Critical Science and Mathematics Early Childhood Education: Theorizing Reggio, Play, and Critical Pedagogy into an Actionable Cycle

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Abstract: Young American children in today's public schools live in a world in which tensions around about identity (i.e., ethnicity and race, gender continuums, language backgrounds and proficiencies, cultural values and beliefs, economic resources, schooled experiences, literacy, and im/migration history) are part of everyday conversation. However, many early childhood science and mathematics educators are reticent to engage deeply in dialogue around these identities, not only due to a common narrative where science and mathematics are interpreted as culturally-neutral, but also because few models within early childhood science and mathematics education exist on how to engage in these conversations. Given this, we ask, how can we prepare and support teachers in developing a positive awareness of culture, identity, diversity, and other critical tensions faced by our youngest learners? How can we prepare and support teachers in engaging in these critical conversations as connected to science and mathematics with young children?

Keywords: Reggio Emilia; play; science; mathematics; early childhood education; critical pedagogy

1. Introduction

In the United States today, young children (birth to age 8) enrolled in school (i.e., head start, universal preschool, private/public preschools, and elementary schools) are growing up in worlds where identity and identity construction (i.e., ethnicity, race, gender continuums, emergent language(s), economic resources, im/migration history) are strife with increasing public discord and vocal intolerances. Identity negotiation, regardless of era or location, involves children (as well as adolescents and adults) defining and claiming their membership role amongst peers, family, society, and classrooms. In the United States, many issues central to burgeoning identities can be found at the heart of everyday controversial and heated conversations. This tension surrounding identity formation is particularly true within the current regressive and repressive political context of the U.S., which finds itself immersed in exclusionary rhetoric championed by Trump [1]. Broadly defined, social scientists view the tasks of individual knowledge construction as an ongoing meaning making of events, which are uniquely personal, yet situated within and influenced by society-at-large [2,3]. From a macro-perspective, the knowledge constructions of children living in the U.S., therefore, are affected by the nation's tumultuous rhetoric espousing intolerance and heightened global tensions. From a micro-perspective, these knowledge constructions depend upon a delicate coordination of a child's in-school and out-of-school knowledge and interactions.

From our works and experiences, we have observed multiple early childhood educators who are reticent to engage deeply into issues of identity, especially during science or mathematics learning engagements [4]. This happens not only because there is a pervasive and common narrative in the US

that as subject areas, science and mathematics are culturally neutral, but also because early childhood science and mathematics educational researchers have only recently started to research the importance of broad conversations involving culture and identity [5–7]. Given these complex considerations, we ask,

1. How can we prepare, encourage, and support teachers in developing awareness of the diverse and complex critical identity issues faced by our youngest learners?
2. How can we prepare, encourage, and support teachers to utilize science and mathematics curricula as spaces of inspiration to engage children in critical conversations?
3. How can we restructure (more traditional) early childhood programs to shift the context of learning so that it reaches beyond classroom walls to connect with new or existing community action(s)?

In this article, we offer approaches for practitioners and researchers to create authentic provocations for young children that connect to critical issues of systemic societal oppression. These provocations serve to elicit students' knowledge(s), interests, inquiries, and conversations in order to provide children with empowered spaces for navigating constructs of self and societal-influenced identities (i.e., race, gender, culture, language, socioeconomic status). By drawing parallels between existing frameworks of empowerment, access, and agency to established educational research, we call for a new critical approach to science and mathematics in early childhood settings. We also seek for feedback from practitioners and researchers alike to offer perspectives and ways in which these conversations can be encouraged more broadly. Furthermore, we call for empirical data and research studies in classrooms informed by this new critical framework we title, Critical Science and Mathematics Early Childhood Education (CSMEC). As research in Critical Early Childhood Education is just emerging within science and mathematics [8], our theoretical approach to a critical science and mathematics early childhood pedagogy pulls from multiple theories but little empirical data.

We envision the pedagogical approaches stemming from CSMEC to be comprehensive of multiple research fields: critical theory (at large), early childhood education, science education, and mathematics education. Given this complex plurality, we exercise caution and implore a critical meta-analysis of our planning, thinking, and enactments for measures to assist in our attempts to honor best practices of each research field (See Figure 1).
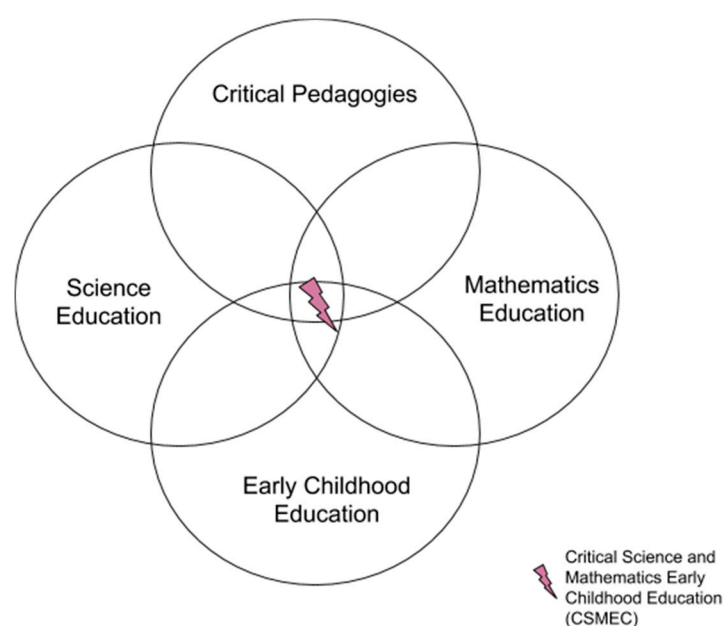
Figure 1. The CSMEC framework examines the intersection of four research bases: critical pedagogy, early childhood education, science education, and mathematics education.

In this manuscript, we describe a complimentary dynamic between critical theor(ies) and play as purposeful pedagogy and what this looks like in early childhood education, particularly with respect to science and mathematics learning experiences.

2. Influencing Frameworks

As noted, we draw upon multiple research bases to build our conception of a Critical Science and Mathematics Early Childhood Education (CSMEC) education framework (see Figure 1). We begin our construction by exploring critical pedagogy and identity within science and mathematics education by specifically theorizing identity not as a checkbox category nor as a linear measure, but rather, we situate identity as the intersectional stories, narratives, and actions one tells and enacts [9–11]. We then purposefully connect these frameworks to best practices within early childhood science education and mathematics education, such as play-based mathematics learning [12], early childhood mathematics [13], play-based science learning [4,14–16], early childhood science [17–19], Reggio-Inspired practices [20], inquiry [21–23] and developmentally appropriate practice (DAP) [24,25] Finally, we organize the emergent CSMEC framework through the lens of child-centered, play-based classrooms.

3. Critical Pedagogies

Critical pedagogy involves teaching for social justice, heavily influenced by Paulo Freire's [26] work in empowering Brazilian educators to develop *conscientização*—critical consciousness. A critical pedagogical stance views all teaching as political and recognizes education's role in emancipation from oppression [26].

3.1. Critical Race Theory

Critical Race Theory (CRT) refers to a framework that has roots in legal theory rather than education [10,27]. CRT is used to specifically draw attention to issues addressing race and power. The five tenets of CRT are counter-storytelling, the permanence of racism, whiteness as property, interest convergence, and the critique of liberalism [28] Within the realm of early childhood education, CRT connected pedagogy can mean assisting children's development of critical thinking skills and recognizing the deep knowledge children bring with them from their own communities [29].

3.2. Intersectionality

Intersectionality is a term introduced by [30] to highlight the unique oppression(s) faced by Black women, who experience discrimination within male-dominated Black communities and then again within white-dominated female communities. By examining the unique oppressions faced at the intersection of these multiple social identities, aggressions that were previously ignored and/or overlooked come to light. Crenshaw writes.

Recognizing that identity politics takes place at the site where categories intersect thus seems more fruitful than challenging the possibility of talking about categories at all. Through an awareness of intersectionality, we can better acknowledge and ground the differences among us and negotiate the means by which these differences will find expression in constructing group politics [30] (p. 1299). To highlight the importance of intersectionality/ies and the classroom implications of personal (hybrid) identity construction, colonization and its after-effects, particularly the way colonial thinking still influences who and who does not have power must be understood [31]. Such power implications of/from colonization are vital considerations for education researchers in the U.S. to examine and consider, given our current political and social context. This recognition of colonial practices that are still deeply embedded within our educational system can lead to increasing white fragility and white privilege, as colonization power are elements of *all* identity constructions regardless of space and time [32].

3.3. Identity

These multiple critical lenses of critical theory and intersectionality all illuminate the importance of combating oppression by empowering one to construct and form aspects of their identity for themselves and possessing ownership of their narrative of how to define one's self within given spaces, communities, and cultures. Identity, therefore, can be positioned as malleable [33] and an action one takes, rather than a static definition [34]. From an educational perspective, identity can be thought of as an agentive move involving counter-storytelling that acknowledges and confronts oppressive constructs such as race, gender, ableism, language proficiency, and the intersections of multiple spaces. Identity, therefore, involves the stories and narratives one tells; and the stories themselves are the identity [35].

4. Science and Mathematics Education

4.1. Critical Science Education

The Journal of Research in Science Teaching (JRST) performed a systematic and historical account of articles focused on multicultural science education (MSE), equity (EQ), or social justice (SJ) published during a 30-year span, concluding in 2010. This study noted that science education had been late to enter and fully engage with equity education research [36] and was generally quite siloed socio-politically [37]. However, just as the field's top journals were calling for a focus on the inequities inherent in science education experiences, science education also had to contend with a renewed and large public focus on science (and STEM) education as an economic driver. These competing trends led to the marketing of science education as embedded within a cycle of consumerism popular in America today [38]. As portrayed by the mainstream Western media, a "good" STEM education opens doorways to "good" jobs, a "good" job gives one money to buy things, the ability to buy things is equivalent to power, and this money then goes back into the system to encourage more "good" STEM education—a dangerous and false government/corporate cycle [39]. Newer calls for science education and science education research involve telling counter narratives to such Neoliberal education reforms, where the emphasis shifts away from positioning students as fiscal drivers or consumers, to one in which students are encouraged to *experience* and *do* science in connected and meaningful ways, such as science-based social justice or what Bencze and Carter (2011) [38] label the "*common good.*"

4.2. Critical Mathematics Education

Gutstein [40] extended Freire's [25] framework of combating oppression by helping children read and write the world through exploring social justice mathematics lessons. Critical mathematics pedagogy involves empowering children to develop identities in which they powerfully use mathematics in their lives [41,42]. Mathematics teaching, then, becomes identity work by helping children situate their mathematics identities as a part of their ethnic, racial, and/or socioeconomic identities and develop activist dispositions [34].

Much of what we label as Critical Mathematics Education builds from the examples of ethnomathematics, which details the intricate mathematics that exists outside of classroom contexts such as the mathematics of Brazilian street vendors or how basketball players determine averages and scoring during the game [43–46]. This acknowledgement of the rich mathematical thinking that exists within families and communities also draws from a funds of knowledge approach, which recognizes the mathematics that children see and notice within the "the historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual's functioning and well-being" [47] (p. 133).

5. Early Childhood Education

5.1. Reggio Emilia

The Reggio Emilia approach to learning in early childhood emphasizes the rights and experiences of the child through strong connectedness to culture, community, and the (natural) environment. Reggio and Reggio-Inspired classrooms can be observed incorporating the use of found and natural materials, "loose" parts, and child-created artistic displays with a heavy emphasis on documentation. A Reggio approach positions children as both capable and creative, viewing children as having 'rights' and recognizing that children have at least 100 "languages" to express their ideas and thinking.

Educators in Reggio-inspired settings believe children's social and personal experiences are intertwined. Therefore, children's meaning-making, learning, and/or the construction of knowledge occurs through both the solo construction from one's uniquely and inherent subjective lens, one's contextual interactions with teachers and peers [48], and the Reggio-informed practice of identifying the classroom space itself as teacher. Reggio perspectives are aligned with Vygotsky's ideals of social construction of knowledge [49]. A Reggio focus on social interaction and culture suggests that children should be encouraged to interact, discuss, and even disagree or argue respectfully with each other and adults. These values are visible in Reggio schools by the strong relationships among the children, teachers, and the community. Reggio Emilia teachers believe that reciprocity, exchange, and dialogue among children, teachers, and the community lie at the heart of successful education [50].

Reggio informed activities foster both individual and group curiosity, creativity, exploration and discovery; encouraging exploration with the five senses, asking questions, testing theories, making and verbalizing plans, and thinking deeply. The Reggio-inspired classroom teacher often utilizes provocations, at stations or as visual images, to invite children to explore, create, and invite students into questioning and discussion. Provocations as inquiry parallel best practices of early childhood science and mathematics education by serving to inspire children's ideas, creativity, problem-solving and sense-making where there may not be a 'right' answer, or possibly more than one 'right' answer. Later in this manuscript we share examples from our own experiences and ways to craft and hone provocations that not only address science and mathematics in authentic ways, but also invite children to engage in powerful and authentic conversations surrounding empowerment, access, and agency.

5.2. Play-Based Learning

Play-based programs (sometimes also labeled discovery schools) encourage children to interact with everyday materials and their environment based on their interests and at their own pace [12]. In such classrooms, teachers identify themselves as guides who facilitate children's interest explorations by providing materials and scaffolding questions. They do not identify themselves, or their role, as being central to the classroom or its curricular decisions. While play is an essential component to Reggio practice, not all play-based preschools would label themselves as Reggio-inspired. Classroom play provides a natural context for children's cognitive, social, and emotional growth. Experiencing science and mathematics through play and play through science and mathematics provides authentic spaces, contexts and conversations (peer-peer and student-teacher) for addressing critical issues facing young learners [12].

In play-based programs, children choose activities based on their current interests and the materials made available. "Play-based" is often used interchangeably with "child-centered," which leaves a broad range of interpretation. Both, play-based and child-centered classrooms focus on the learners' agency and a diminished role for the teacher as central director. Teachers utilize children's questions by providing meaningful interactions with materials and activities that are highly contextualized, meaningful, and familiar to preschool children. Typically play-based classrooms are broken up into sections or centers, such as a block area, water table, light table, reading nook, spaces for dramatic play, and other everyday materials or toys. Children are free to explore materials and spaces as they choose for their play while building autonomy, self-regulation, and social and emotional

skills. Also developing alongside these play-experience skills are foundations of pre-literacy, early numeracy, wonder, inquiry, and critical and scientific thinking skills.

Examples of play-based early childhood classrooms emphasizing science and mathematics are just starting to emerge more abundantly in the research literature. For instance, Parks, [12] showcased how the use of a play-based approach in a mixed-race preschool allowed children to show detailed and critical mathematical thinking while gaining confidence in their mathematical identities.

5.3. Science and Mathematics Education in the Early Childhood Classroom

Reforms within both science and mathematics education in recent years have led to hope for more inclusive and culturally responsive education communities. These reforms call for changes in the ways we prepare teachers, view the agencies of children, families, and communities, conduct research in classrooms, ask research questions, and analyze classroom interactions, discourse, and data.

We advocate a return to play-based early education that not only pushes back on the recent calls for academic rigor at younger ages, but also against the Neoliberal accountability and standardization movement [51]. This return to play-based schooling is not only a more developmentally appropriate approach, but also one that connects directly to critical learning of science and mathematics through exploration of one's emergent identity. We believe this shift in emphasis to empowerment, access, and agency will challenge current norms and lead to increased participation, identity, and membership for children as they form and (re)form their emergent identities. We hypothesize this approach of employing critical and identity lenses layered with developmentally appropriate practices (DAP) for young children will set the foundation so children connect and (re-)create spaces of membership and belonging, which will change the identity of whom is included as "belonging" in science and mathematics. In time, resulting shifts from the CSMEC will allow for a re-defining of who(m) self-identifies as "belonging" in science and mathematics education. We believe this will also lead to increased experiences of the practices of science and mathematics as well as the content understandings of both fields, since we know the importance of viewing oneself as a participant of a community of practice [52].

5.4. Science

From national standards, reform documents, and teaching-based research, the field of science education is changing. The new terrain of school science includes emphasis not only on the traditional content, but also on the Nature of Science, scientific literacy, cross-disciplinary concepts, citizen-science, science for social justice, equity-based science education, the engineering design process [53,54]. While much has been done to incorporate changes to the curriculum or programmatic side of science education, the same energy has not been invested in understanding the complex identities of young children. As the field of science education continues to evolve, inherent and systemic oppressions/oppressors must be critically examined in order to create a truly empowering science education.

Providing science experiences in classroom with young children requires teachers to tune into children's interests and design 'play' centers around these interests. Teachers must also be avid listeners to children's peer-dialogues and learner-to-teacher dialogues. This intentional listening and observing is multi-purposed. First, it allows adults and peers opportunities to hear children express understandings of objects or phenomenon based on their personal, family, or community histories. Second, it allows all children playful spaces to learn about their own linguistic repertoires, share with peers and teachers and learn from their peers' linguistic identities. All languages (childlike language, non-verbal languages, formal spoken languages, dialects, etc.) need to be valued, emphasized, utilized, and respected. For example, teachers may incorporate the children's childlike words (i.e., Kakuna, from the popular Pokémon game for a mealworm's pupa stage) into conversation with the students initially and then begin offering the scientific term (pupa) in all of the classroom's spoken languages (Authors, in review). The end goal is not to have all students speaking better English, but to have

students understand more scientific language (in any language) and how the scientific world overlaps with their own identities and prior knowledge.

While there is much empirical data (e.g., [55,56]) to support the sophisticated scientific thinking and understanding of young children, many early childhood teachers are hesitant to plan classroom science engagements either because they feel unsupported from a lack of resources or they lack confidence in their own science content understandings [57]. The National Science Teachers Association (NSTA) in conjunction with the National Association for the Education of Young Children (NAEYC) issued position statements aimed for early childhood teachers (ages 0–6), parents, and caregivers to act as support for preparing young learners for a "seamless transition for learning in elementary school" [54]. In brief, the six principles communicate:

(1) young children have capacities and abilities to learn abstract constructs and engage in the practices of science (i.e., inquiry, questioning, reasoning, investigating and communicating)
(2) environment and language are important (adult-driven) factors in children's science learning
(3) materials should be varied and provided in numerous ways and instances [58]
(4) science is learned in formal and informal settings
(5) children need ongoing exposure to science (i.e., over weeks, months, years)
(6) environments intentionally designed for experiential learning and the manipulation of material allow for the development of children's science skills

These principles are a basic, yet key resource supporting the developmental appropriateness of science education and scientific practices in early childhood classrooms, especially for those who question the inclusion of science in an early childhood curriculum. The CSMEC is informed by this position statement and also pulls from the new early childhood science learning cycle [16], which incorporates children's interests through play and links to numbers five and six of the NSTA/NAEYC position statement. Play itself, when utilized as a developmentally appropriate practice (DAP), parallels science in that they are both grounded in inquiry and embrace constructivist and social-constructivist approaches to teaching and learning [12]. Of particular interest in the NAEYC/NSTA position statement is the attention paid to the spaces or environments of science learning, which is similar to Reggio philosophy which notes the instructive importance of environment and refers to space as "the third teacher" [59].

While we have seen many positive changes towards more just and equitable science education experiences for young children, there is still much work to be done. First, notions that 'real' science education is not happening in early childhood classrooms still exist within the public at large. Yet more concerning is that this same notion that deep science learning does not occur in early childhood spaces is pervasive, even within the science education research community. Second, we must work harder to highlight the imperfect social, subjective, biased, and humanistic nature of science education. By highlighting the implicit biases we all carry from our personal and limited perspectives, we can emphasize how biases and perspectives influence the ways in which we design experiments, describe personal observations, understand time, construct explanations of data, approach problem solving, and make sense of different cultural tools and uses. We hope attention on the subjective and humanistic side of the practices of science can help in revising the fictious narrative of science (and mathematics) as culturally neutral contents and therefore not appropriate spaces for critical conversations of power, race, and identity. Lastly, the field of science education (as all fields of education) has numerous emergent issues from the inherent oppressive structures ingrained in the field's history and power structures at the time of original curriculum design. For example, as highlighted in the quotes from NGSS and the NSTA statements and standards, the language of science is often exclusionary and elitist. Beyond a call for attention to the language of science education, the textbooks, models, spoken language(s), and laboratory orientations tends to be heteronormative and masculine [37,60].

5.5. Mathematics

Early childhood mathematics teaching has traditionally focused only on counting and cardinality, even though the research in early childhood mathematical thinking shows that children are capable of much more sophisticated mathematics [6,61]. For instance, over the last two decades, the work of Clements and Sarama has shown how young children are capable of complex pattern recognition and geometric manipulation, disrupting many of the myths surrounding young children's mathematical ability [13,62,63].

Working with young children requires a shift in focusing not only on appropriate representations of real-world situations, but also understanding children's identities and prior knowledge. Critical mathematics teaching at the early childhood level must connect formalized mathematics to the complex and sophisticated mathematics already present in children's histories and communities [64–66]. For young children, fairy tales and stories presented as play are the real-world situations that they process and reflect upon [12,67]. Therefore, critical mathematics teaching must honor and connect to children's histories, stories, and fairy tales that highlight the mathematics and empowering uses of mathematics to recognize and confront the injustice children notice [6,67]. Children learn to express their critical observations using mathematics because adults dismiss complaints (i.e., "That's not fair!") without the support of number evidence. To adults, mathematics is taken as objective fact, and therefore strengthens a child's argument (i.e., "That's not fair because only 5 children got in, none of them girls").

Our framework for teaching mathematics revolves around the following ideas. First, all children are capable of sophisticated mathematical thinking which can come about through listening to them explain their strategies [68]. Additionally, children have the capacity to think in sophisticated ways about fairness [69]. Next, children bring a wealth of mathematical knowledge with them from their communities and families [64,66]. Children live in spaces in which mathematics is often used: they see it, they observe it, they know it. Connecting this knowledge to the formalized mathematics in the classroom helps children develop strong mathematical identities [41].

Particularly, since many young children have considerably less power than the adults in their world, mathematics teaching for equity and social justice becomes a way for young children to attack this power discrepancy by showing that they have just as much an ability to recognize oppression as adults. Therefore, our framework for teaching mathematics for equity with young children revolves around empowering children to use mathematics to call out unfairness in their lives so that the adults in power around them have to do something about it.

6. The Critical Science and Mathematics Early Childhood (CSMEC) Framework

Within the realm of early childhood education, these constructs take on multiple forms. First, in order to help children acquire content knowledge and gain insight from new experiences, their identities and the intersectionality of these (re-)emergent identities must be at the forefront of how we plan classroom experiences to engage student interests and spark critical conversations for the empowerment, access, and agency of young children. Children's identities are narratives that encompass prior experiences in learning, and/or social identities such as gender, race, languages spoken, or socioeconomic status. Additionally, within science and mathematics education, it is important to pay attention to children's descriptions (in their own words or way of describing) about their prior experiences within science and mathematics education. Next, we use these descriptions to inform how classroom experiences balance process versus content, develops trust in the inquiry process, develops comfort with asking questions, and connects to children's natural curiosities. Furthermore, the children's work and words should infuse and inform the full spectrum of the planning process. For example, if children are struggling with social issues they are hearing in their own living rooms, news sources, radio, or television, it is likely they will naturally vocalize these issues with peers or teachers as they are also struggling to make sense of the larger world in which they live.

As we describe below, our work is situated in and influenced by the Reggio Emilia philosophy and social constructivist frameworks as the latter is the widely accepted U.S. norm for early childhood practitioners and researchers. Our works, and especially those detailed in this article, are well aligned to the work Bricker, Reeve and Bell (2014) used with older learners, concluding that "'youths' 'prior knowledge' cannot be separated from the cultural milieu in which it is situated" [70] (p. 1458). The indications are straightforward—we, as early childhood science and mathematics educators need to expand our conceptions of knowledge beyond merely cognitive aspects to be equally inclusive and informed by learners' social and cultural knowledges, as the fields of science and mathematics education in older grades has done [43,69,71,72]. Knowledge conceptions defined only by a learner's cognitive aspects are incomplete and elitist in favor of those in majority or power. Until we meet learners "at *their* premises" [73], and value the social and cultural contexts of the knowledges formed at home, in the community, and outside of formal school settings, we will fail in our efforts for in-school science and mathematics experiences to be relevant for all learners. Furthermore, it is not sufficient to simply make 'room' for all learners in science and mathematics classes, if we do nothing to change *our* accounts and understandings of how these schooled experiences were constructed within the larger canvas of the United States education system, which was born from gendered, colonial and Protestant interest [74].

Struggles are often commonplace in education when different fields of expertise (content) collaborate. Current educational trends and funding models favor 'collaborations', however, where resources are low and stakes are often high, collaborators can unknowingly enter such endeavors with a tug-of-war mentality. In the CSMEC, we set aside the 'rope' often used as self-measures of greater collaborator influence, and instead call upon our collective fields to create early childhood classrooms as spaces where young children are engaged (and likewise where they may engage adults) in conversations exploring empowerment, access, and agency in ways which are true to best practices of science and mathematics education. Teachers need not shy away, redirect or avoid answering children's questions for fear it may stray too far from 'content' area learning, even if the questions and discussions delve into uncomfortable issues such as whiteness, white fragility, white supremacy, sexual assault and harassment, opioid addictions, drug use, family border separations and so on. These issues are pressing and vital to initiate systemic changes in the United States, broadening not only *who participates*, but also establishing structures of support to impact *who can succeed* in STEM.

Using these multiple frameworks, we now present a three-phased cycle of what we call Critical Science and Mathematics Early Childhood Education (CSMEC). The first phase of this cycle involves recognizing, acknowledging, and accounting for community knowledge. The second phase explores and connects broader STEM content knowledge and constructs to this community knowledge. The third phase then involves children using these connections to take action within their communities, by questioning, exploring, and creating their own community resources and knowledge.

7. The Critical Science and Mathematics Early Childhood Education Cycle

The Critical Science and Mathematics Early Childhood Education (CSMEC) Cycle (see Figure 2) emerges from Paulo Freire's [26] detailing of the pedagogy of the oppressed and the identification of issues to enact positive action for change, Reggio-Emilia, purposeful play pedagogy, and the engineering design process (See references for links to NSTA/NGSS resources) [18,53,54] in order to provide young children opportunities for access, agency, and empowerment. We are not making claims that these ideas are new or somehow groundbreaking. However, we believe these ideas, when coordinated, can uniquely serve children, families, and communities. With time, the connections within the sphere of the CSMEC will grow in strength and power, while new connections will also become apparent. Beyond the sphere of the CSMEC itself, we foresee this cycle become more richly connected to the larger fields of each area and the overall research fields in STEM education.
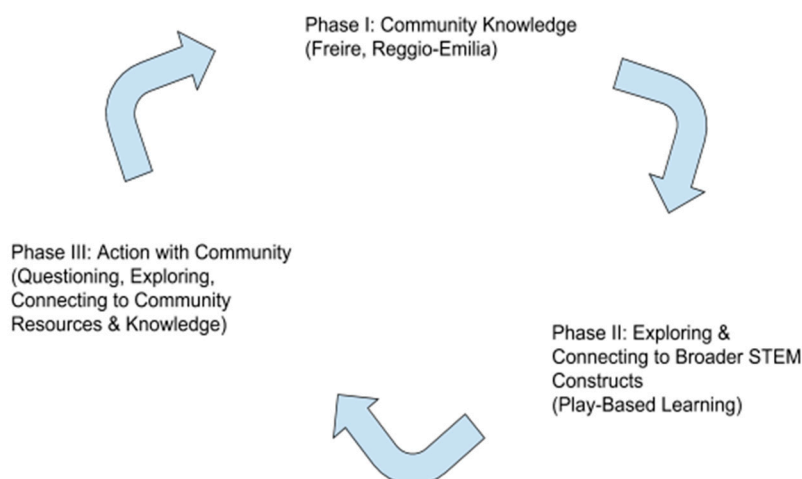
Figure 2. The Three Phases of the Critical Science and Mathematics Early Childhood Education (CSMEC) Cycle.

7.1. Phase One: Community Knowledge

This is one of the most joyful activities for any early childhood educator, to stand aside and listen to the brilliance of ideas, creativity, perspectives, and modes of communication among children. This is a time of appreciating all of the knowledges (cultural, social, and cognitive) among and within the students. Appreciating the interests, areas of overlap, and area gaps that may exist between a community of learners. While these areas of common knowledges may feel 'safer' to explore or discuss, we encourage pressing boundaries to have discussions about why "that's not fair!" or why they feel they feel they must abide by binary gender norms/dress in dramatic play. This is also an excellent time to appreciatively inquire about students' emergent identities including how they see these interweaving within the cultural and social norms at home. Expanding these conversations to include families and neighboring communities provides dialogues with greater depth, profound thought, and builds empathy for extensive understanding and inclusion. Shaking the structure of a traditional classroom or parent/family night, where the teacher or administrator views themselves as the 'keeper of the knowledge to be shared', and instead views the community and families as the experts, teachers as learners, combats dimensions of institutional oppression inherent in U.S. school systems.

7.2. Phase 2: Exploring and Connecting to Prior Science and Mathematics Knowledge

In these stages of deep listening, noticing, and responding [75], educators are gathering all of the prior experiences, knowledges, conceptions, and possible alternative conceptions of science and mathematics held by the young students in the class. From this, educators can plan experiences to all children to interact and act out demonstrations with materials. We believe children should have ample time to interact with new materials (or familiar materials placed in new stations) in their own ways before we ask them to use them in any teacher directed ways. This allows for two things to emerge: (1) children can further understand the world around them in the ways in which this material fits into their existing conceptions and (2) children can explore on their own terms when they are developmentally ready to use the material in a way that is self-directed or self driven inquiry. Teachers plan and provide materials for play and then step aside to observe and absorb the genius of childhood, interjecting with productive or thinking questions when appropriate. When children are no longer interacting with materials in productive ways, it is either time to change the stations of play or determine if the class is ready for next steps and determine what those steps might be. These conversations typically happen organically during circle time or at a parent night where a parent (or small group of parents) educate classroom families on a certain topic (i.e., sharing of cultural customs, celebration ceremonies, definitions of family, family living dynamics, holidays, languages, life

in a current neighborhood or home country, issues of concern for their community or neighborhood, or issues of concern for the immediate neighborhood of the school). We then wait for the children's voices to emerge, which may take several days to come to consensus, as to what speaks to their interest, tugs on their heart strings or calls them to be (small) agents of (big) change.

We have been involved in creating and honing a number of activities for early childhood educators revolving around our CSMEC framework. We have previously written about a Pre-Kindergarten teacher who teachers in a vibrant and low-income Black community [76]. This teacher focuses heavily on connecting her lessons and activities to issues affecting the Black community she serves. We have helped this teacher "mathematize" existing activities exploring Rosa Parks and the Montgomery County Bus Boycott and Harriet Tubman and the Underground Railroad [76–78]. For instance, in the Montgomery Bus Boycott activity, young children were able to move past the surface-level narrative of Rosa Parks being a "brave" role model to utilizing mathematics to fully explore the effect of the boycott. First, children learned the power of using numbers to explain why a situation was unfair: "Six seats at the front of the bus are empty while four Black friends have to stand at the back of the bus". Second, children counted how much money the bus system lost every day of the 381 days of the boycott, exploring the economic power of organized political action.

In another study, young children in another classroom used the mathematics of probability to explore the unequal rates at which white versus non-white residents of Ferguson, Missouri were arrested prior to the beginnings of the #BlackLivesMatter movement [76–78]. Children engaged in role-play connected to current events to use mathematical thinking to unpack why citizens of Ferguson organized to protest unfair policing practices.

And in a third study, we connected the preschool cycle for science learning [16], the story of "The Three Little Pigs" and the engineering design process (See references for link to expanded NSTA/NGSS resource for the engineering design process style to which we are referring) [53,54]. Utilizing children's literature as inspiration to design challenges are not new, but in this study, the 'goods' of constructing a house to withstand '*the big bad wolf*' are distributed inequitably across groups. Furthermore, students could 'earn' classroom currency to purchase new or 'upgraded' materials, but different students were awarded different currency amounts for doing the exact same tasks to the same ability. Fourth, taking children on walks through the neighborhoods around their schools and asking them to map the areas is another activity rich with children's creativity, spatial awareness skills, pre-literacy, and begins to show them larger patterns of visible inequities [4].

7.3. Phase 3: Action within Community

The last phase, Action within Community, is probably the hardest for practitioners to implement, and the least explored within the early childhood research literature. By utilizing critical frameworks and the exploration of identity, this last phase becomes the child's direct action, the space where they can tell their counter story to add to existing community knowledge. This phase connects the early childhood STEM fields more substantially with critical frameworks.

We call for more examples of what Critical Science and Mathematics Early Childhood Education might resemble in early childhood classrooms, particularly in writing about how these interactions lead to action within the community. Our cited examples show how the early childhood classroom can connect with critical frameworks and start a broader conversation regarding the importance of these conversations amongst the youngest learners. These connections serve in ways to empower young children in their emerging identities, global perspectives, empathy to construct arguments from data, recognize patterns, engage in inquiry, code information, think critically, and be literate in science and mathematics content. Yet, we recognize that these connections are often not made. And in our own work, we have also found it difficult to enact this last phase of our CSMEC cycle.

We hope the CSMEC will start a dialog of how local communities and early childhood centers/schools can define and/or redefine the social construction of the organization of schools, schooling and knowledge to be a catalyst for change in local communities and beyond. Providing

contextual and community connections provides young children tangible spheres of influence as well as framework or schema for the infinite world beyond their classroom walls and the powerful ways in which they, as young children, connect with the immediate neighborhood, communities and world in which they live. These significant connections reinforce children's empowerment, agency, and access as they conceptualize their emergent identities and sense of belonging amongst multiple larger communities. Our hope is for children and families to experience early childhood schools that plan for and learn with the communities which they serve.

This perspective, brought full circle in phase 3 of the CSMEC, flips the traditional model where the systems and structures of a school remain stagnant and is expectant of the enrolled community to fit within an already established, and typically antiquated, system. Phase 3 of the CSMEC, calls for responsive schools and teams who meet the changing needs of the enrolled community. We hope for the Critical Science and Mathematics Early Childhood Education model to provide meaningful experiences in schools where children are able to see their ability to produce change within a larger community or the broader world. This also calls for educators and communities to shift the (end result) learning emphasis to reach beyond classroom walls to connect with new or existing community action(s) when re-conceptualizing their local definition of knowledge, school, schooling and knowledge.

8. Discussion

We have observed and worked with many early childhood educators who hesitate to engage in critical conversations regarding children and identity construction especially in the current and uncertain times we are experiencing as a nation. Teachers and/or teacher candidates can shy away from participating in critical discussions among peers or when speaking with young children. This opposition typically gains momentum when we suggest connections between DAP, science, or mathematics learning and issues of children's identity construction [4]. This happens not only because of a ficticious narrative where science and mathematics are viewed as culturally neutral subjects, but also because it is only recently that early childhood educators and early childhood science and mathematics education researchers have joined broader conversations involving culture and identity [5–7]. While we have been using the Critical Science and Mathematics Early Childhood Education Cycle (CSMEC) in our own methods courses, professional talks, and professional development (PD) experiences, we hope the CSMEC provides pathways for all teacher educators, professional development coordinators, and education researchers to incorporate this model into their pedagogy coursework, trainings, and/or research trajectories.

Successful incorporation of the Critical Science and Mathematics Early Childhood Education Cycle requires honest, trusting, and judgment-free spaces accompanied with significant blocks of time for teachers and teacher candidates to participate in dialogue, process new perspectives, and reflect upon the issues of identity and (in)equities young children face today. It is our hope that the CSMEC provides the necessary spaces and places to allow participants to internalize these powerful (and often new) conversations. And we hope that teachers, both in-and pre-service, will feel prepared to participate when such classroom conversations arise. Long-term, our hope is for teachers who feel called to serve their students, families, and communities in ways that force them to plant their feet and open their ears, eyes, hearts and speak when such conversations arise. Beyond engaging in these conversations, we hope educators can utilize their 'spheres of influence' and power to be catalysts for change by utilizing the CSMEC. The CSMEC provides classroom educators a structure of designing and supporting developmentally appropriate methods so children may explore critical issues of importance to them or their classmates, families, or neighborhoods. Utilizing play as the classroom pillar allows educators to learn from and with young students, identify student interests, curiosities, and questions central to them in order to connect science and mathematics as tools for empowerment, agency and access for learners, their families, the school community, and the surrounding neighborhood. We see the CSMEC as a supporting backbone for science and mathematics ECE pedagogy courses or PD experiences where conversations, readings, reflections, feedback, and assignments all relate back

to the CSMEC and the empowerment, agency, and access of young learners, their families and the community at large. We hope these conversations will *begin* to prepare, encourage, and support preservice teachers in developing awareness of the diverse and complex critical issues faced by our youngest learners. We advocate a return to Play-based early childhood education to fight against the domination of current Neoliberal accountability and recent standardization movements. As we detailed earlier, play-based early childhood education connects directly to critical science and math early childhood learning through exploration of one's developing identities.

Beyond the Critical Science and Mathematics Early Childhood Education Cycle (CSMEC), we call on science and mathematics education practitioners and researchers to provide narratives and feedback of how this looks when implemented in your settings. We are called to point out again, in the spirit of Reggio philosophy, that these conversations and contexts should be representative of the community in which they are situated. Reggio philosophy calls for us to serve the needs of the community while honoring the local contexts. We ask for data and rigorous studies to help us understand what this looks like in varied geographical contexts and with diverse populations and communities. Future empirical studies will provide information regarding community and contextual influence, broader implications for our fields, and suggestions for how we can prepare, encourage, and support teachers to utilize science and mathematics curricula as spaces of inspiration to engage children in critical conversations.

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