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Designing for Ethical Reasoning in Mathematics [and STEM] Education

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ABSTRACT

Several mathematicians, social scientists, and psychologists have written about the role that mathematics has played in disenfranchising traditionally marginalized groups. Mathematics educators who are concerned with equity and inclusion have been calling for mathematics curricula that place social justice at the center of mathematics teaching and learning. Existing studies typically focus on using local community contexts to engage students in using mathematics to "read and re-write" their world. Few studies have investigated the role of ethics in the mathematics classroom or how students might develop a morally grounded mathematical disposition. This article begins with a discussion of the ethical considerations that emerged during a Classroom Design Research study of 7th grade students' integrated STEM reasoning. These unexpected findings serve as the inspiration for the succeeding literature review on students' perceptions of mathematics as useful, the potential dangers of mathematical (STEM) illiteracy for society, and the current role of ethics in mathematics (and STEM) classrooms. Finally, it introduces Critical STEM Consciousness as a new and essential construct in mathematics [STEM] education. Recommendations for praxis and research aimed at promoting Critical STEM Consciousness are provided.

Keywords: ethical reasoning, mathematics education, Critical STEM Consciousness

Introduction

The ability to engage in quantitative discourse is necessary for both civic participation and personal advocacy (Gravemeijer et al., 2017). Multiple studies have addressed the negative consequences of ethics-free mathematics on individuals, society, and the environment (Barwell, 2018; O'Neil, 2016; Wheelan, 2014). Its inerrant reputation, coupled with a mathematically and statistically illiterate general population, contribute to the unethical and unscrutinized use of mathematical and statistical models which have been argued to affect marginalized groups and individuals more often (Best, 2013; Cobb, 1999; Ernest, 2018; O'Neil, 2016; Skovsmose, 2016). Feeding this phenomenon are the pressures of high stakes testing and school report cards which have transformed the mathematics classroom into a computation centered environment detached from students' realities (Cobb, 1999; Landsman & Lewis, 2011; Moore & Lewis, 2012; Triplett & Ford, 2019). In addition to widening opportunity and achievement gaps, this lack of authentic context contributes to students' skewed perceptions of mathematical utility, positioning them to misinterpret the quantitative nature of the world and undervalue the importance of mathematical participation (Ernest, 2018; Gravemeijer et al., 2017). Though the academic effects for students are problematic, the long-term effects of a skewed perception of mathematical utility are detrimental to society.

Ernest (2018) presents a convincing argument regarding the negative impact of a context- and ethics-free mathematics curriculum on widespread mathematical illiteracy. Except for the large volume of articles advocating the teaching of ethics in mathematics classes (cf., Frankenstein 1983; Gutstein, 2006; Skovsmose, 1994), we could find very few experimental studies that explored K-12 students' ethical reasoning (exceptions Brantlinger, 2014, 2018; Gutstein, 2016). Due to the increased power, affordability, and usage of data analytics as well as algorithms and computing science, there is a push to teach ethics in STEM college courses as a prominent part of the program (Tractenburg et al., 2015). Many STEM professional organizations have crafted Ethical Codes of Conduct (National Society of Engineers, American Statistics Association, Association for Computing Machinery, Mathematical Association of America, to name a few), but these are focused on the behaviors of the people in the profession, not on the ethical reasoning of students who are preparing to join the field. Like mathematics education, very few studies have explored the ethical thinking of K-12 students who study engineering, science, statistics, computing, etc. Like Tractenburg et al. (2015), we argue that ethics must be integrated into STEM education at the K-12 levels, to prepare students for its use in both the civic and working worlds. To accommodate this need, this paper initiates a call to research that addresses how ethical STEM dispositions can be cultivated in the classroom.

This article begins with a discussion of the ethical considerations that emerged during a Classroom Design Research study of 7th grade students' integrated STEM reasoning. These unexpected findings serve as the inspiration for the succeeding literature review on students' perceptions of mathematics as useful, the potential dangers of mathematical (STEM) illiteracy for society, and the current role of ethics in mathematics (and STEM) classrooms. Finally, it introduces Critical STEM Consciousness as a new and essential construct in mathematics [STEM] education. Recommendations for praxis and research aimed at promoting Critical STEM Consciousness are provided.

Impetus for Our Call

In the spring of 2018, we engaged in a Classroom Design Research Project (Stephan, 2014) which aimed to design, implement, analyze, and revise an instructional innovation that integrated mathematics, science, and engineering in authentic ways (Pugalenthi, 2019). The instructional innovation focused on the mathematical objectives of ratios, proportions and parallel lines, and science standards of energy, force and motion, in an engineering context. Through this Classroom-Design Based Research (C-DBR) project, we created a hypothetical learning trajectory and instructional materials to explore the emergence of 7th grade students' STEM practices and dispositions (Pugalenthi, 2019). Pre- and post-interviews were conducted before and after we implemented the instructional materials via a classroom teaching experiment (Cobb et al., 2012). The goal of the interviews was to document four focus students' understanding of the targeted engineering, science and mathematics concepts. The four interviewed students were diverse in regard to race, ethnicity, and socioeconomic status and were varied in their academic achievement levels (as identified by the teacher). It was during our analysis of these four students' interviews that we noticed their spontaneous ethical reasoning as they solved an engineering design task. This led us to question the extent to which ethical reasoning is taught as a part of STEM instruction. Ethical reasoning, for us, refers to the cognitive activity of deciding what is right and wrong when facing a dilemma that affects other living beings. Ethical reasoning is shaped by one's ethical ideology or the framework of beliefs, attitudes, and values that one holds (Barnett, Bass, & Brown, 1994)

A series of mathematics and engineering tasks were given during the pre- and post-interviews in order to capture these students' understanding of parallel lines, angles, and the engineering design process, both before and after the classroom teaching experiment. The mathematics tasks involved showing students several sets of lines and asking them to determine if they were parallel. To gauge their understanding of angles, they were also asked to identify how many angles they saw in a collection of geometric images. The engineering design task for the pre-interview is shown in Figure 1, with the *Asteroid Impact* task used in the pre-interview and the *Moon Colony* in the post-interview. It was during our analysis of this segment of the interview that an unexpected theme of ethical reasoning emerged from the four focus students.

In the engineering portion of the pre-interview, students were given a handout describing a message from the President of the United States informing them of a mile-wide asteroid that was about to hit the fictitious state of Alabraska (adapted from *Teaching Engineering* https://www.teachengineering.org/curricularunits/view/csm_asteroid_tg). As the lead engineer for their firm, they were tasked with creating an underground cavern(s) to escape the asteroid impact. After initial questions about the context, the students were given two maps of the area that the asteroid was projected to hit, one attending to the geological makeup of the fictitious state and the other general, topological. They were then asked to describe how they would go about building the cavern (see questions in Figure 1).

Engineering Interview Questions
[Show the President's Memo] Highlight parts of the memo that are relevant to your engineering team to help design the size and location of your cavern(s). Why is that important? *[Show them the General Map]* What information on the General Map might help you with your decision about possible cavern locations? Explain. *[Show them the Geological Map]* What "natural features" of the earth should you be concerned about when designing the caverns? Explain. Should you design and build more than one cavern? Explain? How big does the cavern need to be - the size of the whole State, half the size of the State, one tenth the size of the state? Explain. If the asteroid has a diameter of 1 mile, how deep do you think your cavern needs to be? Explain.

Figure 1. Pre-interview questions: *The Asteroid Impact*

Two students who, for the purposes of this paper, will be called Max and Tyler, demonstrated ethical considerations in the interviews without provocation from the interviewer. Specifically, they demonstrated either an idealist or pragmatic philosophical orientation toward saving civilians. In general, idealists are those who tend to strive for perfection, desiring an ideal world (McDermid, n.d), while pragmatists are practical and goal oriented (Guyer & Horstmann, 2015). Though it was not a requirement, two of the students discussed designs and procedures that were socially conscious and ethical in nature, including drawing on idealist and pragmatic philosophical orientations in the design process, attending to accessibility for people with diverse means and corresponding needs, reflecting on the effects of design decisions, and attempting to preserve others' quality of life.

Max: The Idealist

Max demonstrated an idealistic philosophical orientation to designing the cavern in that his goal was to save the entire population with minimal casualties (Pugalenthi, 2019).

Max: Idealistic Philosophical Orientation

Student/Interviewer	Response
Max:	*[looking at the general map]* Ok so, major highways, railroads, rivers, fault lines... military base, airport… We can build an opening [*to the cavern*] near the railroad in case anybody's on it…. And so major cities, anywhere that people can enter. I'd also like to build one near an airport because a lot of people are gonna be at the airports… major highways… think like Hurricane Katrina, some people tried to leave on the highways but they were too backed up so they had to turn back… Does it have to be like an underground system? Or can it, is there another way? I wish that the airports could evacuate everyone for free. I mean some people need help. They don't got [*sic*] the money to have a car.
I:	So that is part of the problem, isn't it? You've got people with different means within the state.
Max:	Yes, and that's why I need more, yes.

Max recognized that individuals would be affected differently and would have different needs in the prospective time of crisis. He seemed to be extremely concerned about the lack of accessibility for people with minimal resources and was determined to accommodate those people. He reflected on historical times of crisis to identify areas of need which he believed would be prime locations to build a cavern. Max felt that multiple caverns should be built for accessibility as opposed to one that was centrally located. This part of the discussion led into the second dimension of Max's ethical reasoning which focused on how to keep residents of the cavern safe in the aftermath.

Max: Consideration for Quality of Life After Impact

Student/Interviewer	Response
I:	Did you talk to me about the size of the cavern? You said there would need to be more than one?
Max:	I was thinking about building different caverns just for the accessibility... I would build it in certain areas and then along the canal or river… the problem is now there's water poison from the asteroid… man, now we need a filtration system!
I:	Are you marking areas on the map to show where you're going to put caverns or just indicating a possible area?
Max:	I'm indicating areas. I don't know there could be poisonous areas [*puts an x through areas that he thinks would not support the cavern, might have poisonous soil or water sources form the asteroid*].

In this excerpt, Max demonstrated his ability to see beyond an immediate and seemingly sensible solution. He recognized that his solution to the initial problem (the asteroid) did not account for peripheral issues that would need to be addressed. His attention to such details went beyond what he was required to do and indicated his capacity to think ethically and reflect on the effects of his proposed solutions. We have described Max's reasoning as idealist because he elaborates a plan that is impractical given there are 10,000,000 residents and only 10 days before the asteroid hits. Max seems intent to save everyone by building as many caverns in critical locations around the state.

Tyler: The Pragmatist

Tyler expressed a similar concern for maintaining quality of life and rebuilding after the impact. In contrast to Max, however, Tyler recognized that the time constraint of 10 days would be problematic for saving everyone, and thus demonstrated a more pragmatic philosophical orientation in his cavern design (Pugalenthi, 2019). His first step would be to provide temporary refuge to accommodate people during the blast and to rebuild after.

Tyler: Pragmatic Philosophical Orientation

Tyler:	If we only have 10 days we should probably make a crude bunker and then build off of it...we'd have to keep supplies in the bunker. Then we could probably build farms below ground for food and stuff during the winter

Tyler expands on this concept later in the interview, describing how he would position the bunker(s) to access citizens and resources after the impact. He emphasized the need to be situated close to waterways and transportation hubs in order to search for and be accessed by survivors, and provide easier access to sustainable resources which could be used to both maintain the quality of life and accommodate more people.

Tyler: Pragmatic Philosophical Orientation

Student/Interviewer	Response
Tyler:	So the elevation… it would be nice to have it right here because there's a mountain range… it's close enough to the river so that we can get a good amount of water pumping into the place… if the fallout, or whatever we call it, ended, we could travel to a nearby airport or military base to get more supplies and there's a railroad near that… we could travel to the railroad to get out of the state to see if there's any other survivors that we could try to rebuild with… we could travel to the major cities to look for survivors. It's connected to a big river so we could probably last for a long time so that we could have more resources so that we can hold more people.
I:	How big would we need to build it?
Tyler:	Humongous…. It's 10 million citizens. Yeah, it'd probably have to be really big, like 5 or 6 schools stacked on top of each other.

I:	Would that save the citizens?
Tyler:	As many as we could.
I:	If the asteroid was one mile in diameter would that affect how you build?
Tyler:	Yes, it would be very wide because if something was to happen to one of the bunkers, like it hit the bunker, it would be nice to spread it out, because if it is all stacked on top of each other all cramped it would just destroy the bunker and any chance of living in it. And we could spread out the resources between it.

Like Max, Tyler demonstrated his ability to create an ethically grounded solution to the issue at hand, as well as engage in a level of reflection about his proposed solution.

Max and Tyler's commitment to saving all (idealist) or as many people as possible (pragmatist) through their engineering design inspired us to review the literature on ethical reasoning in STEM. Since STEM is a relatively new area of research, we focused on both mathematics and STEM articles, finding much more in mathematics. In the next few sections, we summarize the most current research and use these ideas to introduce a new construct.

Research in Critical Mathematics [STEM] Pedagogy

Researchers suggest that the absence of applied mathematics in authentic contexts contributes to a disconnect between the skills that are required in the classroom and the 21st century skills that are required for democratic citizenship and workforce membership (Ernest, 2018; Gravemeijer, et al., 2017; Steen, 2001). Several bodies of literature centered in Critical Pedagogy, STEM integration, and Project Based Learning (PBL) have advocated for the use of critical and authentic contexts in STEM education (Capraro & Jones, 2013; Gutstein, 2018; Kelley & Knowels, 2016). Other scholars have explored the impact of calculational versus conceptual orientations towards the use of mathematics, arguing that a conceptual orientation is beneficial for student outcomes (Boaler, 2016; Thompson, Phillip, Thompson & Boyd, 1994). While such studies are extremely important for closing what is known as the Achievement Gap (Moore & Lewis, 2012), few have addressed the need to develop ethical and critically reflective mathematicians.

Researchers grounded in Critical Mathematics Pedagogy have explored students' perceptions of mathematics as a tool for social inquiry (Brelias, 2015; Gutstein, 2016; Rubel et al., 2016). When challenged to explore mathematics in critical contexts, these student participants acknowledged its potential to represent societal issues. Student participants in Brelias' (2015) study recognized mathematics as an "indispensable tool for understanding societal issues" while also recognizing its inherent need for scrutiny (p. 5). Through their exploration of mathematical modeling and statistics in critical settings, they were able to identify the objective and socially neutral nature of mathematics which they connected to both positive and negative outcomes for society. Although mathematics can be useful for representing data on societal phenomena, they claimed that it is easily used as a tool for persuasion. Parallel to these suggestions, Brelias (2015) and Ernest (1991, 2018) argue that the widespread perception of mathematics as an infallible tool coupled with the general public's statistical and mathematical illiteracy, enables the unethical use of mathematics to go unchecked (Brelias, 2015; Ernest, 1991).

The Dangers of Ethics-Free Mathematics [STEM] for Society

Ernest (2018) challenges the idea of mathematics as an impenetrable force, solely used for good, by shedding light on its potentially harmful qualities. He contends that the objectivity of mathematics lends itself to "dehumanized thinking which fosters instrumentalism and ethics-free governance and social practices" (Ernest, 2018, p. 205). O'Neil (2016) confirms this assessment in an account of her experiences as a data scientist, where she documents the frequent use of discriminatory algorithms in politics, policy, and the corporate world, a phenomenon that Wheelan (2014) corroborates in the realm of descriptive statistics. According to O'Neil (2016), dangerous algorithms, which she calls *weapons of math destruction* (WMDs), are seemingly complex mathematical models that aid the decision-making process for corporate and large-scale entities at very low costs. They are widely unscrutinized and influence the job market, incarceration rates, college acceptance, teacher evaluation, politics, loan dispersion, etc. in ways that predominantly disadvantage poor, middle class, and minority citizens (O'Neil, 2016).

The use of prejudicial data in mathematical modeling and statistical analysis is especially concerning since matters involving disadvantaged and low-income individuals are more often processed by technology than their advantaged counterparts (O'Neil, 2016). O'Neil (2016) notes that the cost-effectiveness of WMDs relies on their ability to assess people quickly and in large numbers, a disturbing reality when one considers that people in privileged positions are more often processed by other human beings, while the masses are reviewed and judged by machines. For example, the use of the Value-Added Model (VAM) for judging teacher quality resulted in a good teacher being let go from a low-income school based on a poor rating, but was later rehired at a high-income school across town (O'Neil, 2016). The former principal was bound by the numbers to release her while the new, high income school administration, considered her references and interview performance over the flawed score. Interestingly, such instances do not imply flawed mathematics, but rather inappropriate input and a lack of scrutiny. According to Wheelan (2014), statistical models perform as well as the data that goes in them, a phenomenon that statisticians describe as *garbage in, garbage out* (O'Neil, 2016; Wheelan, 2014). As Wheelan (2014) illustrates, even the best recipe in a cookbook cannot produce a quality meal from rancid ingredients. WMDs and other misleading statistical models do not lack mathematical accuracy, but rather lack authentic and representative input (O'Neil, 2016; Wheelan, 2014).

Quantitative methods and analyses are used by corporate entities for a predetermined purpose; though mathematical models are objective, the people behind them are not. They have goals, ideologies, and stereotypes that influence the input and resulting output of the quantitative models they use (Best, 2013; Ernest, 2018; O'Neil, 2016; Wheelan; 2014). A major fault of using mathematical algorithms and statistics to guide policy decisions is their inability to differentiate between correlation and causation, and their inherent absence of ethical, emotional, and subjective underpinnings (O'Neil, 2016; Wheelan, 2014). According to O'Neil (2016), the people who create WMDs are often unable to acquire data that is representative of their desired characteristics. They instead resort to proxies based on statistical correlation which are frequently discriminatory, sometimes illegal, and have dire consequences for many. Examples of such data substitutes include credit scores as indicators of responsibility and zip codes as an indicator of the likelihood that a criminal is a repeat offender (O'Neil, 2016; Wheelan, 2014).

The success of a mathematical model depends on who is assessing it and what connection they have to its beneficiaries (Best, 2013; O'Neil, 2016; Wheelan, 2014). According to O'Neil (2016), very few people have the mathematical and statistical knowledge to interpret big data models or the integrity to blow the whistle in cases of malfeasance. Unfortunately, once in use, mathematical and statistical models are rarely audited and less often modified, a critical oversight that could be attributed to their large financial return, inaccessibility, and the general public's statistical illiteracy (O'Neil, 2016; Wheelan, 2014).

Mathematics in Democracy

The quantitative nature of the information age is intimately tied to democratic participation and power (Cobb, 1999; Ernest, 2019). Both Cobb (1999) and Ernest (2018) argue that the development and critique of quantitative arguments is essential for ensuring equitable and ethical outcomes for diverse citizens. According to Cobb (1999):

> It is already apparent that debates about public policy issues tend to involve reasoning with data. In this discourse, policy decisions are justified by presenting arguments based on the analysis of data. In many respects, this discourse is increasingly becoming the language of power in the public policy arena. Inability to participate in this discourse results in de facto disenfranchisement that spawns alienation from, and cynicism about, the political process (p. 38).

Cobb's (1999) description of the quantitative nature of the information age aligns with the current literature concerning the role of mathematics in democracy and civic life (Ernest, 2018; Gravemeijer et al., 2017; Steen, 2001). Such literature highlights the intimate relationship between mathematical competence, power, individual agency, and advocacy, and supports the stance that mathematical and statistical literacy are not exclusive to students who desire a quantitative or data centered profession.

The ability to develop and critique quantitative arguments is necessary for participation in democracy and for ensuring an equitable society concerned with the common good (Best, 2013; Cobb, 1999; Finkel, 2017; O'Neil, 2016). Finkel (2017) states that

> full participation in our increasingly complex and interdependent global community requires the capacity to understand and utilize science and math concepts for the purpose of individual and collective participation in decision making—whether individuals choose careers in science and math or not (p. 117).

K-12 schools maintain a pivotal role in fostering the quantitative literacy and dispositions required for such engagement (Finkel, 2017). Unfortunately, the nature of both the science and mathematics curriculum in K-12 schools are deemed unattractive and irrelevant to the vast majority of students, especially those who do not represent the White or Asian, male demographic (Finkel, 2017). This translates to the number of students who seek a postsecondary degree in a STEM related field. According to the National Center for Education Statistics (NCES), STEM majors made up only 18 percent of the 1.8 million bachelor's degrees awarded in the 2015-2016 school year. When disaggregated by race/ethnicity, this same data indicates that STEM degrees are awarded disproportionately among groups. The percentage of degrees awarded in STEM fields for White (18%), Asian (33%), and students of two or more races (20%) is equal to or greater than the proportion of such degrees earned in the total population, while the percentages of STEM degrees awarded to Black (12%), Hispanic (15%), American Indian/Alaskan Native (14%), and Pacific Islander (15%) students were below the proportion of degrees awarded in STEM fields for that year. Similarly, females are significantly underrepresented in STEM according to the same NCES data. Although 58 percent of the total bachelor's degrees were awarded to females, only 36 percent of STEM degrees were earned by women in that same year (NCES, 2019). This trend holds across all racial/ethnic classifications where the difference between the percentage of males versus the percentage of females who earned a STEM degree is between 10 percent (Black students) and 32 percent (White students) (NCES, 2019).

The mathematical division among students in schools has serious implications for both the representation of diverse groups in STEM careers and for the advocacy of various perspectives in democracy. Students who lack mathematical competence and numeracy in school are more likely to blossom into adults who are statistically and/or mathematically illiterate (NCTM, n.d.; Steen, 2001). In an increasingly quantitative and technological world, an inability to reason quantitatively restricts access to STEM majors and careers and limits their democratic participation (Cobb, 1999; Gravemeijer et al., 2017; NCTM, n.d.; Steen, 2001). The under-representation of minority, and marginalized groups in both STEM careers and as advocates for their respective cultures in politics and policy (NCES, 2019), ensures that societal priorities will continue to reflect the values of the quantitatively literate majority.

Students who are fortunate enough to gain a robust conceptual understanding of school mathematics are rarely equipped to see the connection between classroom, workforce, and daily quantitative reasoning (Gravemeijer et al., 2017; Steen, 2001). Without the ability to recognize mathematics as socially and environmentally situated, mathematically proficient students are more likely to become critically ignorant mathematicians whose products "sustain historical patterns of inequity and disparity in the distribution of society's benefits" (Finkel, 2017, p. 117). Applied mathematics is not context or consequence-free. It exists to describe phenomena, aid the decision-making process, and provide innovative solutions to societal and environmental issues. In such cases, mathematical reasoning is an extremely valuable tool. But without critical reflection on the potential consequences of quantitative models for individuals, society, and the environment, their effects can be devastating. As a response to this reality, the goals for mathematics and STEM education should include the development of relevant concepts and skills as well as the nature and limits of mathematical thinking (Ernest, 2018). Such limits, however, become meaningful only when they are situated in authentic contexts (Wheelan, 2014).

Critical STEM Consciousness

We live in the Information Age where billions of data are collected daily and used to make decisions that affect millions of lives. As seen above, without a moral compass, humans may implement data-based policies that disproportionately affect disadvantaged populations. We contend that, even when an individual possesses a strong moral code, he/she may not be aware of the potential that mathematics, and STEM more generally, has to disenfranchise others. In this section, we offer a new construct, *critical STEM consciousness*, that builds on Freire's construct of critical consciousness. Freire defined critical consciousness as possessing an awareness of one's situated reality, to acknowledge systemic inequities, yet maintain a belief that oppression can be overcome (Freire, 2018). Crabtree and Stephen (in press) adapted this construct to the science discipline by defining critical *science* consciousness as an individual's awareness of the role that science has played in marginalizing groups as well as the potential for science to liberate. Similarly, critical *STEM* consciousness refers to an awareness of the role that the STEM disciplines play in disenfranchising or liberating marginalized populations.

Critical Pedagogy movements such as Teaching for Social Justice (TFSJ), Teaching for Spatial Justice (TFSpJ), and Culturally Responsive Teaching (CRT), align with Freire's theory while attending specifically to Ladson-Billings' (1995) construct of sociopolitical consciousness. These researchers and educators aim to develop students who are able to critically analyze their political, social, and economic realities as well as their positions in them (Gutstein, 2003, 2006; Ladson-Billings, 1995; Rubel, 2017; Rubel et al., 2016; Skovsmose, 2016). Yet, critical consciousness is unique to each educational discipline. Solutions presented to social injustices in a language arts course will likely differ from solutions presented in a mathematics classroom, though the underlying goals may be the same. The histories, traditions, and effects on society will differ according to the nature of the subject, implying that students will develop ethical dispositions in ways that are specific to the subject area. The influence of mathematical models over societal phenomena presents a unique responsibility for those who will eventually work in the field. As outlined previously, mathematics is a potentially powerful tool for oppression when unscrutinized and used to further the agendas of those in advantaged positions (Cobb, 1999; Ernest, 2018; O'Neil, 2016). This establishment of mathematical power and oppression begins in the education system where certain students are granted access to the community of the mathematically literate, while others are left on the fringes (Walshaw, 2013). Such power struggles are exacerbated by the inequities that exist in mathematics classrooms as a result of identity shaping discourses which influence whether students identify with mathematics or reject it (Walshaw, 2013).

Though considerable research explores the execution of critical pedagogy in social justice contexts (Gutstein, 2003, 2006; Ladson-Billings, 1995; Rubel et al. 2016), there is a significant gap in the literature addressing the nature of critical STEM consciousness as well as design heuristics that may foster such consciousness in formal educational settings. Social justice research involves teaching students how they can use mathematics to change the world that they live in whereas fostering critical STEM consciousness addresses the ethical reasoning needed *prior* to creating the world. In other words, social justice involves fixing systemic inequities while our goal would be to develop the critical STEM consciousness needed to make moral decisions beforehand.

In addition, the majority of social justice research addresses students in marginalized positions, but does not yet address students who exist in truly diverse settings where power relations are explicit in the classroom. Such settings include students from both advantaged and disadvantaged positions who learn together. The difficulty with this arises from the tenets of social justice pedagogy which predominantly emphasizes the responsibility of the oppressed in their attainment of freedom. According to Freire, disenfranchised individuals are responsible for freeing themselves from their oppression, and any attempt on the oppressor's part to advocate for them, is a superficial and charitable scheme associated with a convergence of both parties' interests (Freire, 2018; Milner, 2008). The pursuit of mathematical power is one that is laden with conflict at both the internal and social level (Shah & Leonardo, 2017). In truly diverse classrooms, this will be experienced differently for each student. It will be influenced by the social makeup of the classroom, student's perception of their societal position relative to their peers, their dispositions towards mathematics, and their perception of mathematics as useful for addressing societal issues. Such elements influence the discourse of the classroom and position students along a continuum of mathematical capability. In this regard, it is important to foster mathematical power for diverse students in which shared goals are equity in society and the pursuit of a common good.

We hypothesize that critical STEM consciousness may only be fostered in contexts that are rich in diverse forms of discourse and are situated in contexts that reflect how mathematics is used in the 21st century. According to Freire, authentic and reality-based thinking does not take place in isolation, but through communication, where meaning is generated in real world contexts and situations (Freire, 2018). As such, we invite researchers in STEM disciplines to continue designing for classrooms who Teach for Social Justice and Teach for Spatial Justice, and add Teaching for Critical STEM Consciousness. As instructional designers, what are possible heuristics associated with this call?

Designing for Critical STEM Consciousness

The analysis of student interviews resulted in the realization that authentic contexts are more conducive to ethical reasoning than abstract problems. Though the nature of relevant learning conditions requires further research, it seems that socially situated tasks position students to consider the morality of their decisions in ways that unsituated tasks cannot. For instance, the science and engineering segments of the interviews include contexts that are conducive to making moral judgments because they affect people. In contrast, the abstract mathematics portion of the interview did not provide any authentic connections to students' realities, resulting in their indifference towards the effects of their processes and solutions. This has major implications for mathematics education if we wish to train ethical mathematicians and provides further insight into how students might be motivated to reflect on their work. As Gresalfi (2015) states, "ensuring that problems are both contextualized and meaningful" makes it possible for students to "feel a sense of *intentionality* in solving problems" (p. 945) [italics in original]. We offer three principles to consider when designing instructional materials/environments that support critical STEM consciousness: 1) choose authentic contexts that offer students the opportunity to engage with STEM content to make socio political decisions, 2) engage students in two-dimensional STEM learning, both computational and reflective reasoning, and 3) support students to challenge to whom mathematical thought is attributed and who is encouraged to do it.

The Role of Authentic Contexts

Careers in theoretical or "pure" mathematics, outside of academia are limited, if not obsolete. A simple Google search on "jobs for mathematicians" returns career options such as a cryptographer, economist, actuary, financial planner, investment analyst, statistician, and operations research analyst, among other applied mathematics careers. The mathematics used in the workforce today exists in collaboration with, or in the context of other disciplines, where the decisions made have consequences on real people and the environment (Gravemeijer et al., 2017; O'Neil, 2016). Critical learning in mathematics requires that students engage with age-appropriate, authentic tasks that reflect the mathematics used in policy, politics, and applied mathematics careers (Gravemeijer et al., 2017). The superficial "real world" scenarios and word problems seen in many classrooms are not conducive to understanding the quantitative nature of society or acquiring the 21st century skills required to thrive in it (Gravemeijer et al., 2017). Students must be given the opportunity to ponder the effects that their mathematical decisions will have on the world, an unconventional practice in most mathematics classrooms. Such discourse includes the freedom to compare and contrast potential solutions and methods as well as their associated consequences in order to realize that what may be the most sophisticated, efficient, or financially sound solution, may not be the most ethical one (Ernest, 2018; Hodge & Cobb, 2019; Skovsmose, 2016). Further research needs to be conducted that designs and tests instructional materials that provoke ethical mathematical reasoning in realistic contexts.

Two-Dimensional Mathematics Learning

Empathetic and mathematically literate citizens are essential to the ultimate goal of social and political synergy. The one-dimensional nature of *doing* in STEM disciplines and classrooms must be developed in a way that accounts for *doing* as well as *reflecting* on what is to be done (Skovsmose, 2016). Scholars highlight that technically-oriented reflections regularly outweigh those that consider the critical effects of mathematics applications; a phenomenon that persists in the classroom (Brelias, 2015; Christiansen, 1996; Gellert, Jablonka, & Keitel, 2001). While technically-oriented reflections include a review of the appropriateness of methods and results, critically-oriented reflections focus on the broader effects of the mathematics on people, society, and the environment (Brelias, 2015; Skovsmose, 2016). Both orientations for mathematical reflection are essential for the use of mathematics in society.

Critical reflection on the use of mathematics in social contexts requires "an *ethical* and *sociopolitical* evaluation" of its consequences (Brelias, 2015) [emphasis added]. Citizens need not only mathematical literacy to scrutinize mathematical arguments, but an empathetic disposition that will enable them to use mathematics in an ethical manner (Ernest, 2018). Such dispositions may be facilitated in formal mathematics classrooms when opportunities for critical reflection are readily promoted. The findings of this study demand that students are not only capable of developing such dispositions, but that ethics are inherent in their considerations, given the right context.

In addition to the socially situated context of the task, participants in our study were given the opportunity to explore and justify the morality of their design. Their idealist and pragmatic perspectives are grounds for rich, authentic discourse, capable of facilitating mathematics learning, critical reflection, and civic responsibility. Because mathematical sophistication, efficiency, and correct answers are glorified in mathematics education, students miss critical opportunities to explore the societal consequences of their mathematical solutions. To transform spontaneous ethical considerations into calculated dispositions, students need access to authentic, applied mathematics tasks that include theoretical consequences on people, communities, and the environment. They must be able to contemplate the diverse perspectives demonstrated by their diversely positioned peers. Through continued interpretation and participation in mathematically oriented moral dilemmas, students may begin to acquire the ethical mathematics dispositions that contribute to a just society.

Mathematics for Whom?

Skovsmose (2016) contends that critical mathematics education is necessary for diverse groups of students and is equally important for students in both comfortable and technical positions. Though social justice and critical pedagogy in mathematics has been justifiably centered around disadvantaged youth (Gutstein, 2016; Rubel et al., 2016), students in advantaged positions contribute as much, if not more, to establishing a just society (Brelias, 2015; Skovsmose, 2016). Brelias (2015) argues that "limiting the contexts in which critical mathematics literacy is promoted and studied marginalizes it as a tool for democratic citizenship" (p. 3). This fact is highlighted by the belief that those in advantaged positions tend to promote social justice agendas when such advances benefit, or at the very least, do not impede on their ways of living (Castagno & Lee, 2007; Milner, 2008).

According to Freire (2018), any attempt by an oppressor to express generosity must, by nature, "perpetuate injustice" (p. 44). Students in advantaged positions have a unique responsibility in society; because the world often works in their favor, it is difficult for them to critique and work to change it (Freire, 2018; Milner, 2008). It is imperative that students understand how to make ethical decisions regardless of their own self-interests; an ability that will not develop without consistent exposure to critical discourse. As such, critical mathematics education, including attention to interest convergence and oppression, must be a goal for both disadvantaged and advantaged youth from elementary through university-level STEM education (Milner, 2008; Skovsmose, 2016).

Implications for Diverse Classrooms

The purpose of this study was to initiate a conversation about how mathematics [STEM] instruction can be developed to support quantitative literacy for civic participation and the ethical use of mathematics in the workforce. Its findings serve only to inform how research can begin to tackle the larger questions associated with educating future democratic citizens from both advantaged and disadvantaged backgrounds. In addition to acquiring knowledge about the nature of applied mathematics in the workforce, teachers must seek to understand the political realities of their students in relation to themselves (Gutiérrez, 2013).

The United States education system fails to provide equal access to instruction that is conducive to empowering mathematically literate citizens (Gutiérrez, 2013; Stinson, 2004). In fact, scholars argue that mathematics education serves as a gatekeeper for "economic access, full citizenship, and higher education" through its reproduction and regulation of social stratification (Stinson, 2004, p. 11). Critical pedagogues have shown consistently that such empowerment is possible for low-income, minority, and marginalized groups, but gaps in opportunity persist (Gutiérrez, 2013; Gutstein, 2016; Rubel et al., 2016). Gutiérrez (2013) highlights that teachers who participated in effective urban high school mathematics departments engaged their students through group work, rigorous materials, and appropriate technology. They encouraged multilingual (language as a resource) learning environments, and provided various opportunities for students to engage in projects and tasks that were reflective of their lives. Moreover, such teachers understood and advocated for their students' personal and political needs, a characteristic that Gutiérrez (2013), refers to as "the *political nature of teaching"* (p. 8).

The diversity of United States classrooms poses many difficulties for teachers who wish to support a social justice agenda. To begin, many classrooms do not reflect the demographic makeup of those that have been empirically successful in TFSJ (Rubel et al., 2016). Teachers whose students occupy both advantaged and disadvantaged positions, and who entertain a position in society that is reflective of the former, are likely to struggle with the implementation of critical education agendas. The predominantly White and female teaching force (Landsman & Lewis, 2011; Triplett & Ford, 2019) must become better versed in the political realities of both their students and themselves, in order to navigate the natural disharmony of stratified mathematics classrooms (Gutiérrez, 2013). All students, regardless of their demographic or socioeconomic status, bring a "wide variety of experiences and contributions to the classroom" which may only be recognized through a "co-constructed classroom space" (Kokka, 2015, p. 18). Teachers then must work to build strong relationships with both students and their families so that students may be able to take the lead as experts in learning opportunities that are centered in their communities and lives (Kokka, 2015; Landsman & Lewis, 2011; Moore & Lewis, 2012).

To promote equity in the classroom, teachers must facilitate a learning environment that reflects the participatory nature of democracy and the workforce (Hodge & Cobb, 2019). Equitable mathematics classrooms value authentic participation and student voice (Hodge & Cobb, 2019). According to Hodge and Cobb (2019), a Cultural Participation Orientation towards equitable mathematics education "considers both the nature of the classroom activities and the adequacy of the supports for students' participation in those activities" and "treats the underlying source of their difficulties as an open question that can be identified through investigation (p. 875). Hodge and Cobb (2019) claim that ambitious and equitable instruction involves engaging students in rigorous tasks that are reflective of their culture. Importantly, it requires that the level of rigor is maintained throughout the lesson, that students are supported as they attempt to communicate their reasoning, and that lessons are adjusted according to students' needs (Hodge & Cobb, 2019).

The claims in this section are relevant to the goals of this study in that they establish empirical truths about the nature of equitable learning environments. It would be counterproductive to explore students' development of ethical dispositions towards mathematics in a setting that is not conducive to equitable participation, critical discourse, and authentic contexts. Furthermore, educators bear a substantial responsibility in their facilitatory role. To promote democratic responsibility and ethical decision making, one must possess a robust understanding of both.

Conclusion

Little to no literature exists on promoting critical STEM consciousness in mathematics or STEM students. Though studies on culturally relevant, equitable and critical pedagogy in STEM are a realistic starting point for exploring such concepts, they are not sufficient. There is a need for more research on the nature of students' critical STEM consciousness and the observable characteristics of critical mathematics (and STEM) dispositions to inform how they can be developed in an age-appropriate and culturally responsive manner. STEM integration tasks may be conducive to facilitating the classroom interactions described in the previous sections, though further research is needed to support this claim. Instructional strategies conducive to eliciting ethical considerations and promoting critical discourse must be explored. Furthermore, because documented difficulties with Teaching for Social and Spatial Justice include an increased understanding of social injustices at the expense of mathematics learning, instruction centered on ethical dispositions must not disregard the ultimate goal of obtaining mathematical [STEM] proficiency (Gutstein, 2003; Rubel, 2017).

Scholars in education maintain that there is a significant gap between the mathematics used in the classroom and the mathematics used in the real world. Students are often underexposed to the utility of mathematics as a tool for innovation, persuasion, and decision-making, and consequently, do not realize the value of quantitative reasoning skills in the current age of information and technology. Mathematical and statistical literacy enables citizens to advocate for themselves and make informed decisions in regards to politics, policy, finances, and their everyday needs. In addition, mathematicians in society have a responsibility to practice mathematics in an ethical manner. The review of the research described above supports the notion that mathematics has the potential to negatively impact individuals, society, and the environment; especially those from marginalized subgroups.

To avoid harm, future mathematicians must be regularly exposed to critical contexts in which they are able to propose and reflect on their mathematics solutions. It is hypothesized that integrated STEM tasks might encourage such a learning experience if coupled with learning strategies that are conducive to eliciting ethical considerations and reflective discourse. The findings of this study indicate that ethics are inherent in the minds of adolescents and that providing opportunities to incorporate moral considerations into their mathematics learning might provide a sense of intentionality in their problem solving (Gresalfi, 2015). Long-term and continuous experience with socially and environmentally relevant tasks, and active interpretation of the consequences of proposed solutions, may influence the development of ethical dispositions towards using mathematics. In theory, the nature of ethical dispositions (as opposed to instruction on ethics) implies that moral reasoning becomes an integral part of the individual's personality and worldview. While instruction on ethics may influence an individual's understanding of what may be considered right and wrong, the development of an ethical mathematics [STEM] disposition will increase the likelihood that moral considerations will accompany students' future use of mathematics in the field. It is imperative that further research is conducted in order to characterize the nature of the classroom environment and learning that is conducive to fostering such dispositions in tomorrow's mathematicians.

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