninterrupted by teacher talk Hip-Hop inspired practices (*call-and-response* and *co-teaching)* Collaborative strategies Challenges: Lack of tools and training Curriculum and time restrictions Institutional norms
	Communicating high expectations to advance academic excellence	Practices: Making clear high expectations Strict plans with consequences Monitoring and scaffolding open inquiries Not providing solutions—redirecting students' thinking Challenges: Stereotypic beliefs

Table 2 (continued)

	Evaluating CRE implementations through alternative assessments	Practices: Evaluating students' artifacts; newspaper articles, presentations, STEM inventions, journals Evaluating quality of dialogue Informal assessment points Self-assessment rubrics Challenges: High stakes tests

Table 3 Practices and challenges for achieving critical consciousness

Critical consciousness	Practices aimed for students' understanding about sociopolitical issues	Reading materials as prompts for reflection; math problems, articles, extracts from books, and science fiction stories Group discourse Kinesthetic simulations Discovering injustices through math manipulations or data analysis
	Practices aimed for students to become actors of change	Creating a pedagogy of questioning Normalizing politically taboo topics Developing political relationships with students Empowering students to create arguments through math manipulations and data analysis Guiding students to create artifacts for an audience; presentations, graphs, performances, letters to stakeholders, newspaper articles and webpages
	Challenges	Fear of raising inappropriate issues Lack of tools to address conflicts if raised Lack of experience Teachers' indifference for sociopolitical issues Students' and parents' own reservations for addressing sociopolitical issues in the classroom

math problems to show that stores in some neighborhoods were more expensive than others. Laughter and Adams (2012) prompted discussions about scientific and societal bias, using the counter-storytelling sci-fi story *The Space Traders*, Samuel Morton's skull measurements, and Lawrence Summer's comments on intelligence differences between males and females.

Some teachers used kinesthetic simulations, in which students simulated with their bodies the concepts that they needed to explore, so kinesthetic (embodied) experiences became vehicles for reflecting on social inequities. An often-reported example was a simulation of the disparity of the distribution of wealth in the world (Esmonde, 2014; Gutstein, 2003). In all similar implementations, kinesthetic simulations were followed by whole class discussions.

Teachers empowered students to discover social inequities through data analysis in science classes and mathematical manipulations in math classes. In an elementary science study, students used their zip codes to evaluate how close they lived to air pollution sources and analyzed rates of asthma hospitalization in various areas; they discovered that their Bronx neighborhoods were closer to sources of air pollution and that asthma cases were higher in students' neighborhoods (Mensah, 2011). In a math class, students analyzed the demographics of employment in 10,000 new jobs that were created in the city of Milwaukee (Peterson, 2005). Students analyzed and converted data into percentages and graphs and were surprised to realize (a) that African Americans took over less than 8% of the new jobs, although they represented 30% of the city's population and (b) Latinos and African Americans combined, held just 1% of the higher paid jobs (Peterson, 2005). In another case, a summer course for students who had failed geometry the previous academic year, students were asked to estimate what they thought would be the average ratios of people to movie theaters, liquor stores, and community centers in a typical city (Brantlinger, 2005). Then, they predicted the number of theaters, liquor stores, and community centers in a three-mile-radius area of South Central. Students learned about the riots in South Central, and they discovered that when the riots' violent incidents took place, there were no communities and no movie theaters in the area, while there were 640 liquor stores (Brantlinger, 2005).

Practices Aimed for Students to Become Actors of Change

Generally, teachers applied Gutstein's proposed practices (2016). They (a) created a pedagogy of questioning, (b) they normalized politically taboo topics, and (c) they developed political relationships with students. For example, the teacher in Tate's (1995) study asked students to brainstorm problems that impacted their community negatively. She did not hesitate to openly discuss students' traumatic experiences with drunks in their neighborhood. And after guiding students to discover that there were 13 liquor stores within 1,000 feet of their school, teacher empowered them to act. Among other things, students reconstructed tax and fiscal incentives, studied local maps and compared them with maps they created, and manipulated mathematical concepts in order to present their findings to community stakeholders. Students saw the results of their actions; the police issued

200 citations to the liquor stores, two of the 13 stores shut down, and the City Council adopted resolutions about liquor consumption in their vicinity.

In some cases, students' action was as simple as sharing their understandings to their classmates or their communities (Bartell, 2013; Calabrese Barton & Tan, 2018; Gutstein, 2016). Bouillion and Gomez (2001) document a case in which students performed a play and created a webpage to raise awareness about pollution in a nearby river. In other cases—as in the example from Tate's (1995) study—students tried to convince stakeholders about what they perceived as injustice, aiming to create a visible change (Calabrese Barton & Tan, 2018; Gutierrez, 2005; Tate, 1995; Turner et al., 2009). In any case, students were *empowered to use* all the variables that would result in a compelling mathematic or scientific argument and *to create artifacts*: presentations and plays to the communities, letters to stakeholders, newspaper articles and webpages, graphs.

However, there was a general insecurity among teachers that the outcome of sociopolitical consciousness might be inappropriate (e.g., Buxton, 2010). In a reviewed example, a teacher who designed a unit on social biases commented on her fear that this would be the end of her career. Her colleagues "counseled her against the lesson because they thought it would be just a bunch of racial comments and inappropriateness" (Interview, 2 March 2011, in Laughter & Adams, 2012, p. 1121). Teachers' insecurity stemmed from (a) general beliefs about the controversial nature of sociopolitical issues (Gay, 2015) and/or (b) from a lack of tools to raise sociopolitical consciousness. Indeed, if not well equipped, teachers might face serious challenges during their implementations. Dimick (2012) described an incident in which a teacher did not know how to react to inappropriate comments of his students towards the clothing and accents of other students.

The successful examples reviewed were implemented from teachers who themselves identified as politically active, who strongly believed in addressing social justice issues, and who expressed confidence in supporting their students to act upon those same issues (e.g., Gutstein, 2016; Tate, 1995). Brantlinger (2014) also suggests that teacher's experience plays an important role for these implementations to be successful. Gutstein (2003) comments on teachers' fears as partially justified, because some issues are not easy to handle in the classroom. Brantlinger (2014) also reported difficulties in overcoming students' passive and active resistance to this kind of learning. Students, for example, expressed their concerns that time spent for discussions takes away some time from learning the content of mathematics (Brantlinger, 2014).

Still, professional development programs might target teachers' insecurities. Stinson et al. (2012) taught a graduate-level seminar aiming to introduce students to critical pedagogies and to empower students to reposition math teaching within the critical pedagogy lens. The seminar included an overview of (a) Marx and Engels theory and (b) Freire's scholarship and critical mathematics pedagogy. Results of the seminar as presented in two case studies showed that the aims of the seminar were fulfilled; the two students (teachers) engaged in becoming critical mathematics pedagogues, though the shift of their pedagogical philosophies was faster than the shift of their mathematical practices.

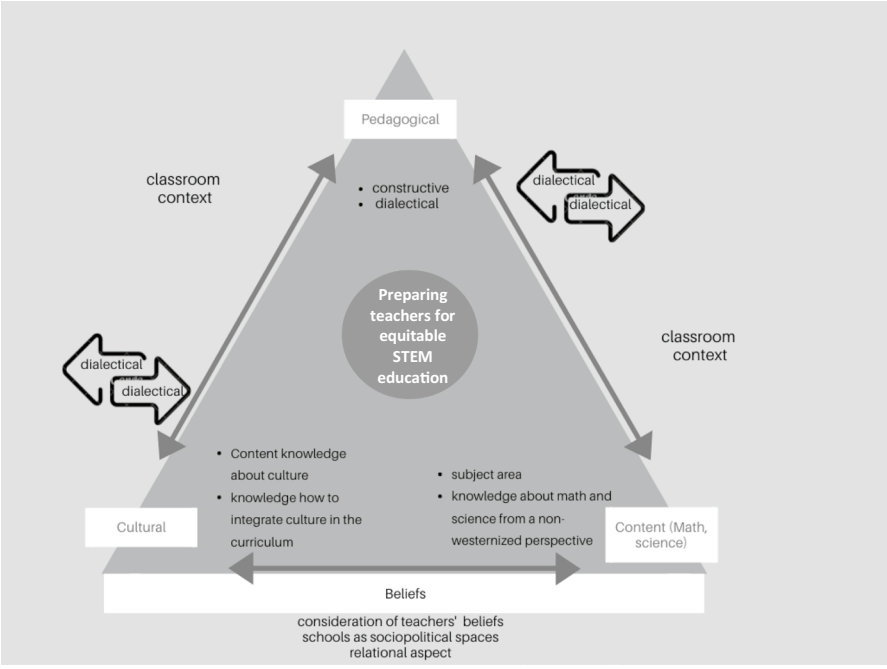

Fig. 3 Revised framework for preparing STEM teachers for urban education

Discussion

The current review used examples of mathematics and science CRE implementations to illuminate: (a) the practices teachers used and (b) the challenges teachers faced, aiming to inform mathematics and science teachers' training and professional development for equitable education. To frame the discussion, Howard and Milner's (2021) adapted framework about preparing teachers (previously illustrated in Fig. 1) will be used. Figure 3 summarizes additional insights to the original framework.

Teachers Should Create and Sustain a Dialectic Channel with Their Students

The framework for preparing teachers for equitable education (as shown in Fig. 1) highlights the areas of knowledge that teachers should possess, namely (a) subject content, (b) pedagogical content, and (c) racial and cultural knowledge. The reviewed studies highlight that teachers' knowledge should not be viewed as a "message" meant to be delivered to the students, but as a base for *interactions* and dialogue with the students; teachers should be prepared to hear their students' message. (The interaction is indicated with the double arrows between the triangle and the classroom context in Fig. 3). In other words, for successful CRE implementations, a shift from traditional instruction to learner-centered instruction is needed. Indicative of this shift in the examined studies is (a) the use of constructivist practices for

achieving all three outcomes (academic achievement, cultural competence, critical consciousness), (b) the culture of dialogue that teachers established with the students. Therefore, *constructivist* and *dialectical* tools consist part of the pedagogical content knowledge that teachers should possess. Such knowledge, though, does not end during teachers' training, but is further developed during the teacher-students' interactions in the context of the classroom.

To understand the interaction aspect, take cultural knowledge as an example. It is often suggested that teachers' pipeline for schools with historically marginalized students should prioritize teachers from historically marginalized populations because they already have the racial and cultural knowledge needed (Toshalis, 2013). Indeed, the current review includes examples of teachers who confirmed that they drew their inspiration for integration from their own cultural experiences that were similar to their students' (e.g., use of dominoes for math teaching, use of hip hop for engaging in learning scientific concepts). But cultural knowledge per se is not a panacea. In addition, in many effective CRE implementations, the teachers (regardless of their racial and cultural background) did not rely on what they already knew but invited their students to reflect on and talk about their personal lived (students') experiences. Such discussions acted as prompts for scientific investigations (e.g., when creating inventions that would solve problems of the neighborhood) and/or math explorations (e.g., after discussing traumatic experiences with drunks, students discovered that the liquor stores in their neighborhood outnumbered the liquor stores in other neighborhoods). What stands out from these studies is how engaged and empowered students felt for talking about their own experiences. Therefore, besides the racial and cultural knowledge teachers should possess (which is an important area of their preparation as the original framework highlights), teachers should be furthermore equipped with constructivist tools, which promote a *dialectical relationship* with their students so that they can understand students' funds of knowledge and lived experiences.

It is Important to Blend Subject Content, Pedagogical Content, and Cultural Knowledge

As Howard and Milner (2021) have identified in their framework, the *content* and *pedagogical* areas should not be viewed as separate, but as interrelated areas. The reviewed studies highlight that none of the three areas is separate, but all areas affect each other (illustrated with the triangle and the thin double arrows in Fig. 3). The previous section highlights the relationship between *pedagogical knowledge* (constructivist and dialectic practices) and the *cultural knowledge*. Another example of blending is the relationship between *content knowledge* and *cultural knowledge*. This relationship is important for integrating students' culture into the curriculum. As mentioned above, in many examined cases, students were asked to talk about their experiences (informing the cultural knowledge of the teachers). For teachers to integrate students' culture into teaching, *a strong subject content* knowledge was needed. For example, Seiler's (2001) deep scientific knowledge helped him to connect his students' interest for drums with introducing the frequency of vibration and

the pitch of sound. Gutstein's (2016) deep and broad knowledge helped him to link students' chosen themes of HIV-AIDS, criminalization, and displacement to the 12th grade math curriculum.

Teachers Should be Equipped with Alternative, Constructivist Assessment Tools

The constructivist model of knowledge follows different assumptions about how learning happens and how learning can be manifested than the traditional lecture-type model. Therefore, when teachers use constructivist practices for teaching, they should shift their methods of evaluating students' learning (Pellegrino, 2014). Considering that the reviewed CRE implementations integrated constructivist teaching practices (as other studies also suggest, e.g. Laughter & Adams, 2012), it is not a surprise that the reported evaluations shifted from traditional text-based evaluations to more process-based and alternative ones. For example, teachers evaluated the quality of dialogue in students' talk, encouraged students to evaluate themselves with the use of self-assessment rubrics, or evaluated students' artifacts, such as newspaper articles, presentations, STEM inventions, and journals. Therefore, as part of the pedagogical training, teachers should also get familiarized with constructivist methods of evaluating students' learning.

It is Important to Notice and Shift Teachers' Beliefs

Howard and Milner's (2021) framework already acknowledges the important role that teachers' beliefs and dispositions play for their preparation, especially for the racial and cultural knowledge. Indeed, beliefs such as colorblindness and meritocratic ideas obstruct White teachers from incorporating inclusive practices in their teaching; such beliefs have also been acknowledged as challenging in some of the examined studies (e.g., Brown & Crippen, 2017).

The current review highlights some additional dimensions of teachers' beliefs, pivotal to consider when preparing math and science teachers (thus, the movement of the "beliefs" label in the *base* of the triangle in Fig. 3). First, teachers who used effective CRE practices believed in the relational aspect of education. For example, teachers who were successful in achieving cultural competence reported their belief in the importance of building strong relationships with their students. Researchers also observed that teachers devoted much time and effort in order to build strong relationships (e.g., Johnson, 2011; Milner, 2011). Indeed, proponents of CRE encourage the development of a culture of communication and caring (Gay, 2010; Ladson-Billings, 1995). Such a mindset may or may not depend on teachers' idiocrasies; and may or may not be attended during teachers' preparation. Future research should examine whether teachers' training can affect teachers' mindset about the relational aspect of education so that to result in effective CRE implementations.

One of the major challenges that teachers encountered in the examined studies was their difficulty to incorporate in the mathematics and science curriculum what they learned about their students' race and culture (e.g., Johnson, 2011). This difficulty can be linked, among other things, to the decontextualized way that

mathematics and science is traditionally taught. This way of teaching is tied to a general belief that mathematics and science are neutral and culture-free subjects (Gutstein, 2003). For teachers to understand that mathematics and science are not culture-free, it is important to educate them about the historical oppression linked to math and science, the different perspectives that non-Eurocentric (e.g., Afrocentric) curricula can bring to math and science teaching, and the various ways that non-Western civilizations approach these disciplines. Likewise, for teachers to be able to integrate their students' culture to teaching, they need to abolish beliefs that scientific and math knowledge is static and objective (rather than dynamic and contextualized). These beliefs though, may be core beliefs that cannot be easily changed (Thompson, 1992). According to Chen et al. (2015), the dynamic and static ways of conceptualizing scientific knowledge are similar to the two ways to see the world as suggested by Piaget et al. (1989). Future studies should examine whether and how teachers' preparation can shift these beliefs.

Reconsidering Schools as Sociopolitical Spaces

In the examined studies, teachers who were themselves socio-politically active, were confident in instilling critical consciousness to their students. If teachers refuse to realize that any action (or non-action) has a political value they will not be able to manage controversial discussions (Howard & Milner, 2021), let alone to empower their students to 'read' and 'write' the world (Gutstein, 2003). Indeed, several teachers were worried about how to handle racial discussions, or what others would think about lessons that raised sociopolitical issues. Professional development programs need to (a) address teacher's socio-political consciousness *and* (b) to equip them with practices that can raise the socio-political consciousness of their students. Using critical race theory as a lens to understand education can raise teachers' awareness (e.g., Stinson et al., 2012).

Conclusion

The discussion of the findings highlights some ideas when considering teacher education and professional development: (a) teachers should be equipped with dialectic approaches, which facilitate their interactions and discussions with students, so that they can understand their students' cultures and lived experiences, (b) teachers can draw from constructivist approaches, which help them build on what they learn about their students' cultures and lived experiences to create curricula which are relevant to minoritized students' lives, (c) strong content knowledge helps teachers to make connections between the content to be taught and students' lives, (d) teachers should learn how to use alternative assessments that align with the constructivist practices they use, (c) teachers' training should attend to teachers' beliefs about the relational aspect of education, the importance of considering their students' cultures, their own role as facilitators, and the role of schooling as a sociopolitical space.

Specifically, for the use of CRE in mathematics and science, teachers should be also aware of the histories of oppression in STEM fields, of the dynamic rather than static nature of mathematics and science, and of the contribution of non-Western civilizations on mathematics and science. Teacher education in STEM can rely on constructivist methods, which align with both CRE pursuits and mathematics and science effective approaches of teaching. It is imperative to address teachers' misconceptions that mathematics and science are a-cultural and objective subjects. An understanding of the role that socio-political and socio-historical contexts play for the construction of knowledge regarding STEM subjects will improve not only CRE aims, but will also contribute to a better understanding of the nature and role of mathematics and science.

CRE takes a different perspective of what education should look like, and what educational outcomes should be. A potential disadvantage of CRE enactments might be a failure to align their outcomes to the dominant science and mathematics expectations (Harper, 2019). If CRE curricula compromise learning, the result might be more harm than good, because science and mathematics achievement plays a gatekeeping role (Harper, 2019). This is particularly important for historically marginalized students, since no educational opportunity should be neglected (Gutstein, 2006). The current review shows that, even when teachers are provided with training and constructivist tools, they may feel that use of constructivist and inclusive practices and the shift from the authoritative role conflicts with curriculum restrictions and institutional norms, such as high-stake tests, classroom discussion patterns, role of the teacher as an authoritative figure who has all the answers, and classroom management techniques. It is imperative that these norms are re-negotiated and reformed.

Whereas it might seem that too many approaches might be under the term CRE as used in this review, all these approaches use minoritized students' culture and social justice purposes and aim to address outcomes of academic achievement, cultural competence, and critical consciousness. Studies that follow a CRE perspective should consider all these three purposes explicitly. Different practices might serve different purposes regarding equity and learning. Finding the right balance might be a challenge which is important to be acknowledged in future CRE research endeavors. Although successful CRE implementations involve collective transformations of habits, beliefs, curricula, and school structures, local social actions—such as classroom and school encounters—are not senseless (Erickson, 2004); they have the potential of becoming "global, entailed in social processes on broader time scales than that of the moment at hand" (Erickson, 2004, p. 102), contributing to larger social changes.

Appendix: Reviewed Empirical Studies

See Table 4.

Table 4 Matrices Used for an Initial Recording of the Reviewed Empirical Papers

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Adjapong and Emdin (2015)	Qualitative: questionnaire, focus groups, video taped recordings, observations, field notes, coding	Urban middle school/ 68% African American students, 26% Latino	Science	Hip hop based education; call and response; co-teaching	Academic success (indirectly) Cultural competence	Not mentioned	Not mentioned
Aguirre and Zavala (2013)	3 year professional development study Qualitative; teacher interviews, classroom artifacts	Six teachers (PD)	Mathematics; following CCI and NCTM standards and curricula	Critical teachers' reflection Purposeful pedagogical dialogue	No reports on students' outcomes (study was included for the outcomes about teachers)	Novices; graduated from a mathematical methods course	Not mentioned
Basu and Barton (2007)	Qualitative; critical ethnography; interviews (life history approach); reflection notes; participant observation; collection of students' work	Urban middle school; 1/3 African-Americans; 2/3 Latino; three case studies, representative of the larger sample	Science; after school program	Dialogic practices	Sociocultural competence Long-term commitment to science	Participant researchers	Science is a human activity; science is not objective
(Bouillion & Gomez, 2001)	Case study; audiotapes, field notes, observations, artifacts, interviews	Fifth grade students, teachers of two classrooms	Science, math, language arts, civics; river polution	Project-based practices (e.g., problem identification, data collection, etc.), partnerships	Academic achievement	Not mentioned	Not mentioned

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Brantlinger (2014)	Qualitative; transcriptions of 16.5 h of videotaped lessons, 12 audio-recorded pre- and post-interviews, students' writings	28 students in a night High school; 13 Mexican descent, 7 Puerto Rican, 6 African American, 1 Honduran, and 1 Pakistani	Geometry; a combination of critical math activities, and traditional scripts for standardized tests	Use of Critical mathematics practices	Sociopolitical consciousness (mixed results)	Researcher practitioner; experienced mathematician, but inexperienced in critical mathematics	Shifted his initial belief that critical maths would
Brown & Crippen (2016)	Qualitative; observations, group interviews, artifacts	Six life science teachers (PD)	Life science; Race and skin cancer, diets and macromolecules	Inquiries, discussions	The study followed the teachers only during their 6 months PD. No reference to students' outcomes	Very experienced (apart from a second- year teacher), exceptional content knowledge, hard working, extremely skilled, active, collaborative	Changes in; views of students; shifts in the authoritative role of the teacher; collectivist orientation to teaching; contextualization of students' experiences
(Buxton, 2010)	Mixed methods; pre- and post-interviews, presentations, scored performance rubrics	23 middle school students in a nature center	Environmental science	Documentary film watching, creating posters, dialogic practices, data collection, open inquiry	Academic achievement Sociocultural competence	Researcher	Critical perspective
(Calabrese Barton & Tan, 2018)	Longitudinal, critical, ethnographic; field notes, artifact interviews	48 STEM youth makers	STEM interdisciplinary	Maker space practices, community interviews, partnerships	Sociocultural competence	Not mentioned	Not mentioned (but students mention relational aspect)

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Civil and Khan (2001)	Qualitative; observations, interviews with students and teacher	Four elementary students and their teacher	Math; measurements	Gardening	Academic achievement (effective math talk, engagement)		
Dimick (2012)	Qualitative; participant observer; case study; pre and post interviews; focus groups	Urban public charter High school/ Teacher and 24 African American students (9 participated)	Environmental science (elected course); river pollution; social injustice	Field trip Experiments Action based inquiry Collaboration Creation of rap songs	Academic achievement (through engagement)	White, male teacher, fifth year of teaching	Not experienced in student-centered projects
Emdin et al. (2016)	Qualitative; interviews, lyrics, field notes, observations, transcriptions	Three students out of participants from ten high schools (African-Americans and Latinos)	science	Reality pedagogy, hip hop based instruction, spoken word therapy, Writing and performing rap	Academic achievement (indirectly, through the integration of lyrics) Cultural competence	Researcher practitioners	Important for marginalized groups to find their voice and express themselves
Ensign (2003)	Qualitative; interviews, classroom observations	Students in two urban elementary schools	Math problems connected to students' experiences in local stores; discussions about social issues	Journal writing	Academic achievement Cultural competence Sociocultural consciousness	Not mentioned	Not mentioned

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
(Enyedy & Mukhopadhyay, 2007)	Mixed methods; pre-post- assessments, video recordings, students' artifacts (oral presentations)	25 High school students in a summer seminar	Math; statistics	Readings in sociology of education, interviews with community members, inquiry, data analysis, use of maps, use of GIS software, creating presentations	Academic achievement Cultural competence	(five teachers), competent in connecting with urban youth, not experienced (1–3 years)	Not mentioned
(Esmonde, 2014)	Qualitative; case study; video analysis, students' artifacts	Two teachers and their 7th grade classes	Math; wealth distribution; distribution of community resources; curricula adapted from a Chapter of *Rethinking mathematics*	Embodied simulations, mapping resources	Sociocultural consciousness	Not mentioned	Not mentioned
(Fusco, 2001)	Action research; field notes, students' artifacts, lesson plans	Teens (aged 12–16) from homeless families in an after school program	Science; community gardening	Joint decisions with students; discussions with students; collaborative collage; brainstorming; inviting adults; artifacts as evaluations	Academic achievement; Cultural competence	Teacher-researcher	Advocate for social change; learning within community important; science is cultural; interested in students' experiences

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Gutstein (2003)	A two year qualitative study; practitioner-research; triangulation; participant observations, open-ended surveys, textual analysis documents, teacher and students' artifacts, test scores, informal discussions	White male teacher/ 26 students in an Urban Middle school; 99% Latino, 98% low income	Math; NCTM Standards based curriculum (rich with examples)	Real life projects	Academic achievement Cultural competence Sociopolitical consciousness	Experienced/ practitioner-researcher	Strongly believed that social justice issues should be addressed in the classroom; students should "read" and "write" the world
Gutstein (2016)	Design of curricula inspired by students' suggestions/ Qualitative study; analysis before and after one academic year; participant observations; student open-ended surveys; 5 focus groups; audio recorded interviews; journals, field notes, video recordings of students' presentations;	White male teacher; 21 low income 70% Latino and 30% black High school students	Mathematics through sociopolitical context; for example linear and quadratic regression or interpreting complex graphs and data through the unit of displacement	Teaching from generative themes; *doing the dance; scaffolding*	Academic achievement Cultural competence Sociopolitical consciousness	Very experienced/ practitioner-researcher	Is aware of power relations; believes in the power of mathematics to understand the roots of injustice
Hubert (2013)	Study on students' responses to CRE/ Qualitative; interviews, transcription and coding	5 (out of 37) at-risk African American High school students	Maths; quadratic and exponential functions; teen pregnancy, HIV, smoking, football, etc		Academic achievement (positive attitudes)	Not mentioned	Not mentioned

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Johnson (2011)	Qualitative; observations of two CRP trained teachers for 3 years; interviews; classroom observations; focused groups; journals; field notes	One male and one female white teacher in an urban Middle school/ majority of students Latino	Science	Classroom discussions; Inquiry	Academic achievement	Willing to build strong relationships	The intervention changed teachers beliefs about: knowledge, social relations, conceptions about self and others
(Kelly-Jackson & Jackson, 2011)	Qualitative case study; questionnaire; focused interview; class observations; field notes; audio notes from the observations, artifacts	Sixth grade science teacher (study part of a bigger project)	Science	Discussions; books; collaborative learning; discovery learning; encouraging for critical thinking; observations; inquiries	Not applicable	African-American, female, was considered excellent teacher by her colleagues	High expectations of urban students; relational aspect; increased willingness to learn from students; science is not static
Laughter and Adams (2012)		White male researcher; white female educator; Middle school	Science/ bias in science	Formative assessments of the discussions Use of literature Class discourse Integration of science fiction Connection to students' real life experiences	Academic achievement Cultural competence Sociopolitical consciousness		
(Lewthwaite & McMillan, 2010)	Qualitative; interviews, conversations, questionnaires, and observations,	Middle school Inuit students	Science; Inuit-centered curriculum	Self-evaluations, high expectations	Academic achievement	Not mentioned	Persistent, caring, relational aspect, high expectations

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Milner (2011)	Qualitative; observations for two years; semi-structured interviews; triangulation of thematic patterns	White, male science teacher in an urban Middle school/ majority of students African-American from lower socio-economic backgrounds	Science Curriculum not mentioned in the study	High expectations Show of care Second chances Relationship building Confronting race Recognize identity Communal commitment Collaboration with colleagues and other students Engagement Motivation	Cultural competence Academic achievement	Selected as the Teacher of the year by his colleagues, while only three years in teaching Working hard, never observed to take a break	Teaching is a relational and communal concept
Rodriguez et al. (2004)	Quantitative; pre and post tests (Test of Integrative Process Skills), Qualitative; students' group interviews	10th graders, low socio-economical status; 193 students 21% African American, 17% Pacific Islander, 46% Mexican American and Latino, 12% Native American, and 4% other	Math and science; curriculum developed by University; applied in a six week summer program which took place in the University	Culturally responsive practices (not specified)	Academic achievement, Cultural competence	Not mentioned	Not mentioned

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
Rubel (2017)	Qualitative; Observations, field notes of teachers' implementations after a PD intervention; interviews	3 (out of 12) white women were chosen because they scored high in DDP/ grades 9–12	Mathematics	Collaborative mathematics problem solving, readings, community walks, reflections	No reports on students' outcomes	Hard working, enthusiastic, color-blinded	Reproduction of deficit views of their students' neighborhoods when they walked in their communities
Seiler (2001)	Qualitative; Use of transcripts	White female researcher and 8 students/ Public High school/ 97% African American students/87% low income	Science; curriculum driven by students' interests and preferences/ science lunch club	Building on cultural funds of knowledge "Student cross-talk, uninterrupted by the teacher" Informal climate; voluntary attendance, sat on couches, shared food	Academic achievement Cultural competence	White female researcher	Three Rs- respect, rapport, relationship Standards testing is problematic for equity
(Seiler & Gonsalves, 2010)	Critical ethnography; video recordings, observations, non-formal discussions, course artifacts, open-ended interviews	Two white male and female teachers teaching High school	Life science (elective); reproductive, nervous, and circulatory system, role play	Dialogic practices; topics emerged by students, discussions, brainstorming, valuing students' voice	Academic achievement	Two white male and female teachers that previously assisted in a science lunch project	Reflected on their previous lack of success, wanted to change that

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
(Stinson et al., 2012)	Qualitative; non formal discussions, artifacts	Two part-time doctoral students and full-time mathematics teachers	Graduate level; math; Course on critical mathematics pedagogy	Overview of critical theory, readings, discussions	Sociopolitical consciousness	White, 30-year old with limited previous exposure to ethnic diversity	Shifted to critical reflections; belief in changing and improvement
Tate (1995)	Qualitative; analysis of documents related to teacher's pedagogy (newspapers, legislative resolutions, videotapes); teacher ethnographic interview	Female teacher African American Urban Middle school students	Mathematics/ AIDS epidemic, drugs, ethics in medicine, sickle cell anemia, tax codes, fiscal incentives	Brainstorming; group collaboration; open inquiry; action driven inquiry; presentation of findings	Sociopolitical consciousness Academic achievement (implied, but not measured)	5 years experience, previously worked as entrepreneur, politically active. Perceived as an "outstanding" teacher who engaged students relevant pedagogy./ run successfully gifted program	Believed that education should prepare students for real life problems/ connect learning with students' experiences/ democratic citizens

Table 4 (continued)

Study	Description of study	Participants	Content area and curriculum	Identified practices	Outcomes Connected to CRP	Teachers' characteristics	Teachers' beliefs
(Tsurusaki et al., 2013)	Qualitative; Observations, students and teacher interviews, video recordings, artifacts	6th grade teacher, her classroom: 44% students categorized as Black, 31% White, 21% Hispanic, 5% Asian/Pacific Islander or American Indian/Alaskan Native	Science; energy and equilibrium in the human body (Choice, Control, and Change curriculum)	Boundary objects (e.g., bar graphs, public service announcements); scientific inquiries; brainstorming	Critical consciousness	Experienced, White, good rapport with colleagues and students, well prepared, planning in advance	Important to incorporate students' experiences in the science curriculum; curriculum is dynamic and not stable

Acknowledgements I'd like to thank Dr. Jennifer Kahn for her feedback during the earlier stages of this manuscript's preparation. I am also grateful to the reviewer who I got to know as "the reviewer #2" for guidance and suggestions, which improved considerably this work.

References

Adjapong, E. S., & Emdin, C. (2015). Rethinking pedagogy in urban spaces: Implementing hip-hop pedagogy in the urban science classroom. *Journal of Urban Learning, Teaching, and Research, 11*, 66–77.

Aguirre, J. M., & del Rosario Zavala, M. (2013). Making culturally responsive mathematics teaching explicit: A lesson analysis tool. *Pedagogies: an International Journal, 8*(2), 163–190.

Aragón, O. R., Dovidio, J. F., & Graham, M. J. (2017). Colorblind and multicultural ideologies are associated with faculty adoption of inclusive teaching practices. *Journal of Diversity in Higher Education, 10*(3), 201–215. https://doi.org/10.1037/dhe0000026

Aronson, B., & Laughter, J. (2016). The theory and practice of culturally relevant education: A synthesis of research across content areas. *Review of Educational Research, 86*(1), 163–206.

Ayers, W., Ladson-Billings, G., & Michie, G. (2008). *City kids, city schools: More reports from the front row*. Berlin: The New Press.

Bartell, T. (2013). Learning to teach mathematics for social justice: Negotiating social justice and mathematical goals. *Journal for Research in Mathematics Education, 44*(1), 129–163.

Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching, 44*(3), 466–489.

Bishop, A. J. (1990). Western mathematics: The secret weapon of cultural imperialism. *Race & Class, 32*(2), 51–65. https://doi.org/10.1177/030639689003200204

Bonilla-Silva, E. (2006). *Racism without racists: Color-blind racism and the persistence of racial inequality in the United States*. Rowman & Littlefield Publishers.

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: Real world problems and school–community partnerships as contextual scaffolds. *Journal of Research in Science Teaching, 38*(8), 878–898. https://doi.org/10.1002/tea.1037

Bourdieu, P. (1986). The forms of capital. In J. G. Richardson (Ed.), *Handbook of theory and research for the sociology of education* (pp. 241–258). Greenwood.

Boutte, G., & Kelly-Jackson, C. (2010). Culturally relevant teaching in science classrooms: Addressing academic achievement, cultural competence, and critical consciousness. *International Journal of Multicultural Education, 12*(2), 20. https://doi.org/10.18251/ijme.v12i2.343

Brantlinger, A. (2005). The geometry of inequality. In E. Gutstein & B. Peterson (Eds.), *Rethinking mathematics: Teaching social justice by the numbers*. Rethinking Schools.

Brantlinger, A. (2014). Critical mathematics discourse in a high school classroom: Examining patterns of student engagement and resistance. *Educational Studies in Mathematics, 85*(2), 201–220. https://doi.org/10.1007/s10649-013-9506-2

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

Brown, J. C., & Crippen, K. J. (2017). The knowledge and practices of high school science teachers in pursuit of cultural responsiveness. *Science Education, 101*(1), 99–133.

Buxton, C. A. (2010). Social problem solving through science: An approach to critical, place-based, science teaching and learning. *Equity & Excellence in Education, 43*(1), 120–135. https://doi.org/10.1080/10665680903408932

Cahnmann, M. S., & Remillard, J. T. (2002). What counts and how: Mathematics teaching in culturally, linguistically, and socioeconomically diverse urban settings. *The Urban Review, 34*(3), 179–204.

Calabrese Barton, A., & Tan, E. (2018). A longitudinal study of equity-oriented STEM-rich making among youth from historically marginalized communities. *American Educational Research Journal, 55*(4), 761–800.

Chen, J. A., Morris, D. B., & Mansour, N. (2015). Science teachers' beliefs: Perceptions of efficacy and the nature of scientific knowledge and knowing. *Science, 9*, 11–2014.

Civil, M., & Khan, L. H. (2001). Mathematics instruction developed from a garden theme. *Teaching Children Mathematics, 7*(7), 400–400.
Cochran, G. L., Boveda, M., & Prescod-Weinstein, C. (2020). Intersectionality in STEM education research. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 257–266). Routledge.
Collins, R. (1979). *The credential society: An historical sociology of education and stratification*. Academic Press.
Collins, R. (2014). *Interaction ritual chains* (Vol. 62). Princeton University Press.
Diamond, J. B., Posey-Maddox, L., & Velázquez, M. D. (2021). Reframing suburbs: Race, place, and opportunity in suburban educational spaces. *Educational Researcher, 50*(4), 249–255.
Dimick, A. S. (2012). Student empowerment in an environmental science classroom: Toward a framework for social justice science education. *Science Education, 96*(6), 990–1012. https://doi.org/10.1002/sce.21035
DuBois, W. E. B. (1999). Double-consciousness and the veil. In C. Lemert (Ed.), *The multicultural and classic readings* (pp. 163–168). Westview Press.
Emdin, C., Adjapong, E., & Levy, I. (2016). Hip-hop based interventions as pedagogy/therapy in STEM: A model from urban science education. *Journal for Multicultural Education, 10*(3), 307–321. https://doi.org/10.1108/JME-03-2016-0023
Ensign, J. (2003). Including culturally relevant math in an urban school. *Educational Studies, 34*(4), 414–423.
Entwisle, D. R. (2018). *Children, schools, and inequality*. Routledge.
Enyedy, N., & Mukhopadhyay, S. (2007). They don't show nothing I didn't know: Emergent tensions between culturally relevant pedagogy and mathematics pedagogy. *Journal of the Learning Sciences, 16*(2), 139–174. https://doi.org/10.1080/10508400701193671
Erickson, F. (2004). *Talk and social theory*. Polity Press.
Fusco, D. (2001). Creating relevant science through urban planning and gardening. *Journal of Research in Science Teaching, 38*(8), 860–877. https://doi.org/10.1002/tea.1036
Freire, P. (1970/2002). *Pedagogy of the oppressed*. Continuum.
Gay, G. (2010). *Culturally responsive teaching: Theory, research, and practice*. Teachers College Press.
Gay, G. (2015). Teachers' beliefs about cultural diversity. In H. Fives & M. G. Gill (Eds.), *International handbook of research on teachers' beliefs* (pp. 453–474). Routledge.
Geertz, C. (1973). *The interpretation of culture*. Basic Books.
Giroux, H. A. (1983). *Theory and resistance in education: A pedagogy for the opposition*. Bergin & Garvey.
Glasson, G. E. (2010). Revitalization of the shared commons: Education for sustainability and marginalized cultures. *Cultural Studies of Science Education, 5*(2), 373–381. https://doi.org/10.1007/s11422-009-9243-0
González, N. (2004). Disciplining the discipline: Anthropology and the pursuit of quality education. *Educational Researcher, 33*(5), 17–25. https://doi.org/10.3102/0013189X033005017
González, N., Moll, L. C., & Amanti, C. (2006). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. Routledge.
Gutierrez, R. (2005). I thought this U.S. place was supposed to be about freedom. In E. Gutstein & B. Peterson, *Rethinking mathematics: Teaching social justice issues by the numbers*. Rethinking schools, LTD.
Gutstein, E. (2003). Teaching and learning mathematics for social justice in an urban, Latino school. *Journal for Research in Mathematics Education*, 37–73.
Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. Taylor & Francis.
Gutstein, E. R. (2016). "Our issues, our people—math as our weapon": Critical mathematics in a Chicago neighborhood high school. *Journal for Research in Mathematics Education, 47*(5), 454–504. https://doi.org/10.5951/jresematheduc.47.5.0454
Hachfeld, A., Hahn, A., Schroeder, S., Anders, Y., Stanat, P., & Kunter, M. (2011). Assessing teachers' multicultural and egalitarian beliefs: The teacher cultural beliefs scale. *Teaching and Teacher Education, 27*(6), 986–996.
Han, S., Capraro, R. M., & Capraro, M. M. (2016). How science, technology, engineering, and mathematics project based learning affects high-need students in the US. *Learning and Individual Differences, 51*, 157–166.

Harding, S. G. (1994). Is science multicultural? Challenges, resources, opportunities, uncertainties. *Configurations, 2*(2), 301–330. https://doi.org/10.1353/con.1994.0019
Harper, F. (2019). A qualitative metasynthesis of teaching mathematics for social justice in action: Pitfalls and promises of practice. *Journal for Research in Mathematics Education, 50*(3), 268–310.
Howard, G. R. (2016). *We can't teach what we don't know: White teachers, multiracial schools* (3rd ed.). Teachers College Press.
Howard, T. C., & Milner, H. R. (2021). Teacher preparation for urban Schools. In H. R. Milner & K. Lomotey (Eds.), *Handbook of urban education* (2nd ed., pp. 221–237). Routledge.
Hubert, T. L. (2014). Learners of mathematics: High school students' perspectives of culturally relevant mathematics pedagogy. *Journal of African American Studies, 18*(3), 324–336. https://doi.org/10.1007/s12111-013-9273-2
Johnson, C. C. (2011). The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *Journal of Research in Science Teaching, 48*(2), 170–198. https://doi.org/10.1002/tea.20405
Kelly-Jackson, C. P., & Jackson, T. O. (2011). Meeting their fullest potential: The beliefs and teaching of a culturally relevant science teacher. *Creative Education, 02*(04), 408–413. https://doi.org/10.4236/ce.2011.24059
King, N. S., & Pringle, R. M. (2019). Black girls speak STEM: Counterstories of informal and formal learning experiences. *Journal of Research in Science Teaching, 56*(5), 539–569. https://doi.org/10.1002/tea.21513
Kumashiro, K. K. (2001). "Posts" perspectives on anti-oppressive education in social studies, English, mathematics, and science classrooms. *Educational Researcher, 30*(3), 3–12. https://doi.org/10.3102/0013189X030003003
Ladson-Billings, G. (1994). *The dreamkeepers: Successful teachers of African American children*. J Ossey-Bass.
Ladson-Billings, G. (1995). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice, 34*(3), 159–165. https://doi.org/10.1080/00405849509543675
Ladson-Billings, G. (2006). From the achievement gap to the education debt: Understanding achievement in U.S. schools. *Educational Researcher, 35*(7), 3–12. https://doi.org/10.3102/0013189X035007003
Ladson-Billings, G. (2008). Yes, but how do we do it?": Practicing culturally relevant pedagogy. *City Kids, City Schools: More Reports from the Front Row*, 162–177.
Lareau, A. (2015). Cultural knowledge and social inequality. *American Sociological Review, 80*(1), 1–27.
Laughter, J. C., & Adams, A. D. (2012). Culturally relevant science teaching in middle school. *Urban Education, 47*(6), 1106–1134. https://doi.org/10.1177/0042085912454443
Lewthwaite, B., & McMillan, B. (2010). "She can bother me, and that's because she cares": What Inuit students say about teaching and their learning. *Canadian Journal of Education, 33*(1), 140–175.
Mattei, P., & Aguilar, A. S. (2016). Assimilation and educational achievement of minority groups in the US. In *Secular institutions, Islam and education policy* (pp. 165–187). Springer.
McIntyre, A. (1997). *Making meaning of whiteness: Exploring racial identity with white teachers*. Suny Press.
Mensah, F. M. (2011). A case for culturally relevant teaching in science education and lessons learned for teacher education. *The Journal of Negro Education, 80*(3), 296–309.
Milner, H. R. (2011). Culturally relevant pedagogy in a diverse urban classroom. *The Urban Review, 43*(1), 66–89. https://doi.org/10.1007/s11256-009-0143-0
Milner, H. R. (2013). Analyzing poverty, learning, and teaching through a critical race theory lens. *Review of Research in Education, 37*(1), 1–53. https://doi.org/10.3102/0091732X12459720
Morrison, K. A., Robbins, H. H., & Rose, D. G. (2008). Operationalizing culturally relevant pedagogy: A synthesis of classroom-based research. *Equity & Excellence in Education, 41*(4), 433–452. https://doi.org/10.1080/10665680802400006
Morton, T. R., Gee, D. S., & Woodson, A. N. (2019). Being vs. becoming: Transcending STEM identity development through Afropessimism, moving toward a Black X consciousness in STEM. *The Journal of Negro Education, 88*(3), 327–342. https://doi.org/10.7709/jnegroeducation.88.3.0327
Neri, R. C., Lozano, M., & Gomez, L. M. (2019). (Re)framing resistance to culturally relevant education as a multilevel learning problem. *Review of Research in Education, 43*(1), 197–226. https://doi.org/10.3102/0091732X18821120
Noddings, N. (2012). The caring relation in teaching. *Oxford Review of Education, 38*(6), 771–781.
NRC. (1996). *National science education standards*. National Academy Press.

Ortiz, N. A., Morton, T. R., Miles, M. L., & Roby, R. S. (2019). What about us? Exploring the challenges and sources of support influencing Black students' STEM identity development in postsecondary education. *The Journal of Negro Education, 88*(3), 311–326. https://doi.org/10.7709/jnegroeducation.88.3.0311

Paris, D. (2012). Culturally sustaining pedagogy: A needed change in stance, terminology, and practice. *Educational Researcher, 41*(3), 93–97. https://doi.org/10.3102/0013189X12441244

Paris, D., & Alim, H. S. (2014). What are we seeking to sustain through culturally sustaining pedagogy? A loving critique forward. *Harvard Educational Review, 84*(1), 85–100. https://doi.org/10.17763/haer.84.1.9821873k2ht16m77

Pellegrino, J. W. (2014). Assessment as a positive influence on 21st century teaching and learning: A systems approach to progress. *Psicología Educativa, 20*(2), 65–77.

Peterson, B. (2005). Teaching math across the curriculum. In E. Gutstein & B. Peterson, *Rethinking mathematics: Teaching social justice issues by the numbers*.

Piaget, J., Garcia, R. V., Garcia, R., & Lara, J. (1989). *Psychogenesis and the history of science*. Columbia University Press.

Posey-Maddox, L. (2017). Schooling in suburbia: The intersections of race, class, gender, and place in black fathers' engagement and family–school relationships. *Gender and Education, 29*(5), 577–593.

Rios-Aguilar, C., Kiyama, J. M., Gravitt, M., & Moll, L. C. (2011). Funds of knowledge for the poor and forms of capital for the rich? A capital approach to examining funds of knowledge. *Theory and Research in Education, 9*(2), 163–184. https://doi.org/10.1177/1477878511409776

Rodriguez, A. J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. *Journal of Research in Science Teaching, 52*(7), 1031–1051.

Seiler, G. (2001). Reversing the "standard" direction: Science emerging from the lives of African American students. *Journal of Research in Science Teaching, 38*(9), 1000–1014. https://doi.org/10.1002/tea.1044

Stinson, D. W., Bidwell, C. R., & Powell, G. C. (2012). Critical pedagogy and teaching mathematics for social justice. *The International Journal of Critical Pedagogy*, *4*(1). http://libjournal.uncg.edu/ijcp/article/view/302

Tate, W. F. (1995). Returning to the root: A culturally relevant approach to mathematics pedagogy. *Theory into Practice, 34*(3), 166–173.

Thompson, A. G. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 127–146). National Council of Teachers of Mathematics.

Toshalis, E. (2013). Grow your own teachers for urban education. In H. R. Milner & K. Lomotey (Eds.), *Handbook of urban education* (pp. 238–259). Routledge.

Tsurusaki, B. K., Barton, A. C., Tan, E., Koch, P., & Contento, I. (2013). Using transformative boundary objects to create critical engagement in science: A case study. *Science Education, 97*(1), 1–31. https://doi.org/10.1002/sce.21037

Turner, E. E., Gutiérrez, M. V., Simic-Muller, K., & Díez-Palomar, J. (2009). "Everything is math in the whole world": Integrating critical and community knowledge in authentic mathematical investigations with elementary Latina/o Students. *Mathematical Thinking and Learning, 11*(3), 136–157. https://doi.org/10.1080/10986060903013382

Vincent-Ruz, P., & Schunn, C. D. (2018). The nature of science identity and its role as the driver of student choices. *International Journal of STEM Education, 5*(1), 48. https://doi.org/10.1186/s40594-018-0140-5

Wahman, J. T. (2009). "Fleshing out consensus": Radical pragmatism, civil rights, and the Algebra Project. *Education and Culture, 25*(1), 7–16.

Woodson, C. G. (1972). *The mis-education of the Negro*. AMS Press.

Yosso, T. J. (2005). Whose culture has capital? A critical race theory discussion of community cultural wealth. *Race, Ethnicity and Education, 8*(1), 69–91. https://doi.org/10.1080/1361332052000341006