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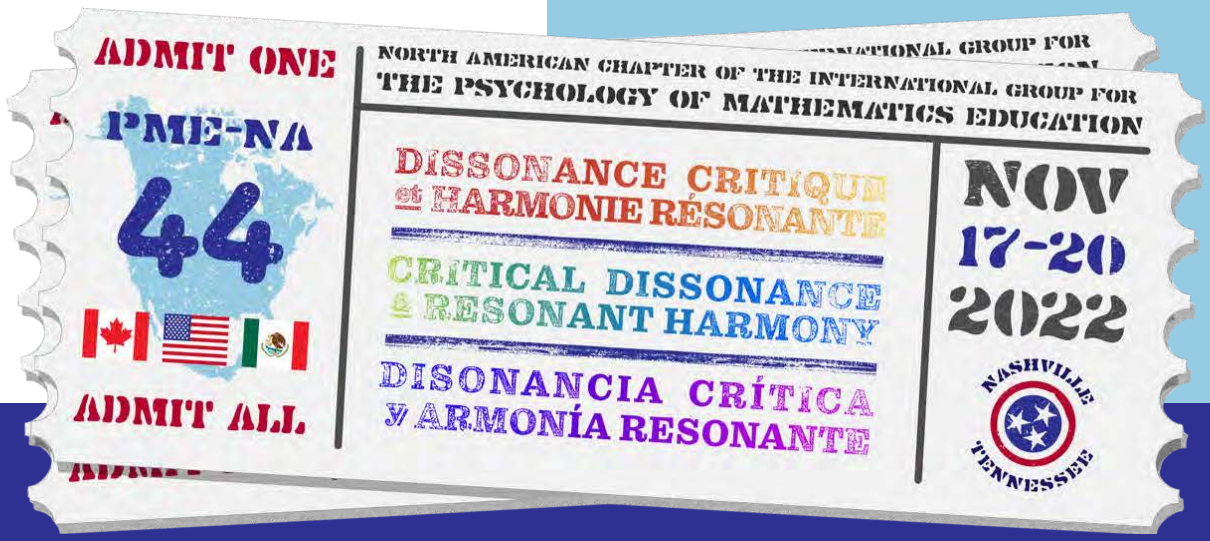
CRITICAL DISSONANCE AND RESONANT HARMONY



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Critical Dissonance and Resonant Harmony

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LEVERAGING EQUITY AND CIVIC EMPATHY THROUGH COMMUNITY-BASED MATHEMATICAL MODELING

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This theoretical paper describes how Community-based Mathematical Modeling can advance equity and cultivate civic empathy in elementary school settings. We provide a framework for community-based mathematical modeling instruction consisting of five goals: facilitating connections, fostering engagement, promoting rigor, cultivating civic empathy, and elevating justice. We illustrate how these goals work together to advance equity and cultivate civic empathy through classroom vignettes of community-based modeling lessons. Through this theoretical synthesis, implications for community-based mathematical modeling instruction will be discussed.

Keywords: Equity, Inclusion and Diversity, Modeling, Elementary Education, Culturally Relevant Pedagogy, Professional Development

Mathematical Modeling as an Equity and Empathy Lever

Mathematical modeling (MM) is an iterative cyclical process that uses mathematics to make-sense of and analyze real-world situations. MM includes posing the real-world problem, identifying important quantities and making assumptions to define variables, which then leads to developing a mathematical model, analyzing and assessing the solution, and refining the model (Garfunkel & Montgomery, 2019). MM nurtures 21st century skills of creativity, critical thinking, communication, and collaboration (Suh & Seshaiyer, 2013). It is an area of mathematics that offers children opportunities to grow mathematically and connect mathematics to their lived experiences, families, and communities. There has been a well-established literature on mathematical modeling. However, the centering of equity and empathy remains underemphasized (see Anhalt et al., 2018; Aguirre et al, 2019; Suh et al, 2018; Turner et al, 2022; Cirillo et al., 2016; for notable exceptions). We argue that MM is a humanizing endeavor that authentically connects to the real world, starting with ill-defined, often messy community-based problems and providing opportunities for students to develop empathy and compassion toward other people, living things and our planet (Lee et al., 2021). By showcasing children's diverse perspectives, curiosities, and mathematical and experiential strengths as resources for learning, mathematical modeling is a powerful *lever for equity and civic empathy* in the elementary mathematics classroom.

In our work, equity means that: All students **in light of their humanity** – personal experiences, backgrounds, histories, languages, physical and emotional well-being – must have the opportunity and support to learn rich mathematics that fosters meaning-making, empowers decision-making, critiques, challenges, and transforms inequities/injustices. It promotes equitable access, attainment, and advancement for all students (Aguirre, 2009; Aguirre et al, 2013).

In terms of empathy, we draw on the foundational work of Freire (1970) on critical consciousness and recent report from the National Academy of Education (Lee et al., 2021) for civic reasoning and discourse to deepen children's empathy with others who may have different perspectives. Civic empathy- "working to see the world from another person's perspective—can help us to overcome some of the impediments to listening and can improve our ability to relate to each other civically" (Lee et al., 2021, p. 39). Mirra's (2018) concept of *critical* civic empathy is useful because she differentiates individual empathy, or simply seeing another's perspective, from critical civic empathy, which includes seeing another's perspective while also engaging in structural analysis of power and privilege to take civic action for social transformation. We lean on this concept of critical civic empathy as we focus on community-based mathematical modeling. There is growing consensus that elementary grade students can engage in community-based mathematical modeling. Researchers specifically highlight how students draw on their lived experiences to support mathematizing activity (Albarracín & Gorgorió, 2020). Turner et al (2011) found that when children mathematized situations rooted in their communities, what the authors referred to as *community mathematization*, children considered the real-world implications of their decisions and models.

Recent research confirms how teachers foster this connection through *community-based* MM tasks and routines (CMM). Turner et al (2022) document how elementary teachers designed community-based modeling tasks centering social and environmental justice such as helping a community-center order food supplies to feed unsheltered families and determining plastic waste generated from the school cafeteria. Aguirre et al (under review) designed an instructional routine called Mathematizing-the-World routines (MWR) that leverages community mathematization. The MWR focuses on three prompts that are similar to those in the introductory act of Three Act Tasks (Lomax et al., 2017). The first question, "What do you notice?" strengthens students' observation skills. The second question, "What do you wonder?," builds on students' curiosities and strengthens problem-posing skills. The third question, "What questions can be solved using mathematics?" draws students' attention to problem-posing with mathematics. To foster empathy and connection while mathematical problem-posing, the teacher offers additional prompts including: Why is this question/issue important? "Why should we care about this question/issue?" "Who else might care about this question/issue?" "Why might it be important to them?" (Arnold et al, 2022). For each prompt, teachers record student responses on a class chart. In some cases, the class identifies a specific mathematical question to investigate further. The teacher may also use this routine to launch a CMM task.

This theoretical paper describes how CMM can advance equity and cultivate civic empathy in elementary school settings. We continue to push the field of MM and teacher education to center on equity, empathy, and justice; opening up space for young children to be critical decision makers and community change agents (Aguirre et al, 2019; Anhalt et al., 2018; Cirillo et al., 2016). We draw on current and past MM projects that advance equity and strengthen teaching in elementary settings. Through this work we identified 5 instructional goals that frame how CMM leverages equity and civic empathy: *facilitating connections, fostering engagement, promoting rigor, cultivating civic empathy, and elevating justice.* To illustrate these goals in action we present two elementary classroom vignettes: a MWR on analyzing racial representation in school libraries and an environmental justice modeling task on water quality. To ground our work, we propose a theoretical framework to leverage equity and empathy with CMM.

Theoretical Framework to Leverage Equity and Empathy in Modeling

Below, we identify five instructional goals in CMM instruction that advances equity and empathy in elementary classrooms: ***facilitating connections, fostering engagement, promoting rigor, cultivating civic empathy and elevating justice*** (see Figure 1). Each goal is grounded in the literature and preliminary findings from our projects.

Goal 1: Facilitate Connections

Through CMM children can connect mathematics to themselves, their peers, families, communities, and to the world. CMM acts as a mirror and a lens for students and their teachers. The emphasis on deliberately connecting to children's lived experiences promotes multiple opportunities for children to see themselves in the mathematics (mirror) and use mathematics to analyze the world around them (lens). CMM connects children with each other in order to share ideas and experiences. By building multiple connections to self, family, community, other subjects, and the world, CMM humanizes mathematics teaching and learning (Suh et al, 2018; Gutierrez, 2018).

Goal 2: Foster Equitable Engagement

CMM activities open up access to meaningful complex problem solving for children with varied mathematical, cultural, and linguistic backgrounds. Modeling lessons incorporate a variety of participation structures to elicit diverse contributions, support peer collaboration, and minimize status issues in the classroom (Featherstone et al., 2011). CMM tasks are also group-worthy tasks that have multiple entry points and solution paths for students with varied mathematical strengths to work collectively and solve (Horn, 2006). We have also seen that modeling activities build math stamina and perseverance. In our project, teachers reported more children engage in mathematics for longer periods of time with modeling activities (Turner et al, 2021).

Goal 3: Promote Rigor

CMM activities are high cognitive demand activities that emphasize observation, analysis, argumentation, and critique (Smith & Stein, 1998). All strands of mathematical proficiency can be accessed through modeling activities: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive dispositions (National Research Council, 2001). Historically, one way children have been marginalized in mathematics is by denying them access to rich and rigorous mathematics. Through racist tracking practices, challenging enrichment opportunities are often reserved for children with a specific label like "gifted" or "highly capable". However, denying access to rich complex tasks that foster curiosity and problem posing is a form of dehumanization (Aguirre, 2009; Freire, 1970). CMM opens up new avenues to engage more children in high cognitive demand (rigorous) activities.

Goal 4: Cultivate Civic Empathy

Learning for Justice (https://www.learningforjustice.org/) provides educators with a set of social justice standards (Learning for Justice, n.d.) as a road map for anti-bias education with four critical domains—identity, diversity, justice and action. In the diversity domain, one anchor standard states-*Students will respond to diversity by building empathy, respect, understanding and connection.* To unpack what building empathy means, we lean on Mirra's (2018) work on critical civic empathy–moving beyond oneself and into the perspective of another person and then to take civic action. Mirra (2021) challenges educators to consider the power of empathy-"If my experience of seeking to empathize with another person's challenges does not encourage me to heal the roots of those challenges–through community action, voting, protesting—then what good is that empathy, right?" (p. 12). CMM has the transformative potential (Jemal, 2017)

to develop a level of critical civic empathy that leads to action to transform contextual factors that may be perpetuating inequitable conditions and that are necessary for change.

Goal 5: Elevate Justice

CMM provides opportunities to examine issues of fairness, access, power, and civic engagement in our homes, communities, and schools. CMM and teaching mathematics for social justice share three important features: both engage students in ill-defined (messy) problems for which there can be multiple and equally valid approaches; both leverage real-world knowledge that students bring to the classroom; both raise students' interest in mathematics by supporting them to better understand their world (Cirillo et al., 2016). Children have questions about the world; they have ideas about what it means for a situation to be fair. They have heard adults talk about societal topics such as healthcare, government sanctioned violence, racism, as well as food, water, and air quality. Some experience economic hardship while others look for ways to relieve it. Some experience natural disasters such as hurricanes, earthquakes, and fires. And most recently, we have all been touched by the COVID19 pandemic. CMM can provide a space for students and their teachers to engage in these justice-focused discussions.

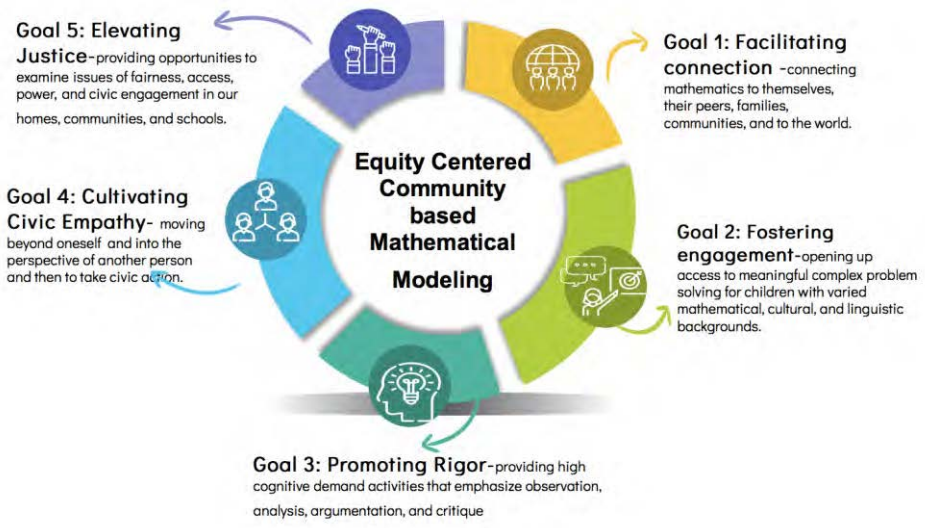

Figure 1: Theoretical Framework to Leverage Equity and Empathy in Modeling

Community-based Mathematical Modeling Case Vignettes

Vignette #1 MWR - Exploring representation of class/school libraries

The first vignette provides a picture of practice from a team of elementary teachers who wanted to integrate MM to prompt deep conversation around the important social issues of ethnic representation in library collections and to learn about race as a part of identity. They launched the unit with a MWR, where a picture prompts (see Figure 2) students to notice and wonder about a phenomenon. In order to mathematize representation of race in classroom libraries, students examined a numberless graphical representation. As students noticed and wondered about the real-world statistics the mathematician was communicating, their conversation suggested awareness of injustice. Students perceived this as an issue of fairness, connecting the availability of main character representation to the disparate number of mirrors for different races and the characters' facial expressions. Empathetic comments emerged such as, "The kids

are frowning because there's a lot of books about White people and not a lot about Brown people," and "The Latinx girl is shocked, the mirror is broken. This is not fair."

(Data on books by and about Black, Indigenous and People of Color published for children and teens compiled by the Cooperative Children's Book Center, School of Education, University of Wisconsin-Madison)

Figure 2: Numberless Graph Depicting Characters From Diverse Backgrounds Used in Data Talk

This data talk compelled third graders to take inventory of their classroom libraries, framing an investigation to see if their personal race was represented in the main character of books (mirror of representation) as well as if they could see another's racial representation among the books (window to representation of others) (Sim-Bishop, 1990). The analysis of their classroom library involved collective decisions from the students about how to sort the books, what racial categories to use, and how to determine the race of the main character. The inventory revealed the underrepresentation of diverse main characters and led to a powerful modeling task to make their library more fairly represent their classroom demographics. The class created a model that determined how many books of diverse characters should be purchased and wrote a letter to the principal asking for funds to make their library collection more representative of the class. This vignette showcases how the CMM had a transformative potential (Jemal, 2017) to develop a level of consciousness around race representations in their library that led to action to get more books for their library.

The absence of a child's culture and race from classroom libraries is problematic as they receive a message that their school does not think their culture is important enough to feature in the library. This library representation modeling task **facilitated connections** by giving students ownership in how they would solve the problem of underrepresentation. Having students identify books that reflected their culture and race provided an opportunity for students to make connections to their identities. It **fostered engagement** through a group-worthy task with multiple entry points for students to participate in mathematical and democratic decision making. Grade appropriate **rigor was promoted** through important data analysis, representation, and mathematical decision-making for justice. It also **cultivated civic empathy**, first with feelings of sadness and outrage at the realization of injustice, then through community pride and healing in taking action to purchase books that affirmed their own representation as well as their peers'. Taking action **elevated students' sense of justice**, and reinforced how they can use mathematics to address inequities and transform their community into a better place.

Vignette #2 Safe Water for Schools

This vignette focuses on students learning about the importance of access to clean water through studying the Flint water crisis and engaging in a math modeling task about safe water for their school community. To **facilitate connections**, teachers launched the CMM task by building context about the water crisis in Flint, Michigan. Students read short articles and viewed images of corroded pipes and brown water in bottles. Teachers shared information about how lead is toxic to the human body, especially for children's brains. Next, teachers engaged in an MWR routine with images of water fountains covered with plastic and signs that said "do not drink" and an image of two elementary students taking a large five-gallon jug of water from a supply room. The MWR provided space to **foster engagement** as different students voiced their noticings, wonderings, and personal connections and emotions about the situation. Figure 3 depicts the wonderings from a 5th grade class. The starred questions are questions that could be answered with math. Students then pursued a modeling task that asked them to imagine themselves in this situation, **cultivating civic empathy** as they determined how many large jugs of water they would need for their class for one day, week or month.

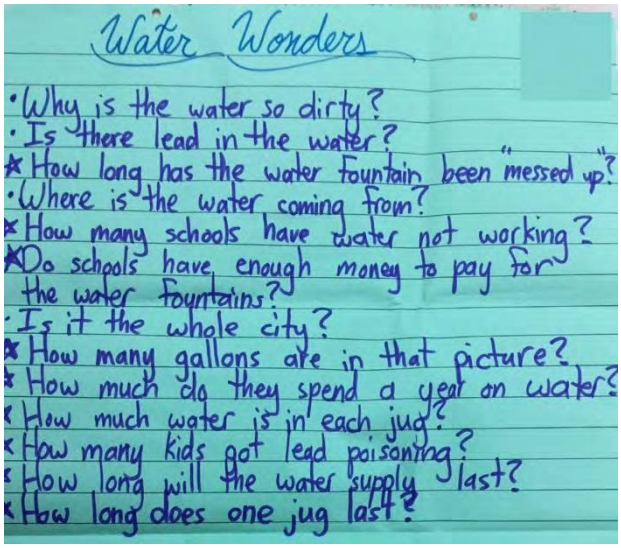

Figure 3: MWR Chart

In Ms. G's 4th grade class, students were living this reality. Their classroom sink/water fountain had recently been shut off due to lead found in the water. They had dispensers with large jugs of water in the hallway shared with other classes. Students identified two important quantities to take into consideration. They needed to figure out how many people would be drinking and how much they would drink per day. Students wrestled with who to include, for example just students; students and teacher; absent students or guests. To help students make decisions about the amount of water to drink, teachers provided a data table that gave ranges of daily water needs (in cups or ounces) by age and grade level. Teachers also shared that the large jugs were 5 gallons and there are 16 cups in 1 gallon. Students worked together in groups to make decisions that took into consideration how long they spent at school, and if people brought their own water bottles. Students' solutions varied with some groups deciding they would need 2 large jugs, 3 large jugs or 4 large jugs. After several students shared their solutions, Ms. G invited students to think about how other students could use their models if a similar situation arose in their school. In other words, to generalize.

Ms. G: So, we've all done our presentations, but we didn't get a chance to talk about what directions would you give another kid. If you were telling a kid in another class how to make a plan for how much water to order, what are some things we could say we could generalize? We can say, that is generally true, that is consistent? So, if another kid from another class wanted to make that plan for the water, what are some things we would tell them that they could do? Max?

Max: I would probably say first start off to find how many kids are in your class. And how often do they drink water? And, ask for their age and just go from there.

Ms. G: Okay so knowing their age. Does it matter that one team said 7 cups because their age was young on the chart and another team said 10 cups? Does it matter or is that okay to make a decision like that?

Many Students: Yeah - Make a decision

Ms. G: So, you make your decision and then you go with it to do the math. What else can we generalize?...

Max: One thing is to define, like, how long are you going to do it. Are you going to do it for a day, or are you going to do it for a week?

Ms. G: Ok. Amari, you have a thought?

Amari: Yeah, how do you know if all the kids are going to show up for school?

Ms. G: Yes, some kids could be absent. Those are other things. So, when you plan how many students, you might assume that somebody is going to be absent.

Ms. G. **promoted rigor** by asking students to generalize, as this communicates that students are capable of complex mathematical work. Ms. G supported students in this rigorous practice by reminding students of the components of their own models, and by revoicing the ideas that students shared. The CMM lesson **facilitated connections** as it was relevant to Ms. G's students; they found lead in the water at their school, and students were genuinely concerned about access to safe water. Finally, Ms. G **advanced equity and civic empathy** by inviting students to connect the specific situation of the task to broader issues of social and environmental justice. By generalizing their solutions, students had opportunities to cultivate empathy, and elevate justice for their own and other's communities.

Theory Synthesis and Implications for Teaching CMM for Equity and Empathy

These two vignettes illustrated how community-based mathematical modeling promotes **five equity goals** for mathematical modeling instruction in elementary settings (*facilitate connections, foster engagement, promote rigor, cultivate empathy and elevate justice*). Next, we discuss these theoretical perspectives on mathematical modeling as a lever for equity and civic empathy in relation to the phases of the mathematical modeling process.

In the first phase, *Making Sense of the Problem*, CMM affords opportunities for teachers to select meaningful contexts that connect to student experiences and issues of fairness, access, representation and justice. In both of our vignettes, elementary students were engaged in *local* community-based problems -- issues of equitable representations of classroom library collections and access to clean water - that also align with broader initiatives to reduce inequity and improve the health and lives of global citizens(https://sdgs.un.org/goals). We make these parallels to global issues to demonstrate how community-based math modeling has transformative potential (Jemal, 2017) for even young mathematical modelers to bring awareness of inequities, and to experience critical civic empathy to take action in powerful ways in their community. By

providing images, videos, realia, and graphs to support students' engagement in discussion, we can position students' funds of knowledge and experiences as resources to pose problems.

In the second phase, *Identify Important Quantities*, CMM afforded opportunities to listen to students' ideas and experiences with a sense of curiosity. Modelers make assumptions and decisions when defining variables and determine what they consider to be important which impact the models they create. This is also where data can present evidence of inequities as the library representation modeling task revealed a disproportionate number of books in one racial category, as compared to the others. Older students might examine inequities in COVID 19 pandemic data such as the disproportionate mortality rate for African American and Latinx communities. These important quantities drive the need to better understand underlying issues.

In the third phase, *Build and Operate on a Model*, CMM affords students opportunities to use diverse tools, strategies and representations to build and operate on models and to recognize the strengths in other students' strategies. Teachers honor the ways that students draw on mathematical understandings and funds of knowledge in their model building work. This phase is what inquiry-based learning and "doing mathematics" looks like in terms of promoting rigor and engagement in a cognitively demanding task (Smith & Stein, 1998). This type of learning disrupts the misguided belief that children need to master the basics before engaging in rich and complex math which often happens in schools with historically marginalized student groups causing harm and differential learning experiences (NCTM, 2020).

In the fourth phase, *Analyze and Interpret Models*, CMM affords opportunities for students to collaborate, refine, and consider multiple models by comparing and contrasting strategies and to identify how decisions and assumptions impact solutions. This is a crucial component of perspective taking that is highlighted in the social justice standards (Learning for Justice, n.d.) and in the civic reasoning and discourse literature (Lee et al., 2021). Encouraging students to revise and refine models *foster engagement.*

In the final phase, *Validate and Generalize Models*, CMM encourages students to consider how the components of their own models would work or need to change in a new situation. The Safe Water task enabled students to consider situations similar to the Flint Water Crisis. And, in fact, one classroom recently had their water shut off because lead was found. Inviting students to generalize models to help others in similar situations cultivates civic empathy and empowers action to change the inequities discovered through mathematical analysis in the CMM task.

We situate this work in the midst of the 'double pandemic' (Brennan, 2020) which refers to the COVID-19 interruptions as well as the heightened awareness of systemic racism. Aligned to the PMENA 44's theme, *Critical Dissonance and Resonant Harmony*, we share this theoretical paper to engage in conversation to move beyond the "dissonance" and inequities in our world and consider how Community-based Mathematical Modeling can be a "post pandemic pedagogy" (Ladson-Billings, 2021) to advance equity and cultivate civic empathy in school mathematics. Our hope is that the framework offers a pathway for harmony and humanizing children's learning experiences in the elementary mathematics classroom.

Acknowledgments

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