Chemicals are contaminants too: Teaching appreciation and critique of science in the era of NGSS

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Abstract: This article examines the tensions that arose as teachers, scientists, youth, and community organizers worked to develop curriculum that was responsive to community concerns *and* the Next Generation Science Standards (NGSS). Within the context of urban heavy metal contamination and building on previous critiques of the standards, we identified how the ideological commitments of the NGSS hinder their applicability to community issues. We examine latent ideological commitments in the performance expectations and disciplinary core ideas as they relate to historical and present causes and consequences of urban heavy metal contamination. Whereas the scientific enterprise and chemical industry produce harms and benefits, the NGSS focus on benefits and ignore that both harms and benefits of science are unevenly distributed. Given the pressure on teachers to implement the NGSS, this paper presents examples from collaborative curriculum development efforts that meet performance expectations while pushing students to ask critical questions and engage with their communities to challenge the standards' alignment with the chemical industry. Ultimately, we argue that the NGSS position teachers as promoters of the status quo of the scientific enterprise and we document possibilities for the role of science teachers in US schools that are more transformative.

A Framework for K-12 Science Education (National Research Council [NRC], 2012, hereafter "the *Framework*"), which guided the development of the Next Generation Science Standards (NGSS Lead States, 2013), takes the sensible position that "a major goal for science education should be to provide all students with the background to systematically investigate issues related to their personal and community priorities" (p. 278). Besides aiming to develop the skills and understandings required to study locally relevant issues, the *Framework* also describes related dispositional goals, affirming that "science learning in school leads to citizens with the confidence, ability, and inclination to continue learning about issues, scientific and otherwise, that affect their lives and communities" (pp. 286-287). These goals broaden the traditional view of science education, replacing a narrow "pipeline enthusiasm" with a more democratic and future-looking vision (Aikenhead, 2006; Carter, 2008).

The *Framework*'s vision of widespread scientific literacy also aims "to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science" (p. 1). In this paper, we argue that in addition to cultivating "appreciation of the beauty and wonder of science," science education is equally responsible for preparing students who are capable of critiquing the shortcomings and recognizing the blind spots of the scientific enterprise. We juxtapose an analysis of the *Framework* and the NGSS with curriculum developed through a teacher research project to argue that in order for science education to meet the community-responsive goals of the *Framework* cited above, science teachers must reject their assumed traditional role as promoters of the scientific enterprise. We argue that being positioned as promoters of the status quo of science undermines science teachers' ability to be educators of students who can work for progress in science and justice in their communities.

In the tradition of teacher research, our aim is not to present neutral or unbiased findings, but rather to answer questions that emerge from both theory and practice to trouble the very goals and aims of schooling (Cochran-Smith & Lytle, 2009). More specifically, the following guiding questions emerged from the contradictions we encountered in trying to develop curriculum that is responsive to both local issues of (post)industrial environmental contamination and to the NGSS:

- How do the ideological commitments of the NGSS inhibit their usefulness or alignment to curriculum about urban heavy metal contamination?
- Can we design curriculum to transcend incongruences between these ideological commitments and our own, in order to teach in ways that are relevant to NGSS performance expectations (PE) and this local problem of environmental justice?

We begin by framing the dilemmas that justice-centered science educators face with respect to the standards and the scientific enterprise by drawing on critiques of standards and of the scientific establishment. Then we explain our theoretical and ideological commitments and our approach to this teacher research project. We draw on the critiques of standards in general and the NGSS in particular to answer the first question above through an analysis of relevant NGSS disciplinary core ideas (DCI) and PE. Then we address the second question by presenting three curricular examples as evidence that, under certain conditions, collaborative efforts can "manipulate" the standards in service of equity (Gallard, Moore Mensah, & Pitts, 2014, p. 1). Finally, we discuss the implications of what we learned in terms of alternate, more transformative possibilities for the role of science teachers in US schools.

The Dilemmas of Equity & Justice for Science Educators

Science educators committed to social transformation often face dilemmas because we are trying to teach students to thrive in the world as it is while also trying to inspire and equip them to critique and change the status quo. Science learning standards and the enterprise of science contribute to these dilemmas. While we want students to have success in school and opportunities in science, we also recognize that the institutions of school and science are deeply problematic and that students are capable of contributing to their transformation.

The Standards Dilemma

The relationship between educational equity and learning standards in science education is fraught. On one hand standards documents provide guidelines that can be used to push against the systematic exclusion of African American, Latinx, and Indigenous students from equitable "opportunities to learn" (Oakes, 1990; Tate, 2001; NRC, 2012). On the other hand, standards are a top-down policy that limits community control while re-inscribing the hegemony of Eurocentric values in the curriculum. In fact, science educators have disagreed about whether science education can be both locally determined and standards-based at the same time (Aikenhead, Calabrese Barton, & Chinn, 2006). In a broad context, others have argued that, rather than achieving standardization, standards beget "standardized differentiation" (Power, 2014). Applied to a school science context, this means that standards may simply provide the framework that allows for the identification of some students, groups of students, or schools as good at science and others as not. This common use of standards undergirds the misguided "achievement gap" discourses that would be better framed as an "education debt" and better assessed by other means (Ladson-Billings, 2006).

The standards dilemma is exacerbated by punitive school accountability measures and narrow prescriptions of what counts as learning (Lipman, 2004). If performance expectations are written with authoritarian language and assessed by high stakes exams, then science educators will feel immense pressure to *teach to the test* rather than being responsive to their unique students and contexts (Wallace, 2012). But if science standards are excluded from high stakes accountability measures that focus only on literacy and math, science is likely to be marginalized, especially in schools whose test scores are under scrutiny. This marginalization often reaches the point where science instruction all but disappears from under-resourced elementary schools and receives less than a fair share of limited time and resources in middle and high schools (Rivera Maulucci, 2010; Rodriguez, 2010, 2015; Tate, 2001).

Another tension related to standards concerns what science is taught in the current U.S. political context. Wallace (2012) warns that “school science would be a chaotic endeavor without some sort of norms for what is to be taught…” (p. 294). The absence of standards may lead to curriculum that is overly dependent on a teacher’s pedagogical content knowledge and preferences, which can be stifling and detrimental to students’ learning. More importantly, science standards may guard against the manipulation of science curriculum by more powerful actors. For example, standards may quell efforts by corporations and politicians to undermine teaching about climate change or by right-wing groups to push religious doctrine into public school biology curriculum, as they have attempted in Texas (Rich, 2013). At the same time, standards are vulnerable to corporate pressures to restrict science curriculum to meet their workforce preparation goals or to minimize attention to the impact of industry on environmental health (Morales-Doyle & Gutstein, 2019; Zou, 2017; Bigelow, 2011). For these reasons, our present inquiry examines latent ideologies and potential influences of power in the NGSS.

The Ideological Commitments of the NGSS

Rodriguez (2015) has argued that the NGSS engages in a “discourse of politeness” with respect to the political barriers to equity in science education. In their efforts to appear politically neutral, the *Framework* and the NGSS fail to confront policies that prevent the implementation of the educational experiences they advocate. These efforts to frame the NGSS as politically neutral also mask the ideologies that undergird the standards. Hoeg and Bencze’s (2017) discourse analysis of the NGSS identified the underlying ideology as neoliberal. Their study follows others in defining neoliberalism as an effort to return to a previous version of free-market capitalism, with a renewed focus on the supposed ability of the free market to provide not just economic prosperity, but also social good.

Bazzul (2012) writes that neoliberalism “embodies the idea that human well-being can best be advanced by freeing up entrepreneurial initiatives, private interests, and free markets” (p. 1005). Bazzul cites Harvey, who is widely credited with popularizing the term. Harvey (2005) described neoliberalism as a political project of the corporate capitalist class to respond to what they believed to be political and economic threats emerging from labor and social movements. In education, neoliberal ideas and policies privilege free market capital acquisition over government regulation and intervention, resulting in the "marketization"" and "privatization" of schools (Lipman, 2011). Lipman discusses the neoliberal foundation of efforts to change the public school system in Chicago through choice, competition, and a focus on “results.” In other words, there is a laser focus on standardized exam results, which are used to differentiate between high and low performing schools. By these metrics, “low performing” schools, which disproportionately serve economically dispossessed students of color, are subject to various punishments, including closure. The resulting ways in which schools, teachers, and students value and conform to external metrics has been called neoliberal performativity (Keddie, 2016).

Hoeg and Bencze (2017) critique the non-participatory language of the NGSS performance expectations as aligning with neoliberal performativity. They argue that this feature of the standards restricts teacher and student agency in ways that may inhibit "opportunities to ground learning in personal and community contexts" (p. 293). Our inquiry extends this critique through a concrete example that illustrates the ways in which the NGSS inhibit community-responsive science education while also illustrating how we have been able to partially overcome these barriers. We also identify the ways in which neoliberal ideology in the NGSS shape what students are to learn about the Earth's materials, environmental regulation, and the materials economy. In neoliberal logic, human interactions with the Earth's resources are defined in economic terms and environmental regulations should be monetized and minimized so as to avoid supposedly unnecessary restrictions on the market.

The Science Dilemma

In a stance that is slightly different from Hoeg and Bencze, Weinstein (2017) argues that the NGSS are ambivalent with respect to neoliberalism and the politics of disposability. He argues that the NGSS follow the lead of the scientific establishment by aligning with neoliberal politics in some self-interested ways and also breaking from neoliberalism to prioritize scientific evidence ahead of the free market in some instances. We interpret the alignment between the NGSS and the scientific establishment as related to the *Framework*'s stated goals of inculcating an appreciation of science in all students. We have no problem with students appreciating the many strengths and benefits of science, but we also recognize that the relationship between science and social justice is fraught. In fact, what is often characterized as students' lack of motivation to study science may actually be justified resistance to an uncritical or irrelevant approach to science teaching (Akom & Shah, 2013; Morales-Doyle, 2018). As a sociocultural undertaking concerned with understanding the universe, science encourages wonder and can be beautiful. As an institution that has developed in conjunction with Western imperialism and capitalism, science is also deeply problematic in numerous ways (Carter, 2008). It has contributed to and benefitted from racism, sexism, economic exploitation, and environmental degradation (Harding, 2006). While the extent and precise nature of its role in these processes can be debated, that science played an important role is undeniable when considering its contributions to false beliefs of racial difference and inferiority (Brown & Mutegi, 2010), weapons that facilitate imperialism (Vossoughi & Vakil, 2018), and technologies that were the basis for unsustainable and exploitative development and consumption (Conner, 2005).

Gunckel and Tolbert (2018) build on critiques of the NGSS by identifying commitments not only to neoliberalism but also to related technocratic and utilitarian ideologies in the engineering emphasis of the standards. By technocratic ideology, Gunckel and Tolbert mean that the NGSS assume that real world problems can be solved by engineering solutions and thus ignore the sociopolitical foundations and complexities of these problems. The utilitarianism in the NGSS is found in the framing of scientific and technological progress as always beneficial and in the emphasis of cost-benefit analyses as a way to measure these benefits. Our inquiry builds on this critique by taking up Gunckel and Tolbert's assertion that these ideological commitments overlook the notion of *harm* and the extent to which the harms of technological innovations or solutions can be predicted and prevented.

Our Ideological Commitments: Science Education for Justice

In a textbook for preservice science teachers, Bybee, Powell, and Trowbridge (2008) argue that the goals of science education should be characterized by a number of "simple criteria," including "goals [that] should be neutral, that is, free of bias and not oriented toward any particular view of science teaching" (p. 107). We reject the myth or possibility of a "neutral" education. Since its inception in the latter half of the 19th century, school science in Euro-American cultural settings has been driven by a particular dominant view of science teaching: to promote the enterprise of science. This promotion involves ensuring a "pipeline" of future professional scientists and also garnering the support of the general public for science (Aikenhead, 2006). In an era of US politics when science is undermined by some of the most powerful politicians with an eye towards industrial deregulation and pandering to an extreme right wing constituency, the response of science educators to promote and defend science is understandable. At the same time, the failure of school science to confront the harms of science makes it complicit in those harms and hinders the development of students' critical thinking.

To center justice in science education requires explicitly considering critical questions about the relationships between scientific knowledge and oppression: Who benefits? Who is harmed? What is the role of scientific knowledge? What is the role of sociopolitical action? How can we change the status quo? Whereas these questions are typically positioned beyond the boundaries of science curriculum, they drive the science learning in a justice-centered classroom. In order for students to have opportunities and support to ask and answer these types of questions, teachers must challenge the boundaries of what constitutes a "phenomenon" in the science classroom. As opposed to the *Framework* and NGSS emphasis on *natural* phenomena, in justice-centered science pedagogy, curriculum is based on social justice science issues or SJSI

(Morales-Doyle, 2018). SJSI challenge technocratic and utilitarian ideologies by considering how oppression has historically shaped scientific knowledge production and application and how it continues to do so.

SJSI are a subset of socio-scientific issues that meet the additional criteria of local relevance and explicit consideration of issues of oppression. For example, heavy metal contamination is a socio-scientific issue. In urban communities with legacies of industry, housing segregation, and post-industrial disinvestment, it becomes an SJSI that is understood within the context of environmental racism (Morales-Doyle, 2017). Heavy metal contamination as a socio-scientific issue is a context for studying the structure and properties of matter and its interactions within chemical, biological, and environmental systems. By posing heavy metal contamination to students as a local problem with historical origins, science education extends beyond science concepts, practices, and ideas to also build students' understandings of how political decisions about technological and industrial development impact their communities. Justice-centered science pedagogy has loftier goals than the *Framework*, positioning students, not just as "careful consumers of scientific and technological information," (NRC p. 1) but as transformative intellectuals who use "hope, [science] education, and action…to advocate for themselves and their communities" (Children's Defense Fund, n.d.).

The Praxis of Teacher Research

By labeling this study teacher research, we do not present positivist objective findings nor seek to uphold traditional notions of validity. Rather, we present answers to problems that emerged from both theory and practice to challenge taken-for-granted goals in science education (Cochran-Smith & Lytle, 2009). Here we describe the process by which we came to answer our questions. This process has three parts: (1) the emergence of the problem, (2) the analysis of the standards, and (3) the collaborative design of curriculum. In describing these three parts in this order, we do not intend to imply that they occurred linearly. Instead, these three parts occurred more iteratively as the insights provided by working on concrete curriculum documents caused us to return to refine our questions, which in turn sharpened our analysis of the standards and suggested new ways of overcoming the obstacles they presented to curriculum.

Emergence of the Problem

As the water crisis in Flint, Michigan unfolded in the national news and social media, we felt compelled to respond through science education. In fact, this compulsion was deeper than our professional responsibilities as science educators. In Chicago, coverage of the Flint crisis led to public pressure to test water in schools and parks for lead. Alarming levels of lead were found in numerous public drinking fountains, including some used regularly by our children or our students. At the school where Childress Price taught for many years, water samples from one-third of the school drinking fountains and faucets had lead levels above the weakly enforceable thresholds set by the federal lead-and-copper rule (15 parts per billion). The school attended by Morales-Doyle's children showed no high levels of lead in the water, but a drinking fountain at the park where they play had levels more than three times the threshold. The realization that our water may be contaminated compounded the persistent problem of heavy metal contamination in our city's soil and housing (Mielke & Regan, 1998). While all of us had prior experience teaching about heavy metal contamination in our individual high school chemistry classrooms, we realized that we could do more together. For example, the curricula we used previously were outdated, incomplete, or inadequately aligned with the still relatively new NGSS. Updating our curricula required the creation of new documents and the compilation of new resources.

The following summer, our group of high school chemistry teachers began meeting regularly to pool resources and share the work of developing curriculum that could meet the ambitious goals of the *Framework* and, more importantly, the educational needs of our communities. As the project developed, we strengthened partnerships with university scientists and were able to secure funding to convene an institute where teachers collaborated with scientists, community organizations, and youth to develop curriculum to support youth participatory science (YPS) projects that address urban heavy metal contamination (Morales-Doyle & Frausto, manuscript in progress). Our efforts were gaining traction but aligning our curriculum with the NGSS proved to be more difficult than we expected. At first, we were frustrated by the way performance expectations (PEs) that were intended as exemplars were being implemented in schools as prescriptive goals. As we worked to weave the three NGSS dimensions together in our own ways, we realized that the issues with the standards were deeper than a mismatch between intentions and implementation. At our second meeting that summer, we (the authors and three additional colleagues) were able to identify four performance expectations that were related, but not aligned with the lessons we envisioned. We were still frustrated. Part of our frustration could be attributed to the standards' authoritarian, performative, and non-participatory language (Hoeg & Bencze, 2017; Wallace, 2012). But we also hypothesized that the misalignment between the topic of heavy metal contamination and the NGSS existed in the disciplinary core ideas (DCI) rather than only in the performativity of the PE and the science and engineering practices.

NGSS analysis

In order to more deeply understand the frustration we felt while trying to align the NGSS with our curriculum development, we analyzed the DCI that our group of teachers had identified in meetings and curriculum documents as potentially relevant to teaching about urban heavy metal contamination. Specifically, we analyzed the text of the *Framework* that introduces the physical sciences DCI and explains PS1 (p. 103-113), PS4 (p. 130-137), and ESS3 (p. 190-198) by identifying statements that mentioned or alluded to "benefits of science and technology" or the "harms of science and technology." There were so few references to the harms of science and technology specifically that we also looked for statements about the harms of human activity more broadly. Then we analyzed the high school PE associated with PS1, PS4, and ESS3 by noting whether each relevant PE implied understanding, using, conserving, or regulating chemicals, materials, or substances. We applied more than one of these labels to a PE if more than one type of interaction with the material world was implied. Table 1 includes examples of these initial steps of the analysis. After identifying these key parts of the text, we tried to explain the disconnect between the DCI and PE with our goals in teaching about heavy metal contamination. This part of the analysis involved considering how the neoliberal, technocratic, and utilitarian ideologies that others have identified in the NGSS show up in the DCI and PE. Finally, because of our commitment to teacher research, the most important part of our analysis was to design learning activities that aligned with NGSS PE and also addressed urban heavy metal contamination. While some scholars might consider this activity to represent the practical work of teaching rather than the scholarly work of knowledge production, this phase of our study represents design-based teacher research that deepened our analysis of the NGSS and also helped us understand how justice-centered teachers can navigate the ideological divide between the NGSS and ourselves. In the next subsection, we share some details about the structure that supported this process. INSERT TABLE 1.

Grassroots Curriculum Planning

Collaboration between chemistry teachers that began with informal meetings in the summer of 2016 was formalized in a 5-day planning institute in the winter of 2018. The goal of the institute was to develop curriculum to support YPS projects about heavy metal contamination that was informed by the voices of several constituent groups and aligned with the NGSS. This institute included eight teachers (including Childress Price and Chappell), three scientists, a community organizer from the Little Village Environmental Justice Organization, five youth who are recent graduates of the teachers' schools, and the first author who is university science educator and former high school chemistry teacher. Table 2 provides an outline of the daily agenda. Each of the first three mornings of the institute began with a presentation and/or panel discussion with one of these groups of constituents positioned as experts. These presentations and panels were followed with small group dialogues between mixed groups of constituents to make links between the presentations and the curriculum planning. After lunch and for the entire fourth day of the institute, teachers worked to develop curriculum documents and plans. On the fifth day of the institute, teachers shared our work with the other participants by teaching pieces of the curriculum we had developed. Finally, the other participants provided structured feedback on this curriculum and the teachers used this feedback to make changes. Through this collaborative, participatory process, we were able to make connections and alignments between NGSS performance expectations and curriculum designed to support YPS projects on urban heavy metal contamination. After sharing our analysis of relevant DCI and PE, we include three illustrative curriculum examples that we developed during the institute. These examples represent a proof-of-concept answer to our second inquiry question about whether curriculum can transcend the ideological differences between justice-centered teachers and the NGSS.

INSERT TABLE 2.

Harms & Chemistry Education

Our analysis of the NGSS suggests that our difficulties aligning the standards with curriculum to address urban heavy metal contamination are related to (1) the isolated and utilitarian ways in which the discipline of chemistry is defined in DCI PS1, and (2) the neoliberal and technocratic ideology that undergird the way the relationships between Earth and human activity are framed in DCI ESS3. We suggest that the implicit commitment to these ideologies in science education shares the blame for the harms of science being unforeseen, unintended, overlooked, and unevenly distributed (Gunckel & Tolbert, 2018). Furthermore, we assert that science educators must reject their presumed role as promoters of the enterprise of science in order to contribute to the repair and prevention of these harms and to students' ability to contribute to changing and improving science. Science education must prompt and support students to ask critical questions and challenge the status quo, which necessitates curriculum that deals with the benefits *and harms* of science. For coherence, we support our critique using examples that pertain to the issue that inspired this paper: urban heavy metal contamination.

The Utilitarian Boundaries of the Discipline of Chemistry

Much of the canonical content of high school chemistry class is captured by the first NGSS disciplinary core idea in the physical sciences (PS1). The *Framework* text describing PS1 reflects the positioning of the physical sciences as a politically, socially, and culturally neutral undertaking. The text describing the three subdivisions of this disciplinary core idea (structure and properties of matter, chemical reactions, and nuclear processes) use what some scholars have called "nonparticipatory language" (Wallace, 2012; Hoeg & Bencze, 2017) to position canonical understandings as fundamental truths. There are also examples of more open positioning of chemical principles as useful ways to understand the universe (as opposed to fundamental truths). But upon closer examination, this seemingly neutral language reveals the utilitarian ideology of the NGSS (Gunckel & Tolbert, 2018). In PS1, chemicals are described as useful products but never as environmental contaminants. For example, the following excerpt refers to materials design as a beneficial application of PS1:

> Different materials with different properties are suited to different uses. The ability to image and manipulate placement of individual atoms in tiny structures allows for the design of new types of materials with particular desired functionality (e.g., plastics, nanoparticles). (NRC, 2012, p. 107).

Here the tools of chemistry are positioned as enabling the engineering of innovative and useful materials, a benefit of science and technology. The text provides two examples of useful synthetic materials: plastics and nanoparticles. The framework posits that "Physics and chemistry…underlie all natural and human-created phenomena" (p. 103), but nowhere in the text of PS1 is there any mention of the human-created risks, dangers, and negative consequences of manipulating chemicals, even as the example of plastics could provide an easy segue into such a discussion.

The limited view of chemicals as useful products fails to challenge the ways in which some of these products and their rampant consumption is at the heart of many of the environmental harms in which the scientific enterprise is implicated. This utilitarian stance in the NGSS that is also visible in PE HS-PS1-6:

> Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. [Clarification
> Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between

changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

This nonparticipatory language of this PE follows the excerpt from the DCI above by focusing on synthetic chemicals *only* as desirable, useful products. It suggests that students should learn to maximize the production of such chemicals by applying the canonical Le Châtlier's principle. It is an approach to scientific knowledge production that maximizes the output of synthetic or industrial chemical reactions in order to maximize profit. This is the only PE associated with PS1 that also includes the NGSS signature integration of engineering principles and practices. The other PE associated with PS1 imply that chemicals should be understood, rather than used. But taken into consideration as a whole, PS1 and the associated PE represent a failure of the NGSS to move beyond the traditional disciplinary limitations of chemistry, which have been heavily influenced by the chemical industry.

Highlighting the benefits and overlooking the harms of technology is a hallmark of utilitarian ideology and the chemical enterprise (Gunckel & Tolbert, 2018). Positioning synthetic chemicals and engineered materials as having "desired" properties and uses while omitting potentially harmful properties and effects indicates an ideological commitment that benefits the chemical industry and harms our communities. The longtime slogan of chemical industry giant, and notable NGSS sponsor, DuPont captures this viewpoint: "Better things for better living…through chemistry." Like the NGSS, this slogan only mentions the benefits of synthetic chemicals. There is actually a promotional blurb about the DuPont Corporation included on the

NGSS website which underscores this ideological alignment by stating that the corporation, "…puts science to work by creating sustainable solutions essential to a better, safer, healthier life for people everywhere."[1] This rhetoric masks the fact that DuPont contributed to substantial heavy metal contamination and poisoning at a superfund site in East Chicago, Indiana where they manufactured pesticides using lead and arsenic. The cost of cleaning up this site was recently determined by the US EPA to be $26.6 million (Cross, 2018). In just the calendar year after the NGSS were released, DuPont paid more than $3 million in federal penalties for the consequences of environmental contamination caused by its chemical products (United States Environmental Protection Agency, 2014a; 2014b). The tendency to focus on beneficial chemical properties and overlook harmful ones leads to the conclusion that the harms of science are "unforeseen," when in fact they often are not.

The histories of leaded gasoline and lead-based paint provide two sobering examples of how the harms of science have often been foreseen yet ignored because of this utilitarian ideology and the profit motive. Viana and Porto (2013) propose that the history of gasoline additive tetraethyl lead is a useful context within which to teach about periodic trends (a focus of NGSS PE HS-PS1-1 and HS-PS1-2). They describe how engineer and chemist Thomas Midgley and his employer, General Motors, ignored the known severe toxicity of the compound in order to explore its usefulness as an anti-knock agent. Then, they ignored explicit warnings from colleagues and physicians as they brought this chemical to market and it became ubiquitous in gasoline for decades. As a result of this decision to focus on the beneficial properties of tetraethyl lead while ignoring its harms, toxic lead contamination persists in U.S. environments decades after leaded gasoline was phased out (Flegal, Gallon, Hibdon, Kuspa, & Laporte, 2010).

[1] DuPont is listed on the NGSS website as a sponsor of the standards. The website includes a short promotional blurb and the corporate logo: https://www.nextgenscience.org/sponsors

Some might argue that the story of tetraethyl lead is one of corporate greed or of the misapplication of scientific knowledge, which it is. But we argue that this story is also characteristic of the enterprise of science, historically and presently. Chemical corporations played a substantial role in institutionalizing the field of chemistry (Viana & Porto, 2013). Markowitz and Rosner (2013) detail how the lead industry, through the Lead Industries Association and other arms, funded much of the scientific research on the toxic metallic element in the mid-twentieth century and promoted the continued use of leaded gasoline and leaded paint (even in children's bedrooms) long after the dangers were apparent. For example, the Ethyl Corporation (founded by General Motors to produce tetraethyl lead) established and funded the Kettering Institute at the University of Cincinnati, whose research activities consistently downplayed the damage caused by lead. Now, more than ever, scientific research is largely funded by corporations, which means that profit motives and the potential benefits of technology drive the research and development that are central to the production of scientific knowledge (Conner, 2005; Carter, 2008).

The unequal distribution of harms and benefits is not accidental, coincidental, or unforeseen, but occurs because of oppression and marginalization. Adding lead to paint and gasoline increased toxic exposure for virtually all children in U.S. cities and many others around the world. But racist policies and practices, like redlining and housing discrimination, shaped urban landscapes in ways that were interwoven with this phenomenon spatially and temporally. The result is that the toxic burden in hyper-segregated U.S. cities is disproportionately borne by African American children from low-income families (Oyana & Margai, 2010). For this reason, lead contamination is an issue of environmental racism.

Neoliberal and Technocratic Earth-Human Interactions

Our consideration of how DCI ESS3: Earth and Human Activity illustrates the ways in which the NGSS espouse neoliberal and technocratic ideologies that shape the way students are to learn about interactions between humans and the Earth. Unlike the DCI PS1, the role of politics and the impact of pollution are explicit in the DCI ESS3, but science and technology are still mostly positioned as providing solutions to environmental problems as opposed to being implicated in their creation. Moreover, there is acknowledgement that the impacts of environmental problems are distributed unevenly, but the *Framework* and the NGSS are silent on the factors that contribute to this unevenness. For example the description of DCI ESS3 states, “The impacts of climate change are uneven and may affect some regions, species, or human populations more severely than others” (p. 197). The next paragraph positions scientific modeling as a useful way to predict and respond to these impacts. Meanwhile, there is no mention of the factors that contribute to this unevenness, like the substantial body of research that has demonstrated the relationship between structural racism and the disproportionate distribution of environmental harms (Bullard, Mohai, Saha, & Wright, 2008). Thus Rodriguez’s (2015) critique of the Framework’s “discourse of politeness” with respect to issues of educational inequity extends to issues of environmental justice as it “talk[s] about issues broadly so that those responsible or with the power to effect change are politely left undisturbed” (p. 1038). This discourse of politeness reveals a technocratic ideology where science (in the form of modeling climate outcomes) is leveraged to find solutions to political problems, without a full consideration of the role of science and technology in creating the problem of climate change (through the exploitation of fossil fuels and the design of technologies that rely upon them). Furthermore, there is no consideration of the ways that power, racism, consumption, and exploitation (rather than simple geographic factors) cause the impacts of climate change to be felt unevenly.

The technocratic ideology is visible again and coupled with neoliberal ideology in a passage about the extraction of natural resources:

> Materials important to modern technological societies are not uniformly distributed across the planet (e.g., oil in the Middle East, gold in California). Most elements exist in Earth's crust at concentrations too low to be extracted, but in some locations—where geological processes have concentrated them—extraction is economically viable. (NRC, 2012, p. 191)

This statement about mineral extraction reduces the exploitation of natural resources to a technocratic geologic and economic process. This is a neoliberal understanding because technical analyses of mineral resources combine with market forces to determine whether a particular portion of the Earth will be excavated and exploited. The examples provided parenthetically in the *Framework* can be understood in this simple market logic, only if we take for granted that the people exploiting these resources have the right to do so. To understand the "gold in California" example in simple geologic-economic terms glosses over the colonization of California first by gold-obsessed Spanish *conquistadors* and then through imperial war waged by the US to seize territory from Mexico just one year before the famous 1849 gold rush (Acuña, 2011; Galeano, 1997). In other words, this neoliberal framing is not neutral – it presumes a logic of Euroamerican settler colonialism, U.S. imperialism, and the associated view of Earth as a repository of materials for humans (of European descent) to exploit (Bang et al, 2014). The framing of mineral extraction as a geologic-economic calculation is ahistorical in omitting that miners gained access to the land through colonization. It assumes that settlers have the right to extract minerals for profit because these materials are “important to modern technological societies.” In the attempt to be apolitical, the NGSS inadvertently adopts narratives of U.S. hegemony and the erasure of Indigenous peoples (Bang et al, 2014). These same technocratic and neoliberal ideologies contribute to ongoing heavy metal contamination around the world as more lead is mined than ever before, despite its known dangers (Markovitz and Rosner, 2013) and artisanal gold mining remains a major source of dangerous mercury contamination (Cordy et al, 2011).

The technocratic and neoliberal ideologies come together with the utilitarian emphasis on these metals’ beneficial properties to downplay severe toxicity of lead and mercury. As a result, they continue to be used in numerous and evolving technological applications. This means that heavy metal contamination is still a worsening problem in many communities around the world even as it has been mitigated, albeit unevenly, in the United States. Mining for these metals themselves is not the only means by which the careless exploitation of mineral resources contaminates communities of color with heavy metal pollution. In two adjacent, densely populated, Mexican immigrant communities in Chicago, two coal power plants operated without modern pollution controls for four decades after being grandfathered into the Clean Air Act (Patterson et al, 2012). Whereas lead was intentionally added to gasoline and paint, it occurs naturally (along with mercury, and other heavy metal contaminants) in coal.

The NGSS PE for DCI ESS3 suggest that students, “Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios” (HS-ESS3-2). This performance expectation provides another example of the technocratic and neoliberal ideologies of the NGSS. It assumes that the solutions to complex problems are technical and should rely on competition to cut costs and maximize benefits. What is left out of this performance expectation are questions or considerations about *who benefits*? By positioning costs as the counter-balance to benefits, the NGSS once again espouse a neoliberal market logic while ignoring that "design solutions" also inflict *harms* and cause suffering. The clarification statement of this PE provides more insight into NGSS biases and the reasons why it is difficult to align the NGSS with lessons that consider the harms of science:

> Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen (NGSS Lead States, 2013).

In focusing on "minimizing impacts" and "developing best practices," the NGSS once again reduce complex sociopolitical problems to technical ones and avoid the question of *who is impacted*? And *who benefits*? Furthermore "developing best practices" for mining unconventional fossil fuels like "tar sands and oil shales," is deeply problematic given the global climate crisis, but fits with the NGSS technocratic framing of Earth's resources as available for human exploitation. Indeed, the slogan of *Acción Ecologica*, an organization in Ecuador where Indigenous communities have been deeply harmed by fossil fuel extraction, indicates that the "best practices" are to leave "the oil in the soil, and the coal in the hole and, of course, tar sand in the land" (Yanez, 2009). With respect to the problem of heavy metal contamination, the exploitation of unconventional fossil fuels continues to exacerbate the problem. For example, in Chicago, community organizers successfully fought a company controlled by the billionaire Koch brothers to force the enclosure of large piles of petcoke, a byproduct of oil refining (Hawthorne, 2013). These piles were stored outdoors in a densely populated community of color that has experienced a long history of environmental racism, including an ongoing concern with heavy metal contamination from steel mills (Hawthorne, 2018). Unconventional fossil fuels, like petcoke, are substantial contributors to heavy metal contamination (Schlesinger, Klein, Vengosh, 2017). In the clarification statement of HS-ESS3-2, and in the "nature of science" appendix, the NGSS argue that "Science knowledge indicates what can happen in natural systems—not what should happen." But this statement artificially disentangles natural, social, and political systems within the HS-ESS3-2 context of mining for minerals in ways that are contradicted by the standards' own suggestions to engage students with neoliberal framings of gold mining, oil drilling, and the best practices for exploiting unconventional fossil fuels. The misalignment of the NGSS with science teaching that is responsive to the communities is a result of failing to consider who bears the brunt of the harms caused by technocratic "cost-benefit-analyses" and utilitarian neoliberal decisions about "what should happen."

Mitigating the Ideological Commitments of the Standards

By engaging the collaborative curriculum development process described in a previous section, a group of teachers, scientists, youth, and a community organizer have been working to transcend incongruencies between the NGSS and local problems of environmental justice. We share three examples from this curriculum as a proof-of-concept response to our second guiding question about overcoming the ways that the ideological commitments of the NGSS limit their local adaptability. These three examples focus on how science in general (and chemistry in particular) might be useful in understanding heavy metal contamination, assessing the harm this contamination causes in communities, and imagining a less toxic and more sustainable future. Notably, all of the people involved have long-term commitments to addressing the concerns and aspirations of local communities in science class. These commitments made this work possible, yet even with our substantial experience, the NGSS acted more as a roadblock than a facilitator. We suspect that for teachers without the types of collaborative and critical networks that we are fortunate to have, this roadblock would be very difficult to overcome.

Understanding Heavy Metal Contamination (HS-PS1-1, HS-PS1-2)

A justice-centered approach does not dismiss scientific knowledge, but asks how it can be useful in addressing SJSI. In order to challenge a technocratic view of scientific knowledge, this necessarily includes considering the way scientific knowledge is limited and is entangled with sociopolitical forces. One way that scientific knowledge can be useful in addressing the SJSI of urban heavy metal contamination is to support students to construct explanations about how heavy metals' properties and their related location in the periodic table relates to their uses and also their toxicity. Understanding the chemical reactions of heavy metals also supports students to explain their persistence and mobility in the environment. We developed curriculum that asks students to investigate the properties of metals to understand the industrial use of lead in plumbing, paint, and gasoline that have been led to widespread environmental contamination. This curriculum is aligned with NGSS PE HS-PS1-1:

> Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.]

The clarification statement of this PE includes the "reactivity of metals." In the curriculum we designed, students investigate the relative reactivity of various metallic elements. The curriculum does not include any activities where students actually work with lead. Instead, a series of activities with metals like copper and zinc supports students to understand that the relatively low reactivity of lead was a property that was central to its use in water pipes. Students also learn that while lead is relatively unreactive, like other metals, it does corrode and this process was at the heart of the Flint water crisis.

In Flint, the corrosion of lead pipes was accelerated by the switching of water sources, a neoliberal austerity measure imposed by an appointed emergency manager. Learning about the Flint crisis allows students to grapple with the complex relationships between scientific and political decisions. The chemistry behind the corrosion of Flint pipes is relatively complex, but by using "the patterns of electrons in the outermost energy level of atoms," students can predict the possible formation of two forms of oxidized lead, Pb^{2+} and Pb^{4+}, while they also understand how neoliberal politics and environmental racism led to lead oxidation in Flint pipes.

In our curriculum, students have the opportunity to explain the basic principles of chemistry in the Flint water crisis and to understand why concerns about lead in the drinking water have been serious but less severe in Chicago. For example, students examine the results of the city's efforts to measure lead concentrations in school water fountains. In Childress Price's classroom, students examined the letter prepared by the district to explain that a third of the fixtures in their school contained alarmingly high concentrations of lead.

Here in Chicago, there are longstanding concerns about lead in the city's soil. Understanding how and why decades-old lead contamination from paint and gasoline persists in soil requires students to draw connections between the reactions of metals and the properties of lead compounds which are mostly insoluble. Once again relying on "the patterns of electrons in the outermost energy level of atoms," students understand how lead ions mimic calcium ions in terms of the 2+ oxidation state and radius, which is related to the neurotoxicity of lead and also for its deposition in children's bones. In a series of classroom stations, students learn about the myths of lead exposure and remediation including the common misconceptions that lead is used in pencils or that boiling water can reduce lead concentration. These stations also introduce students to ways that lead contamination is remediated (like phytoremediation and water filtration) and that lead toxicity can be marginally mitigated through nutrition or treated with chelating compounds in extreme cases of poisoning. In these ways, our curriculum supports students to meet not only HS-PS1-1, but also HS-PS1-2, which asks students to:

> Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.]

In the process of developing learning activities, we came to identify the way in which the NGSS narrowly re-inscribe the disciplinary boundaries of chemistry as a roadblock to community responsive science education. In the PE associated with PS1, the focus is on understanding simple chemical reactions in abstraction and in relation to the central model of the discipline, the periodic table. There is no consideration of contexts in which understanding chemical reactions might be important, other than a PE that focuses on maximizing products. These PE steer teachers towards reproducing a discipline created in the image of the chemical industry and away from the more complex, contextualized, and interdisciplinary approaches that are necessary for students to engage with authentic problems.

Assessing and Communicating the Harms in our Communities (HS-PS4-5)

Another way that scientific knowledge can be useful in addressing the SJSI of urban heavy metal contamination is to measure the extent of heavy metal contamination in urban environments. Spectrometry includes a range of scientific techniques that identify and measure chemicals using interactions between energy and matter. Through collaboration with university-based scientists, we have been able to measure concentrations of heavy metals in soil and water samples that high school students collected, and in many cases, prepared for analysis. University students and faculty have used various spectrometers for this analysis, including inductively coupled plasma atomic emission spectrometers, direct mercury analyzers, and others. While these sophisticated instruments are not available in high school labs, we designed curriculum that uses more affordable materials and instruments so that students could construct an understanding of how spectrometry works. This curriculum is aligned with NGSS performance expectation HS-PS4-5:

> Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. * [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.]

While spectrometry is not explicitly included as an example in the clarification statement, the activities described briefly here are designed to build understanding about the “wave/[particle] interactions with matter to transmit and capture information and energy” within the context of a project about the SJSI of urban heavy metal contamination. The first activity is common in high school chemistry classes and involves using a flame to excite electrons in metal salts to observe the various colors of light that are emitted when electrons relax. The second activity supports students to understand how spectrometers take advantage of the absorption or emission of light to make measurements. The third activity asks students to use a visible-range spectrophotometer to measure the concentration of an unknown solution of copper. In the final activity, students prepare to communicate how a spectrometer works to an audience of community members. In this context, students are supported to meet performance expectation PS4-5 but are also reminded why cultural competence in their local communities is valuable as they are challenged to communicate scientific techniques with an audience that may not view the problem through this lens (Morales-Doyle, 2017). The technocratic view of the NGSS is a hinderance to community responsive science education because of the way it positions science as the solution to complex problems. In contrast, the approach we describe in this series of activities positions science both as a contributor to SJSI and also as one, among many, limited ways of learning about and addressing problems.

Planning for the Future of our Communities (HS-ESS3-1)

In justice-centered science pedagogy, understanding the harms and benefits of science is necessary, but insufficient. Students should also have opportunities to use scientific and other forms of knowledge to do something that addresses the impact of heavy metal contamination in their community. The final part of our curriculum asks students to become civically engaged by developing creative ways of sharing what they learned. This could include creating blogs, infographics, social media campaigns, newsletters, letter writing, town hall meetings or community workshops. Our curriculum manipulates the performance expectations associated with DCI ESS3.A and ESS3.B to assist students in identifying the real personal and local impact of "costs, risks, and benefits of resource extraction," including racial, sociopolitical, and economic disparities. Students were encouraged to ask *who* benefitted and who *is harmed*?

In this part of our curriculum, we manipulate HS-ESS3-1, which asks students to:

> Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

This PE encourages students to construct a relatively simple cause-and-effect relationship between the existence of natural resources and hazards and human activity. Our curriculum encourages students to develop more complex understandings about how humans have created hazards by exploiting natural resources and how human activity can also ameliorate these hazards. In other words, we ask students to construct a *plan* (not just an explanation) for how human activity in the community should deal with the occurrence of *un*natural hazards (like heavy metal contamination) and the uneven availability of natural resources (like clean water and healthy food). Students learn about how local communities have successfully organized for the cleanup and redevelopment of brownfields and also about ongoing local campaigns for environmental justice.

In Childress Price's west side community, there are many brownfields and empty lots that have been created by disinvestment in infrastructure which has also led to the neighborhood being described as a food desert or a food swamp. Within this context, property owners, organized residents, and non-for-profit organizations have been developing community gardens for years as a way to repurpose land. A number of students communicate that their grandparents grow food or that they have gardens on their blocks from which they eat. Some students are members of the afterschool environmental and gardening club, which is the result of a partnership with a local non-for-profit which exists "to give students who live in food desert communities equal access to healthy food and food education" (Tsupros & Zmick, 2017). As students identify and define the local problem of lead contamination, its toxicity to humans, and assess its concentration in their school and community, they make connections to implications for local gardens and farming. As students learn about the effects of lead toxicity, they question what this might mean for local gardens. They ask whether it is safe to grow corn, watermelon, and basil in a vacant lot outside the school.

Students learn that, in the short term, raised beds with clean soil are usually the best option for urban gardening. But our curriculum includes opportunities for students to consider slower, long-term solutions to soil remediation. One type of remediation happening in Detroit, another manufacturing city reclaiming vacated contaminated land, is dendro-remediation.

> Dendro-remediation is the process of using trees to reduce and eliminate toxic substances in the soil. The primary objective is to reduce soil toxicity by introducing green infrastructure to select former industrial and commercial sites. Secondary objectives include improving stormwater management, improving air quality, and beautifying vacant lots in a way that reduces maintenance costs for the City of Detroit." (Detroit Future City, 2014).

Our curriculum thus includes opportunities for students to reimagine their deindustrialized and disinvested neighborhoods as the vanguards of sustainable urban farming. They extend beyond the NGSS PEs to consider how their knowledge of science may help remediate and protect against the harms of lead, mercury, and arsenic while it also may help them to grow food that provides the essential metals of iron, calcium, and zinc.

Discussion and Implications

The NGSS and the *Framework* set out to dramatically change science education by reframing inquiry in terms of science and engineering practices and by organizing instruction around natural phenomena that allow for these practices to be intertwined with disciplinary core ideas and cross cutting concepts. Despite some improvements as compared with previous standards, our analysis shows that the ideological commitments of the NGSS prevent them from realizing the vision of community responsive science education espoused by key segments of the *Framework.* In order to be responsive to communities who have borne the brunt of the harms of the scientific enterprise, the *Framework* and the NGSS would have to be amended to acknowledge, among other harms, that industrial applications of chemistry cause substantial dangerous contamination, which disproportionately impacts people of color.

Our analysis fundamentally objects to DuPont's sponsorship of the NGSS. We are *not* accusing the authors of having a conflict of interest *nor* are we presuming a corporate conspiracy to shape the standards. Instead, we are simply arguing that the community of people assembled to construct the standards reflected the dominant ideologies of the scientific enterprise that has been heavily influenced by the powerful chemical industry. If grassroots voices were as important as this ideological influence in the NGSS, perhaps chemicals would be described as useful products *and* dangerous contaminants. Our analysis here builds on Rodriguez's (2015) critique of the NGSS by identifying how the problematic development process led to particular ideological commitments in the DCI themselves. We also build on Gunckel and Tolbert's (2018) and Hoeg and Bencze's (2017) critiques by illustrating, with concrete examples, how the neoliberal, technocratic, and utilitarian ideologies in the NGSS hinder their applicability to real community concerns. For our *next generation* of scientists to be mindful of sustainability and social justice and to “provide all students with the background to systematically investigate issues related to their personal and community priorities,” (NRC, p. 278) the standards need to be held accountable for their ideological commitments. Furthermore, teachers need to look beyond the standards for inspiration and guidance. Ultimately, science curriculum should engage students with local and global SJSI so that they may learn to consume, produce, and critique scientific knowledge and the enterprise of science itself. As presently constituted, the NGSS may act more as propaganda for the promotion of the scientific establishment than as a framework for critical thinking. That said, the example curricula described here illustrate how educators can meet the performance expectations set out by the NGSS while addressing the issue of urban heavy metal contamination. We emphasize that this work represents the collaboration of several experienced science educators, scientists, community members, and youth. Furthermore, this work was possible because our group was already knowledgeable about issues of environmental justice and committed to addressing them in our classes. If this were not the case, the standards do not include language that would have led us in this direction, nor would they have supported our work. We undertook the analysis presented here to address frustrations with trying to make the standards work in our context. We share what we have learned with humility and to provide an avenue of hope for science teachers committed to social justice intertwined with academic achievement. We join others who have called for the standards to adopt participatory language (Wallace, 2012; Hoeg & Bencze, 2017), dimensions of equity, engagement, diversity (Rodriguez, 2015), and care (Gunckel & Tolbert, 2018). We also call for science education that explicitly fosters appreciation and *critique* of science.

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