Youth Participatory Science: A Grassroots Science Curriculum Framework

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Abstract: This article introduces Youth Participatory Science (YPS) as an approach to science teaching and grassroots knowledge production that draws from traditions of youth participatory action research (YPAR) and citizen science. YPS is differentiated from YPAR by its emphasis on the tools and methods of the so-called natural sciences while it extends citizen science in important ways by prioritizing youth, pedagogy, and democratizing participation in all phases of knowledge production. This article contributes a conceptual definition of YPS and articulates the affordances and limitations of distinguishing it from YPAR and citizen science. It then introduces a curriculum framework that synthesizes approaches to planning for critical pedagogy and science education with the intention of supporting teachers to navigate the barriers to enacting YPS in secondary science classrooms.

Keywords: citizen science; YPAR; science education; social justice

The "March for Science" began in 2017 in response to the efforts of the current U.S. administration to undermine the science that informs the work of federal entities like the Environmental Protection Agency (EPA), the Centers for Disease Control (CDC), and other governmental bodies responsible for regulation and conservation of public health and the environment in the U.S. The seemingly grassroots campaign raises important tensions as it (justifiably) defends an enterprise (science) that is frequently (and likewise justifiably) criticized for its elitism, exclusionary and colonial practices, and support of military and corporate interests (Harding 1986, 2006; Conner 2005; Smith 1999; Vossoughi and Vakil 2018). For large numbers of people to take their defense of science to the streets makes us wonder to what extent various participants in these marches are supporting the enterprise of science "as-is" or to what extent they are imagining and demanding more democratic, equitable, and pluralistic *sciences* (Bang, Marin, & Medin, 2018).

Besides the #MarchforScience, there has been a surge of youth movements in the U.S. over the last several years. Movements like #BlackLivesMatter, #UndocumentedandUnafraid, and the recent #ClimateStrike serve as reminders of the unique power of youth to lead social change as they imagine better futures. While schooling often serves conservative and socially reproductive functions, youth-led movements have been inspired or informed by critical pedagogies in community contexts. Critical pedagogy is often linked with Youth Participatory Action Research (YPAR), which Cammarota and Fine (2008) have called its “research arm”(p. 4). Both of these traditions are often traced to Latin America, with Paulo Freire and Orlando Fals-Borda widely credited for their contributions, and rightfully so (Darder 2002; Manchola-Castillo 2019). But, it is often overlooked that in the US, critical pedagogies and popular education have long been important in the Black freedom struggle and civil rights movements, with intellectuals like Carter G. Woodson and organizers like Septima Clark figuring prominently (Payne and Strickland 2008). There is an associated tradition of PAR and educational action research in Black communities in the US (Akom 2011; Drame and Irby 2016). School-based educators in the US have drawn on these various traditions to work towards the transformation of inequitable contexts in urban schools (Irby, Mawhinney, and Thomas 2013; Morrell 2004; 2008; Duncan-Andrade and Morrell 2008; Cammarrota and Fine 2008; Cammarrota and Romero 2014).

Writing about equity in informal (out-of-school) science education, Philip and Azevedo (2017) identify science education that aligns with movements for social justice as one of the recent discourses about equitable science learning. Unfortunately, the enforcement of disciplinary boundaries has mostly kept critical pedagogy and YPAR out of science classrooms and science teachers out of conversations about knowledge democracy and learning for social transformation. In this paper, our goal is to transgress these boundaries with two contributions: (1) a conceptual definition of YPS that is organized around its three constituent words and situates it as related to, but distinct from YPAR and citizen science and (2) a curriculum framework that aims to support YPS projects in school science classrooms. We hope that these contributions inspire educators to continue grappling with the inherent tensions of school science and its relationships with knowledge democracy. In that spirit, we conclude by discussing limitations of YPS that serve as the basis for three ways to push it forward.

Youth

The Y in YPS recognizes the unique contributions youth make to intergenerational struggles for social justice. It does not romanticize these contributions, but rather challenges adultism and the criminalization of urban youth of color (Kwon 2006). Within the dominant ideology of racial capitalism, youth represent potential future economic productivity but they also represent potential disruptions to social traditions and the status quo. This dominant ideology views science education through a narrow *learn-to-earn* lens (Morales-Doyle and Gutstein 2019). As such, youth who actively resist schooling are criminalized and those who passively resist schooling are accused of lacking motivation (Akom, Scott, and Shah 2013; Morales-Doyle 2018). Specifying the participation of youth pushes back against *adultism*, a particular form of marginalization experienced by youth (Bell 1995). YPS can be conceived as a specific form of *street science*, which democratizes the tools of science in a way that values the wisdom and understandings that exist within communities marginalized by racism and economic dispossession (Corburn 2005). It recognizes that members of these communities have unique contributions to make with respect to solving local problems of environmental health. Unlike street science, one of the priorities of YPS is to provide equitable and meaningful opportunities for students to learn science.

In recent years, perspectives that challenge traditional assumptions about knowledge production in science education have increasingly engaged with participatory methods or critical pedagogies (Bang, Faber, Gurneau, Marin, and Soto 2016; Weinberg, Trott, and McMeeking 2018). Many of these conversations have been focused on out-of-school or informal science education because of the often-problematic constraints of school science. Indeed, one of the most common discourses of equity in informal science education posits that out-of-school science offers more expansive and authentic experiences than is possible within classroom settings (Philip & Azevedo 2017). By bringing street science into the classroom (or bringing the school science lab into the streets), YPS contends with constraints like academic standards and other structures of schooling while it also cultivates the transformative power of youth.

While we are always skeptical and critical of the institutions of schooling, our motivations to support YPS specifically in the school context are connected to the reality that countless young people spend substantial portions of their lives in school settings. These hours would be better spent with a participatory focus on justice and sustainability as opposed to reifying the cannons of science disciplines. As both authors spent a decade or more teaching science in public schools, our goals in defining YPS include bringing science teachers into conversations about knowledge democracy and YPAR by supporting them to enact more authentic, participatory, and expansive projects within the school curriculum. We hope defining YPS and introducing a curriculum framework inspires teachers to engage with goals that stretch beyond science learning standards, like epistemic heterogeneity and diverse visions of justice (Bang and Vossoughi 2016; Tuck and Yang 2018).

Participatory

The P in YPS emphasizes the participation of youth in all aspects of knowledge production. Citizen science is often enacted as crowd-sourcing approach to scientific data collection that has become popularized in ecological studies as a way to extend data collection beyond the capacity of small research teams while also engaging the public more directly with important scientific and environmental concerns (Irwin 1995). A recent report found that “community and youth projects are under-represented” in the literature on citizen science (National Academies of the Sciences 2018, S-5S). YPS pushes citizen science beyond these limitations by engaging youth, community members, and teachers not just as samplers or data collectors, but also in the development of localized questions, in the analysis of data, in the dissemination of results, and in the development of appropriate responses. While the term “citizen” marginalizes (im)migrants (especially those without documentation) and reinforces problematic notions of nationalism, it also connotes active participation in society. By replacing the word “citizen” with participatory, YPS emphasizes participation in scientific knowledge production across all phases of a study and by those who have been marginalized by the institutions of science and society. Making the production of scientific knowledge participatory acknowledges that understandings of the world are developed through praxis and that all people act as intellectuals, even if they do not formally occupy that role in a stratified society (Gramsci 2014).

We have been inspired by the work of colleagues and mentors who extended Gramsci’s concept of an organic intellectual to describe pedagogies aimed at cultivating transformative intellectuals in urban classrooms (Morrell, 2006; Duncan-Andrade & Morrell, 2008; Cammarota & Romero, 2014). Organic or transformative intellectuals build on everyday understandings and maintain solidarity with marginalized communities while also systematically studying to sharpen and deepen the ways in which they understand the world from multiple perspectives. Praxis exists in this interaction between the concrete and the theoretical to refine and expand our understandings of the world and how to act in it.

One of the problems that we faced as science teachers has been that the insights of our disciplines are often not useful to the problems that youth identify as most pressing in their lives. Part of addressing this disconnect has been to follow Camangian's (2011) call to "…practice the intellectual, cultural, and political creativity to connect our teaching with our students' needs" (p. 459). But ultimately, the selection of problems to study in science class is constrained by our responsibility to teach science. At the same time, a focus on the so-called natural sciences provides access to opportunities and forms of knowledge that are typically not applied by YPAR projects. YPS thus constrains, but does not eliminate, students' participation in identifying problems in order to provide explicit opportunities for them to participate in appropriating the tools of the so-called natural sciences. Engaging students in reflective and metacognitive processes to problematize the construction of scientific knowledge is critical to making these compromises with integrity (Rodriguez 1998; 2015). In the first and last phases of the curriculum framework, we describe how teachers can engage students with defining and reflecting on social justice science issues (SJSI) to transform the disciplinary boundaries of school science from intellectual barriers into sites where they learn to critique and change the status quo.

Science

The S in YPS acknowledges the unique insights and limitations associated with scientific ways of knowing. As science teachers, engaging in YPS requires acknowledging that the disciplines we teach have been shaped by (and, in turn have undergirded) various forms of oppression. But this does not imply disregarding the importance or useful contributions of these disciplines. YPS is predicated on a complex relationship between action and knowledge.

Both YPS and YPAR stress the production of knowledge by those who do not hold formal positions as intellectuals and thus position youth as transformative intellectuals (Duncan-Andrade and Morrell 2008; Cammarota and Romero 2014; Morales-Doyle 2017). Whereas YPAR has mostly employed social science methods, YPS combines the participatory elements of YPAR with the tools and methods of the so-called natural sciences. In so doing, YPS acknowledges that hegemonic science is one way of understanding the world, which is very powerful in some ways and very limited in others (Lewontin and Levins 2007). YPS acknowledges that the development of hegemonic science has been inextricably tied to European and US imperialism (Smith 1999; Conner 2005). Pedagogically, this implies cross-cultural and decolonizing approaches to teaching science where students come to understand science as one way of knowing among many (Bang et al 2012; Aguilar-Valdez et al 2013; Aikenhead 2006). Methodologically, YPS complicates the more direct relationship between research and action that exists in YPAR. Scientific understandings may or may not move youth towards sociopolitical action. And even when sociopolitical action is not motivated by scientific understandings, it may very well be motivated by other ways of understanding the world. In substituting “science” for “action research,” YPS proposes that learning and knowledge production in fields like chemistry, physics, and biology can be democratized, while it also seeks to encourage epistemic heterogeneity and the need for us to create new kinds of relationships between people and the world they seek to understand (Bang and Vossoughi 2016). This means that YPS recognizes the strengths and limits of scientific knowledge as it also seeks to expand scientific ways of knowing with young people.

One of the ways that YPS is different from both traditional forms of science teaching and other forms of PAR is in explicitly teaching young people to critique and appreciate science by looking for both insights and blind spots (Morales-Doyle, Childress Price, and Chappell 2019). In this way, YPS aims at developing what Freire (1998) called "epistemological curiosity" (p.83), or a critical perspective about how we know what know and what this means for how we act. The curriculum framework described below includes opportunities for students to reflect on how and when scientific knowledge is relevant and useful or not, in their lived experience and community contexts. YPS also aims to support students to consider how the enterprise of science causes harm or justifies oppression. This YPS emphasis involves not only applying science to address community challenges, but consciously appropriating, critiquing, and potentially reimagining the sciences. This pedagogical approach fundamentally changes the experiences that students have in their science classes and the ideas and relationships they develop with respect to the so-called natural sciences.

Supporting YPS in Classrooms: YPS Curriculum Framework

The Next Generation Science Standards (NGSS Lead States 2013), which have been adopted by most state school systems in the US, emphasize science instruction organized around natural phenomena. Much of the professional development related to the NGSS focuses on supporting teachers to "carefully construct a storyline to help learners build sophisticated ideas from prior ideas using evidence" (Krajcik et al 2014, p. 162). We argue that engaging with authentic scientific problems in community contexts is not sufficiently predictable to make "carefully construct[ing] a storyline" achievable. But this does not mean that curriculum planning is any less important to teachers taking up YPS and we recognize that negotiating the tensions between YPS and traditional school science is difficult and can be intimidating for teachers. With that in mind, we present YPS as an emerging concept and the curriculum framework as a structure that has been helpful for us and other teachers as we negotiate these tensions. It is *not* as a step-by-step guide or a rigid formula for YPS.

In science education, the 5E model (engage, explore, explain, elaborate, evaluate) has been a popular curriculum framework for the last three decades (Bybee et al 2006). Similarly, the praxis cycle provides a framework to guide YPAR projects (Duncan-Andrade 2008). In proposing the YPS curriculum framework, we draw on the 5E and praxis cycles to link theory and practice and to build bridges between YPAR and science education. In the vein of the praxis cycle and the 5E, the curriculum framework has five phases (see Table 1), conceptualized as a cycle (see Figure 1). We emphasize that the goals of this curriculum framework are aligned with the socially transformative goals of critical pedagogy and the praxis cycle rather than the conceptual change goals of the 5E.

The theories informing both the 5E and the praxis cycle both acknowledge that students do not enter the classroom as blank slates and that their prior knowledge must be prioritized. The 5E model reflects and aligns with a decades-long assumption in science education that "conceptual change" is the primary learning goal of science instruction (Bybee et al 2006). The conceptual change model assumes that students' prior knowledge mostly consists of misconceptions (sometimes euphemistically called "preconceptions"). It follows that teaching is about engaging students in learning activities that move them towards the accepted canonical explanations. In this model, whether students ultimately pursue science professionally or not, the ultimate outcome is to adopt the worldview of hegemonic science (Aikenhead, 2006). In recent years, prominent scholars have challenged this presumed goal of science education and argued instead for learning activities that support students' development of heterogeneous, vernacular, and pluralistic explanations and understandings of phenomena (Medin &

Bang, 2014; Brown, 2019; Windschitl, Thomson, & Braaten, 2018). YPS takes up these challenges to hegemonic science education. It is aligned with critical pedagogy, which recognizes students' community knowledge and critical forms of knowledge as valuable and legitimate (Gutstein, 2006). Social transformation, rather than disciplinary reproduction, is the desired outcome of learning.

In the first and last phases of this YPS curriculum framework, the teacher and students work together to (re)define the SJSI and consider the ways in which scientific understandings may inform or obscure different possibilities for social, political, or cultural action. In the middle phases of the cycle (at the bottom of Figure 1), teachers take a cross-cultural approach to learning science by appropriating scientific theories, methods, and tools as one way to understand the SJSI. In our own implementation of this framework, we have recognized the need for doubling back within this larger cycle, especially between the middle phases of the cycle, which can thus constitute mini-cycles within the larger cycle. In the following subsections, we describe and illustrate the curriculum framework with examples from our own classrooms and from an initiative to support YPS projects around the issue of urban heavy metal contamination.

INSERT TABLE 1

INSERT FIGURE 1

Define the Social Justice Science Issue.

There has been a push in mainstream science education towards organizing curriculum around so-called natural phenomena. This approach presumes a nature-culture binary (Kayumova, McGuire, and Cardello 2018) and pushes critical questions about justice and equity to the margins of the science curriculum, if not out of the curriculum altogether (Mutegi, 2011). Justice-centered science pedagogy advocates SJSI, rather than natural phenomena, be the central themes in science curriculum. SJSI are issues that have both scientific and social components that have also been identified as important by local community members. In focusing on SJSI, we recognize that there are conflicted meanings of social justice and also ways of conceiving of justice that are less anthropocentric (Tuck and Yang 2018). We believe that SJSI provide an excellent starting point to consider the insights of critical social theory and science while also providing opportunities to question and blur the nature-culture binary.

In the first phase of a YPS project, students and teachers work together to define the SJSI in their own terms. This necessitates foregrounding students' knowledge of the issue and providing prompts and opportunities for students to consider the problem in ways they may not have previously. Several communities in our city have identified the issue of heavy metal contamination as an important problem over a period of decades, but the salient aspects of this problem are different across the city. For example, in some neighborhoods, lead contamination from the paint of old and dilapidated housing stock remains a prominent concern. Other neighborhoods were the sites of long-defunct lead smelters or paint factories that have left a toxic legacy. In one neighborhood, manganese contamination from the steel industry is the focus of local organizations. And across the city, the problems caused by lead water mains and the residual impact of leaded gasoline exacerbate other sources of exposure. As serious as these concerns are, it is important that these environmental issues, which were caused by industry and not community residents, do not come to define the places that our students (and we) call home. We recognize that there is a risk of participatory research slipping into a "damage-centered" perspective, with a focus on the despair and pain caused by oppression (Tuck 2009).

An important component of YPS is to foreground the brilliance, strength, and aspirations of young people and their communities even as we investigate real problems that people identify. For that reason, in our YPS projects that have focused on urban heavy metal contamination in middle and high school science classrooms, we have used a Photovoice (Wang and Burris 1997; Strong et al 2016) assignment where we ask students to take four photographs of their community: one of something beautiful, one of something ugly, one of something clean, and one of something contaminated. We use these pictures as a starting point for a conversation about environmental racism and heavy metal contamination. As we view the pictures together, we realize that not all the issues students identify may benefit from scientific analysis. For example a student may share a picture of graffiti painted on a local viaduct. We can validate that the aesthetics of our neighborhoods are an important part of our environment and also direct our focus towards the old peeling paint on the same viaduct that may contain lead because we are responsible for teaching science. Thus the selection of the problem we study is constrained by the discipline and YPS has limitations that YPAR does not. Dealing with the pedagogical implications of these constraints is one of the reasons to distinguish YPS from YPAR.

After this assignment, we invite a community organizer from a local environmental justice organization to visit our classes and discuss both challenges and victories relevant to the topic of heavy metal contamination and/or the history of the neighborhood and city. We also read articles from local newspapers about heavy metal contamination related to the (de)industrialization of the city. By foregrounding student knowledge of their community and then placing what they observed within the larger context of environmental racism and the local struggles for environmental justice, we begin to define the SJSI in a way that is useful, hopeful, and locally determined.

Apply a Scientific Lens

There is a risk in YPS projects of suggesting that science alone is capable of solving problems that are facing the community. This perspective reinforces problematic colonial narratives about Western knowledge and fails to deal with the socio-political complexities of SJSI. It also often means that "…local knowledge is denigrated, silenced, and ignored" (Wood, McAteer, Whitehead 2019 p. 11). YPS shares the democratic principles of YPAR, which serve as a means to yield who is in charge of the construction and application of knowledge by supporting participants opportunities to appropriate scientific processes and systems (Ayala et al 2018). For this reason, it is important to avoid defining the SJSI in technocratic terms and it is critical to consider the affordances and limitations of applying a scientific lens to address the problem.

YPS is more explicit than YPAR about teaching students to problematize science itself. In addition to considering the limitations of scientific ways of knowing as it relates to solving local problems, this also involves providing opportunities for students to consider the role of hegemonic science in creating the SJSI in the first place (Morales-Doyle, Childress Price, and Chappell 2019). For example, in studying heavy metal contamination, students can learn that powerful industry forces funded much of the research on the toxicity of lead and that prominent chemical engineers ignored the warnings of colleagues and pushed for its widespread use in paint, gasoline, and other applications (Markowitz and Rosner 2013). Students could also consider that the mainstream enterprise of science played a significant role in establishing and institutionalizing the ideology of white supremacy that undergirds environmental racism and other inequities (Brown and Mutegi 2010; Rusert 2017).

For these reasons and because of our belief in the importance of grassroots knowledges and subaltern ways of knowing, YPS projects take a cross-cultural approach to science teaching where students are introduced to the practices and values of hegemonic science as potentially useful tools (Jegede and Aikenhead 1999). Justice-centered pedagogy emphasizes that science is one way of knowing that produces powerful insights and dangerous oversights that emerge from its development as an institution of Western imperialism.

Our metric conversions activity illustrates this approach to applying a scientific lens, as the second phase of YPS curriculum. This activity begins by introducing EPA standards for tolerable lead concentrations in drinking water (expressed in parts per billion and percentiles) and soil in residential soils (expressed in parts per million) and juxtaposes these regulations with the CDC definition of childhood lead poisoning (expressed in micrograms of lead per deciliter of blood) and a statement by the National Institute for Environmental Health Services that no amount of lead is safe. The activity thus establishes the importance of understanding metric units and scientific forms of measurement as it relates to protecting our communities and children from toxic contaminants. The next part of the activity explains that these units of measurement are predicated on the base-ten number system and stresses that while the metric system was developed in France, it relies on the innovation of a number system that was created by people in India and very much democratized access to mathematics (Conner 2005). Through a series of hands-on activities that follows, students are prompted to consider that peoples around the world developed systems of measurement while they develop concrete and abstract understandings of conversion factors. In this activity, units of measurement and conversion factors are taught as tools of science that are helpful for understanding environmental regulations and local problems of environmental racism. In this way, the second phase of YPS projects support students to engage in scientific practices not as *the* correct or best way to understand local problems, but as a tool that they can appropriate (if they choose) to address problems that, in many ways, emerged from the scientific enterprise and have been visited upon their communities through oppression.

It is important to note that this cross-cultural or problem-posing approach challenges teachers in several ways. It requires a shift from science teachers' presumed role as promoters of science (Morales-Doyle, Childress Price, and Chappell 2019). Many teachers may also need to build their own capacity to critique science as they encourage and support students to do so. Furthermore, YPS requires that teachers learn not only the applicable science but also learn from students' and communities' and learn to analyze the socio-political complexities and origins of the problem.

Plan and conduct an investigation

For more than twenty years, mainstream efforts in science education reform have focused on providing students with opportunities to *do science*. In the US, this is evident in the 1996 NRC standards' emphasis on inquiry and with the 2013 NGSS strand of science and engineering practices, which include "planning and carrying out investigations" (NRC 2012). What has figured less prominently in mainstream conversations have been the questions of doing science *for what? and for whom?* YPS acknowledges that appropriating scientific practices can be useful for students in at least two ways. First, because of the emphasis on these practices in mainstream education reforms, appropriating scientific practices can provide students with access to educational opportunities they may not otherwise have had. These opportunities are not unproblematic, but they do often come with resources and credentials that young people can leverage in service of their community. Second, scientific practices can be useful tools in addressing the SJSI that impact local communities.

With a more explicit and community-centered answer to the question of science for whom and science for what, YPS encourages students to plan and carryout an investigation that flattens the presumed hierarchy between scientific and local knowledge and includes young people in authentic scientific activity from the design of a study through the dissemination of data and the formulation of appropriate responses.

In the wake of the Flint water crisis, we worked with students to design local studies of urban heavy metal contamination by sharing scientific evidence and examples of local struggles that suggest that besides lead contamination in water, soil contamination involving lead and other heavy metals is also a concern in our city (Mielke 1998). Then, we introduced students to online tools (e.g. the EPA's toxic release inventory, https://www.epa.gov/toxics-release-inventory-tri-program) and information about other non-point sources for legacy lead contamination like leaded gasoline and lead-based paint. Students were encouraged to combine this information with their local knowledge about where community residents are likely to be exposed to soil contamination to design a sampling plan on public land. We also introduced students to a number of sampling techniques with various levels of methodological rigor and discussed the trade-offs between the amount of work sampling requires and the reliability of results.

Students have been able to get the samples they collect analyzed by sophisticated instruments that would not usually be available to secondary school teachers and students because of partnerships with university scientists. Various logistical constraints have meant that university students or faculty have actually operated these instruments. Still, it has been important for youth to understand how these instruments work to measure the concentrations of heavy metals in soil. To provide students with opportunities to construct such understandings, we designed a series of activities using more accessible instruments, techniques, and chemicals to model the functionality of the university instruments. Through these series of activities, students are supported to construct explanations for their community about how the data was generated in our YPS projects (Morales-Doyle, Childress Price, and Chappell 2019). In this way, our projects also cycle back between planning and carrying out an investigation and applying a scientific lens as students learn canonical chemistry content within the context of carrying out their YPS project.

Analyze data and assess learning

In order to make sure that young people are prepared to share what they have learned from a YPS investigation, it is important to provide opportunities for them to make sense of the data they collected and also to assess the understandings they have constructed during the project. A challenge for teachers in enacting YPS is that while they have a real need and responsibility to assess students' understandings of canonical science concepts and practices, they must also consider presenting students with ways to analyze data that may not be a part of their scope and sequence. Making sense of data about heavy metal contamination draws on various understandings such as policies about contamination thresholds in various types of soil or water, methods of analysis and reliability, historical understandings of contamination sources, as well as technological and mathematical ways to interpret and represent findings.

During this phase of a YPS project, we work with students to identify useful ways to analyze the data they have conducted during their investigation while also considering the grade level content and skills we are asking them to apply. For example, with middle school students who were learning ratios, percentages, and proportions in their math class, analysis of the data focused on constructing ways to represent heavy metal contamination results in comparison to national limits or standards. While trying to understand the results from decaying paint from a neighborhood viaduct that was tested for lead, one student sought out information from the U.S. Consumer Product Safety Commission and found the limit of lead now allowed in paint. While independently preparing for a presentation to an elected official, the student used this limit and the data from a university lab to form a ratio, of her own accord. She determined the peeling paint on the viaducts more than 170 times the national limit of lead, indicating that old lead-based paint had never been abated and instead had been allowed to peel and decay. This student's analysis became the central point of a presentation to a city council member and epitomizes the type of youth-led knowledge production that can occur in YPS. In this case, a sixth grade student created a rhetorically powerful way of communicating understandings that she built at the intersection of analytical chemistry, mathematics, public policy, and local knowledge.

Undertaking data analysis often leads students to understand the power and also the challenges and limits of scientific ways of knowing. While middle school students found evidence of lead-based paint contaminating their community, that information alone was not enough to force the city to remediate the lead paint on the viaducts that students passed on their way to and from school every day. We have learned with students how challenging it is to bring scientific evidence to bear on local environmental problems, which exist in complex systems and involve political power.

We would also be remiss if we did not acknowledge the challenge that science teachers face when students ask "for what?" and "for whom?" but administrators answer "to improve standardized exam scores." In this phase of the YPS curriculum framework, the process of meaning making between teachers and students also doubles as an assessment of academic knowledge that teachers can use to gather evidence of learning. We have also used more traditional means of assessing canonical understandings in this phase. Lab reports or teacher-constructed exams can demonstrate to school administrators, parents, skeptical colleagues and even students themselves that engagement in YPS supports academic achievement. Furthermore, many districts (including ours) have initiatives and requirements related to service learning, civic engagement, and student voice. In our district, science classes accounted for only about 8% of the service learning projects that high school students completed to meet graduation requirements last year. The YPS curriculum framework provides a structure to bring civic engagement and service learning into science class in radical ways. It also allows districts to expand student voice and civic engagement initiatives beyond their social studies departments.

Reflect, disseminate, act

In a justice-centered curriculum, there is a need for authentic assessments, meaning that students' knowledge construction must have a purpose beyond showing their teacher what they learned. We view this phase of the curriculum cycle as akin to the final stage of the interdisciplinary project that Paulo Freire supported as the superintendent of São Paulo schools.

> Central to this idea is that subject area content matter is not an end and of itself but a means by which to better comprehend a given aspect of reality, all the while rejecting the fragmentation and disassociation of knowledge from the life conditions of the students. With this enhanced comprehension comes the ability and agency to act on that reality and transform it. (O'Cadiz, Wong, and Torres 1998, 121)

During a planning session for teachers doing YPS in their secondary science classrooms, we generated a list of possible ways to reflect, disseminate, or act on what we learn. Figure 2 shows the product of a brainstorm that involved 7 teachers, a science educator, and a scientist thinking about the various ways students could address the problem of urban heavy metal contamination based on what they learned through YPS projects. All of these ideas, even those that have more traditional academic forms (presenting at a conference, writing a journal article) ask students to participate in the world beyond their classroom in ways that school science projects typically do not. But we also imagine students producing blogs and “artivism” in ways that incorporate scientific knowledge beyond what might typically appear in artifacts of youth culture. In past projects, our students have presented what they learned about the local environment to the community or shared what they learned with their younger siblings or nieces and nephews through writing children’s books. Regardless of the particular form it takes, the goal of this phase of a YPS project is twofold. Teachers can assess what their students have learned in a way that extends beyond canonical understandings and students can consider how what they have learned may be useful to their lives and communities and act upon those considerations.

INSERT FIGURE 2

The final phase of the curriculum framework is the most challenging, but also possibly the most important. Engaging with real problems in our communities carries the risk of overwhelming teachers and students alike. Teachers enacting YPS must face the challenges of working through practical limitations of timing and lesson planning from aligning the school and course calendar to the real context of the SJSI, backwards mapping the project over a unit, a semester, or a school year, or deciding how multiple sections of a course will contribute to the project. We hope that the curriculum framework presented here is a useful tool for these planning considerations.

Providing structures and support for students to *do* something with what they have learned, positions them as transformative intellectuals who are committed to their communities, have a certain grassroots credibility, and view SJSI with complexity (Morales-Doyle 2017). This is a source of hope. Furthermore, by collaborating with local organizations in this final phase, students are reminded that their communities have rich traditions of activism and organizing against injustice. Too often school removes students from these traditions by espousing a narrow definition of academic success and operating in isolation from the community. Whereas the field of science education emphasizes engaging in scientific practices in order to develop canonical understandings, YPS emphasizes community engagement in social change projects in order to see the ways that scientific ways of knowing may, or may not, be useful towards the broader goals of fighting for justice and building sustainability.

Our early efforts to support youth to investigate local problems of environmental racism sought scientific evidence of environmental damage associated with unwanted polluters in our communities. We assumed that such evidence would be the basis for youth-led action to demand remediation. Our experience planning, implementing, and reflecting upon our YPS efforts has challenged these assumptions and complicated our understandings of the relationships between knowledge and action.

In differentiating YPS from YPAR, we intend to highlight the limited scope and powerful insights of scientific knowledge and also the possibilities and importance of enacting critical pedagogy in science classes. YPS is necessarily narrower than YPAR, but it is also more explicitly self-aware of its epistemologies and limitations. The set of challenges in our communities that can be informed by scientific ways of knowing is interwoven and yet substantially smaller than the set of challenges we might engage youth in addressing. For example, students might learn about the development of pepper spray in chemistry class, but their efforts to organize against police brutality (like using pepper spray against peaceful protestors) are likely to be better informed by YPAR projects that employ social science methods. Furthermore, even when scientific ways of knowing may inform a problem facing the community, there is not a linear relationship between scientific evidence and our course of action. For example, the burden of proof that an unwanted polluter is causing a particular harm to a community should not lie on the community itself. In communities with political clout, zoning laws and various types of permits are controlled by the community based on the desires and political will of local residents. Why should marginalized communities be required to produce evidence of harm to have a voice in issues of land use near their homes and schools? That said, scientific tools may be useful in communities' efforts to move strategically through the political realities they face. But we do not believe that YPS projects should operate using a linear logic where scientific evidence determines, or even acts as the primary source of information, in planning and acting in the socio-political realm.

Teachers and students also must acknowledge that collective social change is not immediate, linear, or bound by the school calendar. One of the ways that we have dealt with this reality is to encourage each class to think of themselves as making a contribution to a larger project, especially in this final phase. We remind students that their work can be taken up by the next class or that they can continue to stay involved beyond the class. This is another way in which working with community organizations is important because these organizations provide structures for the ongoing involvement of young people who become committed to social change. And indeed, we have seen examples of projects continuing in this way, which serves as an important reminder about the way YPS links science learning and community engagement. Despite all the complexities and contradictions, student-created scientific knowledge can be a powerful tool to inspire on-going involvement, to pressure public officials, and to support the agency of young people to *write the world* (Freire as cited in Gutstein 2006).

Moving YPS Forward

We wrote this paper to share some of what we have learned in our collaborative and iterative attempts to teach science by engaging young people in in authentic projects that mattered in their communities. In other words, the definition of YPS and the curriculum framework were constructed in praxis. As we continue to engage in this work, we have identified the following ways in which YPS can continue to grow, improve, and engage with inherent contradictions.

Supports for teachers.

We anticipate some criticism of the curriculum framework we share here as too formulaic. We do not intend for the YPS curriculum framework to be used in prescriptive or restrictive ways. Rather, we know from experience that the day-to-day work of teaching is extremely difficult and that teachers attempting YPS projects in their classrooms face all sorts of structures and restrictions that work against the community-engaged, youth-centered, and justice-oriented character of YPS.

We have discussed various barriers and challenges that teachers have encountered in attempts to enact YPS in schools. Among these are school and district administrators who devalue or dismiss YPS because it does not follow the packaged or scripted scope and sequence. School accountability measures set priorities that differ from those of YPS. Therefore, it is important to look for ways to align YPS projects to those school or district initiatives that may focus on community partnerships, culturally relevant teaching, promoting student voice, or civic engagement. For example, rather than raging against the limitations of district-sanctioned science curriculum, we have made space for YPS in schools in our district by showing how these projects unite science learning with high school graduation requirements for service learning.

Our framework is a tool for teachers to conceive of YPS projects in a way that supports their classroom planning. For example, we argued above that the twists and turns of doing an authentic investigation in the community are unlikely to mesh with the "story-lining" approach advocated by science curriculum reformers. Teachers may also have a hard time codifying their YPS projects within requirements for lesson plans and unit maps. Given these realities, the YPS curriculum framework is a support structure that may help teachers organize their work and planning in ways that meet these other demands. Using the curriculum framework to structure a YPS project also may help teachers to feel more prepared for unanticipated ideas, data, or events that arise. For example, in two YPS projects that Frausto led around heavy metal contamination, the framework was a helpful way to reconsider how to thread the curriculum throughout the school year when logistic constraints made inscribing the project within a single unit impossible.

In our experience planning YPS projects, we have each done a substantial amount of learning about scientific content, environmental regulations, the communities where we live and teach, and about environmental justice movements. We must account for and support the substantial learning required of teachers to support these projects. We believe that this learning will be best supported by bringing together teachers with scientists, youth, and community organizers.

Emphasis on intergenerational work and knowledge production.

Facilitating YPS projects in schools pits YPS emphases on democratic knowledge production, community responsiveness, and youth leadership against the top-down and conservative nature of school systems. There is consensus among knowledge democracy scholars that knowledge should be questioned and understood as flexible (Wood, McAteer, and Whitehead 2019). But, science curricula still place a heavy emphasis on students' ability to reproduce canonical explanations of natural phenomena and position hegemonic science as the single best way to understand the universe. Enacting YPS asks teachers to consider more than just relevant canonical scientific knowledge but also Indigenous, social, historical, political and local knowledges that are relevant to understanding the root causes of problems being investigated.

While *youth* are foregrounded in YPS, we are reminded by colleagues that YPAR and community-based science education must be intergenerational if they are to be truly transformative (Bang, Faber, Marin, Gurneau, and Soto 2016; Cammarota and Fine 2008). There are opportunities, especially in defining the SJSI and in disseminating and reflecting, to extend across generations YPS work that often mostly happens in the classroom. This requires that teachers be proactive and humble as they find ways to engage students' parents, grandparents, and other elders in their communities.

Continuing to grapple with contradictions.

We continue to struggle with the tensions between providing opportunities within YPS projects for students to engage in socio-political action while encouraging students to be engaged in organic ways in the issues and causes that are most pressing and meaningful in their lives. This is related to the tension between differentiating YPS from YPAR where the disciplinary distinction may expand the boundaries of the science curriculum while simultaneously limiting the problems and issues that students investigate. We believe that in these tensions, there exists opportunities to position students as transformative intellectuals and to provide them with opportunities to try out and try on different forms of intellectual, scientific, and socio-political engagement. We believe that an important role of science classes is to teach young people about the limitations and blind spots of scientific ways of knowing and to encourage them to critique the interconnectedness of the enterprise of science and oppressive social projects like imperialism, neoliberalism, and white supremacy (Vossoughi & Vakil 2018). We understand that engaging with "regimes of evidence," risks reproducing the relationships between science and society that have led to a "permanently polluted world" (Liboiron, Tironi, and Calvillo 2018). In some ways, a justice-centered approach to teaching science may be akin to "slow activism," as it involves everyday forms of caring and living in resistance (Liboiron, Tironi, and Calvillo 2018) and creating new ways of relating with each other and the world (Bang, Faber, Marin, Gurneau, and Soto 2016). At the same time, we recognize that access to the institutions of science provides young people and their communities with resources and tools that can be useful for the causes of community self-determination and sustainability (Bang and Medin 2010). This means that we leave open the possibility that YPS projects may, in some cases, lead to more traditional and event-based forms of activism and organizing that we believe are important for creating a more just and sustainable society. In our experience, YPS projects create opportunities for students and teachers to grapple with contradictions of access and dissent together (Morrell 2008). Enacting YPS *as science class* is an effort to bring the most democratic and radical the sentiments of the "March for Science" into science education and moves us towards science education for and by the people.

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