



Bank Street Occasional Paper Series

Occasional
Paper
Series

Volume 2022
Number 48 *Learning Within Socio-Political
Landscapes: (Re)imagining Children's
Geographies*

Article 2

November 2022

More than Civil Engineering and Civic Reasoning: World-Building in Middle School STEM

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Recommended Citation

Frausto Aceves, A., & Morales-Doyle, D. (2022). More than civil engineering and civic reasoning: World-building in middle school STEM. *Occasional Paper Series*, (48), 13-32. DOI: <https://doi.org/10.58295/2375-3668.1473>

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Cover Page Footnote

The work reported in this paper has been supported by a grant from the National Science Foundation Division of Research on Learning, Abstract #1720856. The statements made and views expressed in this article are solely the responsibilities of the authors and do not reflect the views of the National Science Foundation. The authors would like to acknowledge the Youth Participatory Science Collective for their role in shaping this work. In particular, thank you to (in alphabetic order): Alanah Fitch, Shelby Hatch, Jesus Hernandez, Amy Levingston, Julie Moy, and Tomasz Rajski. The authors would also like to acknowledge Sepehr Vakil, Andrew Kim, and Shirin Vossoughi's advisory group for their feedback on earlier versions of this manuscript. The statements made and views expressed in this article are solely the responsibilities of the authors.

More than Civil Engineering and Civic Reasoning: World-Building in Middle School STEM

Alejandra Frausto Aceves and Daniel Morales-Doyle

Ay, mis ingenieros civiles y asociados
No crean que no me duele irme de su lado
Pero es que yo pienso que ha llegado el tiempo
De darle lugar a los espacios sin cemento

Por eso yo ya me voy
No quiero tener nada que ver
Con esa fea relación de acción
Construcción, destrucción, ah, ah

Oh, my civil engineers and associates
Do not think that it does not hurt me to leave your side
But I think that the time has come
To give place to spaces without cement

That's why I'm leaving
I don't want to have anything to do
With that ugly relationship of action
Construction, destruction, ah, ah

—Café Tacvba, “Trópico de Cáncer”

El trópico de cáncer is an imaginary line in the Northern Hemisphere marking the northernmost latitude at which the sun can be fully overhead, which occurs on the summer solstice. It is also the title of a song by the Mexican band Café Tacvba that captures tensions encountered when nations in the Global South emulate the development of the North. The song tells the story of an engineer, fittingly named *Salvador* (savior), called upon to rescue his country, México, by modernizing the nation-state. The lyrics in the epigraph explain Salvador's decision to stop participating in engineering that ignores humanistic, ecological, and Indigenous realities and imaginations in order to build a more “modern” world. Salvador laments that although he loves his profession and his colleagues, he sees engineers engaging in an “ugly relationship of action, construction, [and] destruction” (Café Tacvba, 1994, stanza 7, lines 3–4) that does not attend to the unsustainable and unjust impacts of their built worlds.

Almost three decades after the song's release, its themes remain relevant and stand in contrast to the ways in which science, technology, engineering, and mathematics (STEM) education communicate a false vision of the STEM enterprise as value neutral. As recent reforms in the United States, like the Next Generation Science Standards (NGSS), aim to broaden exposure to engineering education by carving out a place for it in kindergarten or even earlier, racial equity remains a central concern (National Academies of Sciences, Engineering, and Medicine, 2022). Equity in STEM education has multiple facets and has been conceived in multiple, sometimes contradictory, ways (Philip & Azevedo, 2017). Taking themes of development, sustainability, and justice into consideration alongside the push for engineering education among younger students recognizes that students deserve opportunities to develop realistic and hopeful understandings of engineering as a range of professions and practices with embedded values and politics that shape our built world.

There are few examples of K-12 engineering education that explicitly weave together sophisticated STEM practices with equally robust considerations of values and politics. In this narrative essay, we focus on a project led by Alejandra with her sixth-grade students at a neighborhood public elementary (K-8) school. In our city, the vast majority of elementary schools include kindergarten through eighth grades. There are very few stand-alone middle schools. Thus, in our context and in this essay, the term

elementary school includes the middle grades. Aguila Elementary¹ is located in City Field, a working-class neighborhood in a large US city where most of the residents, like Salvador the engineer, have roots in México. Alejandra engaged her science class in investigating crumbling concrete viaducts that students walk under on their way to and from school. By considering how engineering practices are imbued with values and ideologies, we present an interpretive narrative about how students engaged in STEM education as world-making in the context of development and urban decay in this transnational community.

This story begins with a project in Alejandra's sixth-grade science classroom that intertwines science education with civic engagement. We explain how the project and the students helped us to see local urban infrastructures as political artifacts of civil engineering and sites of learning. As students communicated with an elected official, they mobilized scientific evidence as part of their civic reasoning. But they also began to understand how the professions and practices of engineering contribute to building our world in value-laden ways. We propose moving beyond notions of civil engineering and civic reasoning that are connected to projects of nation-building to more pluralistic and internationalist approaches. Problem-posing and world-making approaches to engineering education can lead to students' participation in more complex and authentically situated learning *que le da lugar a* (giving space and place to) students' contributions to the world (Barajas-López & Ishimaru, 2020). Our story includes examples of students engaging with NGSS science and engineering practices (SEPs) in ways that explicitly consider values. We contend that to educate youth as world-makers with the capacity to dream and the power to act implies encouraging them to see the world as it has been made and to take up an ethic of care by relying on "*should we* questions" (Tzou et al., 2021). In the context of engineering education, this means encouraging students not just to design solutions, but also to probe the *should we* dimensions of the engineering challenges we present to them. Imagining possibilities therefore includes thinking and making decisions with the implications and consequences of those possibilities in mind.

Even as we became frustrated with the way the elected official responded to students' use of scientific evidence, the young people themselves remained hopeful and committed. Thus, we call on teachers to cultivate SEPs that take seriously the rightful presence of youth and their communities in service of disrupting the world as it is and moving toward speculative civic possibilities and imaginations that allow for the dreams of our youth to take root (Calabrese Barton & Tan, 2020; Garcia & Mirra, 2021).

CIVIC REASONING WITH SCIENTIFIC EVIDENCE

The classroom project described in this paper was supported by the youth participatory science (YPS) collective, a local group of teachers, scientists, and community organizers dedicated to engaging young people in authentic scientific investigations about local issues of environmental racism. We write as members of the YPS collective and also as residents of the City Field community. Every day, we walk our own children under the viaducts to attend Aguila. As community members who share a background in chemistry and years of involvement with urban environmental issues, we suspected that the peeling paint on the viaducts was a potential source of heavy metal contamination. But we were surprised by some of the ways in which students took up the issue of urban infrastructure as their own.

For us, linking science education with civic engagement is grounded in our commitment to our neighborhood and our profession. This link pushes back against the tendency for science education

1 The school, neighborhood, and people have been assigned pseudonyms.

to discourage students' community and political involvement. At the undergraduate level, STEM majors tend to be less socio-politically engaged than their peers in other disciplines (Garibay, 2015). As engineering becomes a priority for younger students, we hope to avoid reproducing this tendency of postsecondary engineering education in K-12 settings (Vakil, 2018). With this story, we hope to contribute to the collective imagination about ways to resist an engineering education in which young students are raw materials for the STEM pipeline and future contributors to the national gross domestic product (Morales-Doyle & Booker, 2022). As this project began, we were not intentionally engaging in engineering education nor explicitly thinking of our work as world-making. And yet, as Café Tacvba (1994) invites us to notice in "Trópico de Cáncer," we are all participating in the building of worlds. As we elaborate below, the ways in which students took up urban infrastructure and built worlds as meaningful themes informed the ways we thought about the possibilities of our work. Thus, our focus here is to tell a story that may inform educators who position their students as community members and co-contributors toward more just and equitable present and future worlds.

DARLE LUGAR A LOS ESPACIOS SIN CEMENTO

Using a photovoice activity, our investigation began by problematizing the decaying viaducts (de los Rios, 2020). The problem-posing activity asked students to take four photos: one of something clean, one of something contaminated, one of something ugly, and one of something beautiful. We have discussed this activity elsewhere in terms of posing problems while avoiding damage-centered perspectives (Morales-Doyle & Frausto, 2021; Tuck, 2009). For our purposes here, there are two important points to highlight with respect to the intersection of engineering with values. First, this photovoice activity explicitly connected students' values, in terms of aesthetics, to the NGSS SEPs of defining problems. Second, we highlight that several students photographed cement structures as the representation of something ugly in their neighborhood and submitted photos of the large community park or other greenspaces as their example of local beauty (see examples in Table 1). Through these photos, students were echoing Salvador's plea in the lyrics to "Trópico de Cáncer" (Café Tacvba, 1994, stanza 6, line 4) to "*darle lugar a los espacios sin cemento*" (give place to spaces without cement).

In reflective conversations about this project, students raised crumbling infrastructures as a problem in their communities. For example, when asked about challenges faced by the community, Rocio responded, "Some of the problems in the community are like you walk around and it's not that clean. The sidewalks are messed up and then there is a lot of potholes on the roads." While we identified peeling paint on the viaducts as a potential problem for students to investigate, we were surprised that students picked up on and expanded these themes, identifying deteriorating urban infrastructure as a broader concern. It was only upon reflecting on student responses that we saw how Alejandra's teaching was taking up issues of civil engineering in addition to our original focus on civic reasoning and scientific investigations. Rocio explained that science class with Alejandra was different because "she teaches with us and she learned with us. Not like other teachers who just tell you a book." While this kind of teaching is often idealized, it actually happens when teachers experience uncomfortable tensions of co-conspiring and co-authoring while at the same time being responsible for teaching rigorous and developmentally appropriate science. Hence, these learning activities do not reflect a simple distinction between projects that are teacher-directed and those that are student-centered—especially when we are open to co-constructing problems and learning from and with our students (Vossoughi et al., 2021).

Student	Clean	Contaminated	Ugly	Beautiful
Ramona				
Manuel				

Table 1. Student photovoice contribution examples

HOLISTIC EARLY ENGINEERING EDUCATION

A Framework for K-12 Science Education (National Research Council, 2012) inserted engineering education as a priority for all levels of school science instruction in an unprecedented way. This priority was articulated explicitly in the three strands of the resulting NGSS. It is most prominent in SEPs, which were elevated to the same level of importance as disciplinary core ideas that also include a category for engineering, technology, and the application of science (ETS). Science as taught in schools has long propagated an idealized vision of basic science that does not reflect the realities of research and development as they have evolved since the mid-twentieth century (Aikenhead, 2006). The changes encoded by the NGSS potentially provide students with a more realistic interdisciplinary sense of the STEM enterprise, as long as students also experience an active role in producing knowledge (Stroupe, 2014).

The NGSS replaced vague notions of inquiry in the previous standards with a commitment to teaching practices as much as concepts. At the same time, the *Framework* defines engineering in open-ended ways that gaze toward systemic designs and analyses of human problems, systems, and processes:

We use the term engineering in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term technology to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. (National Research Council, 2012, pp. 11–12)

In this broadly conceived extension of engineering education into elementary and middle grades, we see an opportunity to affirm and extend the ways that K-8 teachers tend to view their work as teaching children, while educators of older students tend to view their work as teaching specific disciplines. A critical synthesis of these viewpoints reminds us that students' engagement with SEPs is not

disconnected from who they are, since disciplinary engagement happens within historical and cultural contexts that are imbued with power and values (Agarwal & Sengupta-Irving, 2019; Krist & Suárez, 2018; Nasir et al., 2006). (W)holistic science teaching in the middle grades emphasizes connections between students' science learning and their well-being, which includes connections with the broader community, realistic views of racialized and gendered inequities, and affirming and caring classroom experiences (Patterson & Gray, 2019).

ENGINEERING AS WORLD-MAKING

Aguila students' photovoice responses and reflections on their project suggest that local urban infrastructures are potential sites of this kind of holistic learning. Investigating our built worlds implicates not just the engineering practices used to construct those worlds' components, but also their underlying values and how we interact with and participate in the built world. De la Cadena (2015) uses the term "worlding," from Haraway (2008) and Tsing (2010), "to refer to practices that create (forms of) being with (and without) entities, as well as the entities themselves. Worlding is the practice of creating relations of life in a place and the place itself" (p. 291). She further contends that worlding, "or ways of making worlds" (De la Cadena, 2015, p. 4) creates pluralistic worlds, not mere hybrids, and thus positions the dominant and subordinate to exist simultaneously. Implicit here is that the world as it has been built is not a single, universally agreed-upon vision; rather, the built world is contested. To see the world as it has been built implies also examining how our values are upheld or ignored in world-making.

Recognizing world-making is thinking about how our worlds have been (or are) built. The role of engineering in world-making is visible in the examination of infrastructures as technologies. Winner's (1980) notion of artifacts as political contends that engineered technologies can uphold or perpetuate ideologies. Drawing on Winner's framework, we conceptualize pedagogical practices that support young learners in engaging with urban infrastructures in local contexts. Engineers, like Salvador in the lyrics to "Trópico de Cáncer" (Café Tacvbo, 1994) play a key role in realizing the made worlds of nation-states. Our built worlds are not accidents. They were constructed by people for specific visions of development and modernization that have social, political, ecological, and economic dimensions worth examining. Even when unintended, the technologies of engineers are not value neutral because they have consequences (Miller, 2021). The infrastructures themselves, through their places and uses in our built worlds, contain deep-rooted ideologies we can teach our students to evaluate. Whether built ten, 100, or many more years ago, infrastructures comprise not just the physical structures themselves but also the legacies or ghosts of their architects and the architects' politics and the worlds they participated in making (Graham, 1996). Just as we know that young children are capable of understanding and reasoning scientifically, so too are they capable of considering the ethical dimensions of the science they learn and practice (Eshach & Fried, 2005). By supporting students in seeing the world as it has been built, we contend that science class can create opportunities to ask *should we* questions in ways that position students to conceive and enact present and future worlds that are more just, ethical, and ecologically sustainable (Bang, 2020). The next two sections address how urban infrastructures provide an opportunity to engage students with the politics of artifacts and also with the NGSS SEPs.

URBAN INFRASTRUCTURES AS SITES OF LEARNING

In our city, as in many others, train tracks, highways, and other urban infrastructures separate neighborhoods. Viaducts are urban infrastructures that allow pedestrian and automobile traffic to continue uninterrupted below trains or highways, and thus provide an opening, a gateway, between

the divided communities. The hyper-segregation of our city was driven by red-lining and restrictive covenants, but it is structured by the built world, including train tracks, highways, and viaducts. Transportation structures throughout our city divide neighborhoods by race and class. As illustrated in Figure 1, Aguila sits on one side of a series of viaducts with freight train tracks in a neighborhood known as City Field. Decades ago, City Field was known as a hotbed of white supremacy and racial hostility but now is demographically split almost 50/50 between Black and Latinx residents. On the other side of the viaducts is New Field, a working-class neighborhood that has transitioned from a community of various European and Middle Eastern immigrants to one of almost exclusively Latinx residents over the last three decades. There is no way to get from New Field to City Field without walking or driving under the viaducts. Aguila's attendance boundaries include the west end of City Field and the adjacent east end of New Field. The resulting composition of the student body reflects the area immediately surrounding the school and is 95% Latinx and 4% Black.



Figure 1. Aerial view of the freight train line and the two neighborhoods it divides. The viaducts, labeled in red, are located every two blocks beneath the train line tracks

The freight railroads on top of the viaducts running through Greater Field (the area encompassing both New Field and City Field) form part of the infrastructure connecting various industrial corridors in our city. Railroads and viaducts are an important aspect of the modernization that Salvador lamented in the lyrics to “Trópico de Cáncer” (Café Tarvbo, 1994). Indeed, these structures have been instrumental in colonization and exploitation. They are physically and symbolically central to claims of manifest destiny that drove westward expansion of the United States to colonize Indigenous lands and recolonize a huge swath of México in 1848. The execution of engineered public works projects of building railroads for shipping industrial goods, which enriched the capitalist barons who financed the westward expansion, has historically been based on the presumption that workers were exploitable and dispensable. Throughout the construction of transportation infrastructure in the United States, industry took precedence over human life, the preservation of Indigenous lands, and ecological concerns—confirming that the ideologies of capitalism and settler colonialism undergird urban landscapes (Porter & Yiftachel, 2017). In one prominent example, in 1877 police killed dozens of protesting workers in “the battle of the viaduct,” an incident that was a part of the first nationwide strike in the United States (Smith, 2020). Indeed, contestations over private property, public responsibility, and ecological harms remained salient and were an impediment to the Aguila viaduct project, as described below.

Our attention to the viaducts was originally related to the paint peeling off their ceilings and walls and littering the sidewalks and streets around them (see Figures 2 and 3). This decaying paint was not merely an eyesore; from our involvement in the YPS collective, we knew that paint manufactured before 1978 was likely to contain the toxic heavy metal lead. Leaded paint has been most dangerous indoors, where young children, who are most vulnerable to its effects, are more likely to ingest paint chips or contaminated dust by crawling or playing on the floor and putting their hands in their mouths. In this case, we were concerned about neighbors tracking paint chips from the viaducts on their shoes into their houses. We were concerned that the chipping paint would continue to contribute to the high background levels of lead that are found in most urban soils as the result of pollution from leaded gasoline and other industrial products. We worried that city workers might sandblast the viaducts to remove graffiti, which would send particulate lead dust into our neighborhood air.



Figure 2. Decaying paint peels from the walls and ceilings of viaducts



Figure 3. Sidewalks are littered with paint chips from dilapidated viaducts

SEPS TO ANALYZE BUILT WORLDS

With Alejandra, students engaged in the NGSS practice of *planning and carrying out an investigation*. Specifically, they designed a data-collection plan to determine whether the decaying viaducts were contributing to lead contamination in the surrounding environment. As former high school chemistry teachers, we used our knowledge of laboratory safety along with guidelines from experts in the YPS collective to arrange for students to safely carry out their plans to collect samples of soil and paint from the ground around the viaducts. Students wore nitrile gloves and used garden spades to collect samples in plastic bags and removed their disposable gloves and thoroughly washed their hands immediately after sampling. Rather than disturbing paint clinging to the structures, students took samples that were lying on the ground, like the paint chips shown in Figure 3. One weekend, we independently brought a ladder to collect samples of peeling paint directly from the ceilings of the viaducts ourselves, as adult community members. A chemist from the YPS collective arranged for the samples to be analyzed for lead in her university laboratories. Aguila students took a field trip to the campus to hear directly from the chemists who analyzed the samples and to see the laboratory instruments. They also took a campus tour and ate lunch in a student dining hall.

The analysis of the samples collected by students showed background levels of lead in the soil that are typical for urban environments and well below state thresholds for requiring any kind of environmental remediation. The paint chips collected from the ground seemed to be mostly composed of recent layers of paint with minimal lead. But the peeling strips we collected directly from the ceilings of the viaducts were composed of lead-based paint from before 1978. Alejandra shared these results with her class as raw data to facilitate a sense-making discussion. Here SEPs were combined with civic reasoning as students were asked to use their analysis to write a letter to Councilwoman Cervantes, the neighborhood's municipal representative.

Taking up this authentic investigation with students compelled us to deal with uncertainties inherent in doing science in a way that we viewed as supporting students' complex reasoning (Manz & Suárez, 2018). During the data-analysis discussions, one of the students, Ramona, conducted independent research about the specifics of lead paint policy. She found that the United States Consumer Product Safety Commission set the limit of lead in paint at 90 parts per million (ppm). Ramona went on to determine a ratio (170:1) to compare the amount of lead in the ceiling paint samples with this limit. An excerpt from Ramona's own letter to Cervantes shows how she used this ratio to advocate for the remediation of the viaducts:

We need you to do something about it. According to the research we did, the limit for lead is 90 parts per million. What we got back from the 2 samples we sent to [the university] was not 90 parts per million at all. One of the samples came back as 15,455 parts per million and the other 18,259 parts per million ... These results are more than 170 times the limit.

While Alejandra engaged the class in the NGSS SEPs of *analyzing and interpreting data*, Ramona wove this practice together with others like *using mathematics and computational thinking and engaging in argument from evidence* to advocate for environmental remediation on behalf of her community. She used these practices to create a powerful tool for students to use in thinking about the problem. Almost half (11 of 23) of the student letters to Councilwoman Cervantes in that classroom cited Ramona's ratio as evidence.

Ramona's use of the ratio connected scientific evidence with civic reasoning in the context of civil engineering artifacts and hyper-local urban neglect. It led to student questions about how chemicals are regulated and who is responsible for building and maintaining infrastructures. These lines of questioning underscore how the SEPs of *asking questions and defining problems* are not neutral or objective practices. As biologist Mary O'Brien (1993) argues:

Asking certain questions means not asking other questions, and this decision has implications for society, for the environment, and for the future. The decision to ask any question, therefore, is necessarily a value-laden, social, political decision as well as a scientific decision. (p. 706)

The questions scientists ask and the ways engineers define problems have ramifications for the types of worlds that are built. Thus students of engineering, at any level, should be encouraged and supported in learning not just problem-solving but also problem-scoping—asking questions to define “the nature and boundaries of a problem” (Watkins et al., 2014, p. 43).

As students began to ask more critical questions, they became interested in having people in power do something about the dilapidated viaducts with toxic peeling paint. Alejandra mobilized this engagement to implement a process for synthesizing students' writing into a collective class letter. During this time, Alejandra encountered Cervantes, who was door-knocking in the neighborhood near the school. This meeting was serendipitous, but it only occurred because Alejandra lived in that community. She got the councilwoman's direct contact information, emailed the class letter, and soon secured a date for Cervantes to visit Aguila. Meanwhile, students rehearsed their presentation in class and at a conference organized by the YPS collective for students doing similar projects around the city.

The students' presentation provided another opportunity to view the practices of engineering through ethical and ideological lenses. For his part, another student, Carlos, took up the question of why lead was added to paint and used online research to create a slide for the presentation (see Figure 4). Carlos's slide correctly indicates that chemical engineers took advantage of lead's properties to formulate durable paints, but it does not include the information that chemical engineers were also well aware of lead's toxicity when they developed those paints. Lead-based paints continued to be produced for decades and were even marketed for use in children's bedrooms, although those paints were known to be toxic (Markowitz & Rosner, 2013). The viaducts with toxic peeling paint illustrate how the values of engineers shape our world. World-making begins with considering how the world in which we live was constructed. Freire and Macedo (1987) famously referred to this process as *reading and writing the world*.

Why is lead in paint?

Lead was added to paint so...

- the paint can dry faster
- to increase durability
- keep the paint fresh
- resist moisture.

The paint was used in cribs, in houses and buildings and the lead was spread through the air and has made people sick. Lead is a highly toxic metal.

If your home was built before 1978, there is a good chance it has lead-based paint.












Figure 4. Slide prepared by Carlos for the presentation to the Greater Field City Council representative

THE CILANTRO DESIGN CHALLENGE

The examples of Ramona and Carlos’s work illustrate that students used NGSS SEPs to prepare to speak with Cervantes about the reasons to remediate the contaminated peeling paint on the viaducts. In our work with the YPS collective, we previously struggled to connect some civic science projects to the NGSS. Unlike the SEPs, the disciplinary core ideas of the NGSS were not well aligned with environmental justice issues (Morales-Doyle et al., 2019). One solution to this misalignment was to engage students in learning about the mechanisms through which the scientific instruments could precisely measure environmental contamination. An inductively coupled plasma atomic emission spectrometer (ICP-AES), the instrument employed by our university partners, cost tens of thousands of dollars and require hours of training to operate, even for graduate students or professors. Our partnerships enabled us to buy simpler, more affordable instruments designed for use in high school classrooms (visible spectrophotometers). These simpler instruments rely on the same scientific principles as the more sophisticated instruments, so the YPS collective designed a series of laboratory activities where students could use the spectrophotometers as a model of how the university instruments work.

Having worked for years as a high school chemistry teacher, Alejandra believed that it was possible to modify this series of activities to make them developmentally appropriate for sixth graders. In the previous school year, students’ use of the spectrophotometer (see Figure 5), and their classwork affirmed that they were able to describe some of the procedural and technical functions of the instrument. For example, Karina wrote the following end-of-the-year reflection about what she learned by working on the first iteration of the project at Aguila:

The way the spectrophotometer works is you have to plug it into your computer and download a(n) app that tells you the data of your sample so then you turn on the spectrophotometer and wait for it to warm up afterwards, put in your sample and then it will give you the data.

She went on to describe some of the scientific principles undergirding how the spectrophotometer “will give you data” by writing, “different substance(s) absorb different wavelengths of light because maybe they have some kind of connection.” While Karina’s writing demonstrates an impressive recall of the functionality of the instrument, Alejandra believed that given more opportunities, students could develop even more sophisticated understandings. While some of Karina’s classmates literally referred to the spectrophotometer as a “black box,” critical engineering education resists this tendency to treat technology as devices that simply “give you data.” The goal in year two was for the students to be able to explain to Cervantes how they knew that the lead in the peeling paint exceeded legal limits.

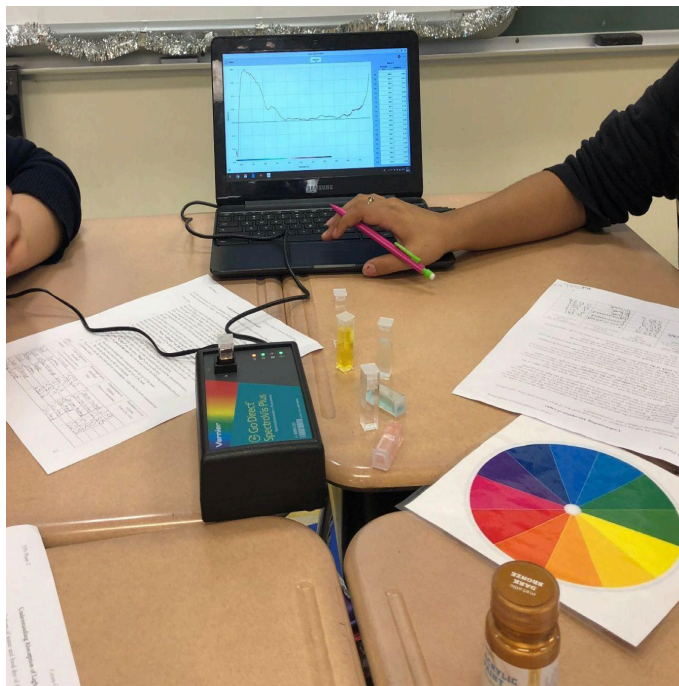


Figure 5. Students working with the spectrophotometer during the first year of the project

Driven by a belief in her students’ ability to understand complex scientific phenomena and inspired by an Advanced Placement chemistry activity authored by another member of the YPS collective, Alejandra designed an additional learning activity to serve several purposes: (a) to provide students additional practice using the spectrophotometer and interpreting data from it; (b) to help students conceptualize how an ICP-AES works, as a spectrophotometer does, to identify the presence and concentration of different heavy metals in environmental samples; and (c) to make culturally sustaining connections between Aguila students’ heritage and the science they were learning. In the YPS collective, we had previously had several conversations about cilantro’s ability to clean soil. Alejandra’s own ancestral ties to México further motivated making connections to research there about cilantro’s ability to remove metal contaminants. After locating a source that was developmentally appropriate and relevant, Alejandra assigned students a magazine article about a collaboration between Mexican and US researchers in the Tule Valley, near Mexico City (Sifferlin, 2013). The article describes how, after testing several local plants for their bio-absorbent properties, the research team began engineering water filters with cilantro to address heavy metal contamination in the valley. This progression from experimenting with the properties of cilantro to using it to design solutions to problems illustrated the relationship that the NGSS articulate between science practices and engineering practices.

After the students read the article, Alejandra gave them a challenge: to design and build filters, using cilantro, that were capable of partially decontaminating a sample of water that contained copper ions, and then test their prototypes. Like several other experiments, this activity used a copper compound as a proxy for toxic heavy metals because it is safe to work with and has a visible blue color when it dissolves in water. Figure 6 shows an example of a student design. Students tested the effectiveness of their filters by using the spectrophotometer to measure the amount of copper ions in their water before and after it passed through their cilantro filter (see Figures 7 and 8).

Promoting science learning that presents the “excellence, thoughts, and contributions” from the Global South requires an intentional disruption of who is given credit for being scientific (Frausto Aceves et al., 2022, p. 219). The cilantro design activity was also an opportunity to call attention to international scientific collaborations in general and to collaborations with scientific communities in México in particular. Cilantro is an ingredient familiar in Mexican cuisine, but it is not Mexican in origin. Rather than making crude or tokenistic connections to students’ heritage, this activity expanded the examples of STEM innovations beyond those made in laboratories or in wealthy countries in the Global North and beyond human-designed technologies, separate from nature. Alejandra also introduced students to floating gardens in Mexico City, known as chinampas, that are an example of ingenious Indigenous engineering and sustainable permaculture. Chinampas illustrate engineering that literally *le da lugar a los espacios sin cemento* (gives a place to spaces without cement), in one of the largest cities of the world. This example disrupts notions of engineering as synonymous with modern development by highlighting engineering that relies not only on formal science, but also on traditional wisdom—wisdom that, like formal science, has an empirical basis. The chinampas example considers other ways in which peoples have engaged with the natural world and designed solutions to problems. As teachers integrate more SEPs into their curriculum, it is important to attend to *other ways* of understanding and building worlds because our ideologies of human-nature relations are embodied in what we build (Bang et al., 2015).

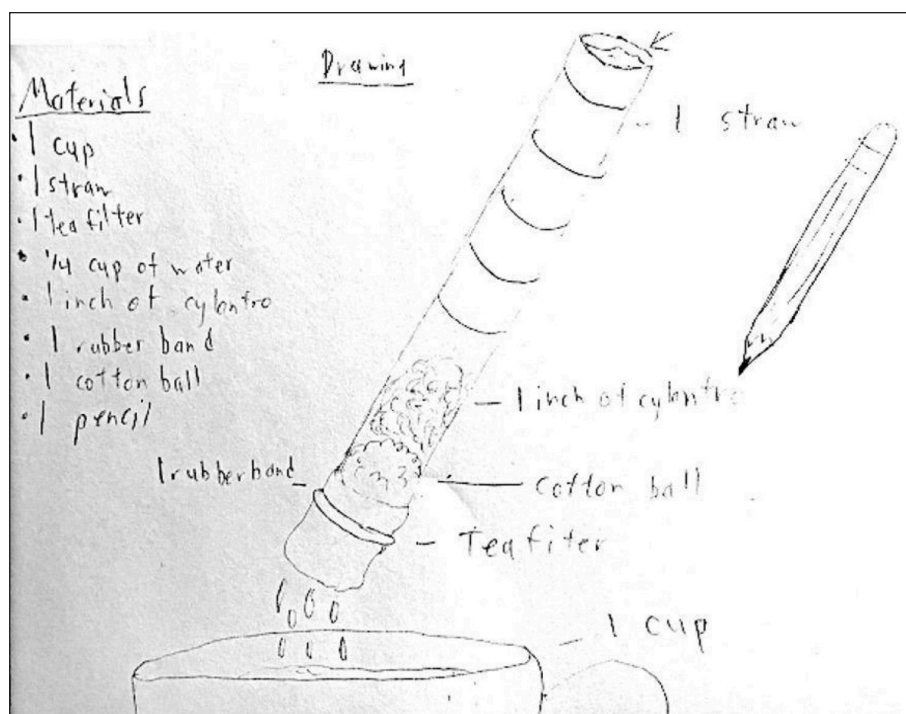


Figure 6. Cilantro filter prototype



Figure 7. Student using a pipette to add the filtered solution into the cuvette for analysis

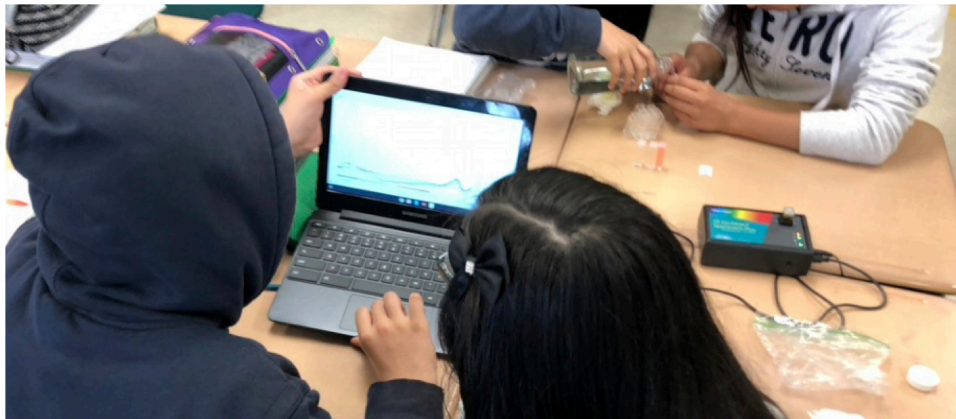


Figure 8. Students interpreting the graph produced by the spectrophotometer

Ultimately, students decided not to include an explanation of how the instruments worked in their presentation to the elected official. We have some evidence that several students did not fully connect the dots, suggesting the need for more explicit or scaffolded coherence between the cilantro design challenge and the viaducts project (Reiser et al., 2021). For example, in a conversation with Daniel, Carlos explained that while the viaduct project was real science, the cilantro design challenge was just for fun. In some sense, Carlos is right: cilantro filters are not a solution to the contamination of the viaducts, and Alejandra did intend the activity to be fun. At the same time, the cilantro design challenge was also intended to support students' understanding of their methods of measurement in the viaduct project, and Carlos's comment indicates that perhaps that connection was not clear.

MORE THAN CIVIC REASONING WITH SCIENTIFIC EVIDENCE

Cervantes visited Aguila on a warm sunny day in early June, near the end of the school year. The students' presentation started with infographics about lead that were designed for community members to learn about possible lead contamination in places like pipes and in products like juices, cosmetics, toys, and candy. Students then spoke about the viaducts, drawing particular attention to the ratio that Ramona had calculated and to Carlos's explanation about why lead was used in paint. They demanded that the viaducts be safely remediated by the city. Even more than that, they provided a vision for the beautification of the remediated viaducts, proposing that Aguila students create and paint murals under the viaducts after the peeling paint was removed. Their proposal is captured on the slide they created (see Figure 9). Their presentation combined SEPs like *engaging in argument from evidence* and *using mathematical and computational thinking* with explicit values of community environmental health, beauty, and important cultural symbols. The adjectives they included in the slide ("safe; inspiring; nice; by us") express the students' values and were referenced during the presentation to argue for our community's right to safe and decorated viaducts instead of those we currently have, pictured on the top right of the slide. The photos also reflected an aesthetic associated with particular social movements in México and in Mexican and Chicana communities in the United States: a portrait of Frida Kahlo, an Indigenous woman's face, and the "huelga bird" flag of the United Farm Workers. Even the emphasis on public art, in the form of murals in city spaces, reflects a particular set of values about public space and the appearance of urban infrastructures.



Figure 9. Students' proposal to the Greater Field City Council representative

Cervantes listened attentively as students spoke and praised their work. She was kind and respectful, but almost as soon as they finished talking, she also began to explain why their vision might not be achievable. Her primary excuse was related to capitalist and settler colonial notions of the distinction between public and private property. The paint chips were falling on a public sidewalk but, Cervantes

noted, they were falling from a private structure which belonged to the railway corporation. She insisted that she could not remediate private property and would, instead, communicate our findings to the corporation. She left students with a hopeful message but made no promises. As adults with some experience in community-led efforts for environmental justice, we were immediately skeptical, angry, and frustrated. But fortunately, students were more hopeful and proud—feelings we encouraged them to embrace. After the presentation, Daniel asked Carlos, “What do you think will happen? Do you think Councilwoman Cervantes will do anything?” Carlos responded, “She said she would try to help us by communicating to the railroad tracks so they can do it. I feel like she is just going to send the people to do it but they have to ask permission from the railroad, from them, it’s their property, so yeah.” Carlos went on to describe how he was proud of his work, reflecting, “I got to present to the councilwoman. I had fun during this project and I learned a lot more stuff.” He thought of his involvement as practice for his future career, saying, “It felt nice because my dream is to be a scientist, so this is, so if you practice something you like since you’re little, like people that play soccer, they practice since they were little, and then now they are in the big leagues, that’s what I mean.” In addition to viewing the project as preparation for a career in STEM, Carlos later explicitly expressed that the values of professional scientists included caring for their communities.

OUR RESPONSIBILITY AS ADULTS IN CIVIC ENGAGEMENT AND WORLD-MAKING

Alejandra recently ran into Carlos, who now attends the neighborhood high school. He asked about the project and whether we had heard back from the councilwoman. Since Cervantes’s visit to Aguila, Alejandra has continued to press her to remediate the viaducts properly. In one conversation, she asked the councilwoman why the city covers or removes graffiti from viaducts but does not feel obligated, or even able, to remediate the lead-contaminated paint. Cervantes’s response was to ask for evidence that all of the viaducts, not just the one where we sampled ceiling paint, were contaminated. It is likely, from a historical and scientific standpoint, that all of the viaducts, which were built in 1929, were part of the public works created by civil engineers for the built worlds of industry and city infrastructure. It is also exceedingly likely that they were all coated in lead-based paint.

The councilwoman’s stalling tactic demonstrates the potential downsides of using scientific evidence together with civic reasoning (Morales-Doyle et al., 2022). While students used evidence convincingly to argue for the remediation of the viaducts, we were met with requests for *more* evidence. But why was the burden of proof placed on a group of sixth graders or even on community members? Why were city officials or railway executives not responsible for collecting the evidence themselves?

Since we did not trust the city to fulfill that responsibility or to otherwise follow up on the evidence we had provided, and since we had access to the scientific means for collecting data, we sought more evidence ourselves. We put together a small group that included one of the scientists from the YPS collective; one of her undergraduate students, who had grown up near City Field; a teacher from the YPS collective who works at the neighborhood high school at which most Aguila students (including Carlos) matriculate; and a staffer from the councilwoman’s office. As a group of concerned adults, we spent a summer morning collecting paint samples from each of the viaducts along a half-mile stretch of road that separates City Field from New Field.

As we composed this manuscript, we simultaneously wrote a community-facing report documenting the high levels of lead we found in each of our samples from the ceilings, which has since been released. Some of Alejandra’s students are now reengaging with this project in their high school chemistry class

with the teacher from the YPS collective who collected samples with us in our small group. The railroad corporation promised they would collect samples again within the following month but refused to inform community representatives about its process until the corporation completed its analysis. The ideologies of capitalism and distinctions between privately and publicly owned infrastructures continue to shape the ways in which we interact with the physical structures in our neighborhood. Yet we remain hopeful that the viaducts will be safely remediated and ultimately adorned with art by neighborhood youth. Unlike hypothetical story lines that get wrapped up nicely at the end of a culminating assessment, our struggle continues.

DISCUSSION

As STEM-mania and associated school reforms push engineering education into the curriculum for young children, many K-12 teachers feel unprepared to meet these demands (Banilower et al., 2018). A deficit view of teachers would lead to policy prescriptions for required engineering courses in teacher education and for more professional development in STEM. But we choose to foreground teachers' assets. Viewing urban infrastructures as sites of learning provides an entry point to celebrate the best characteristics of elementary and middle school classrooms where each student is viewed (w) holistically as a unique human being in relationship with their environment (Patterson & Gray, 2019). This contrasts with the ways engineering education perpetuates a culture of disengagement that often dichotomizes older students between those who will be future members of the STEM workforce and those who should be weeded out from that career path (Cech, 2014). Teachers who view their work as supporting children's self-actualization are well positioned to engage students in considering what values are embedded in SEPs and eventually encoded in the built world.

We recognize this moment as a chance to avoid reproducing the pathologies of engineering education that has not been attentive to the values, ideologies, and politics that underlie it. It is time to stop teaching science and engineering in ways that do not ask students if we *should* do something or that falsely assume that ethical implications are not a part of scientific reasoning. Will we take this opportunity to break away from "that ugly relationship of action, construction, [and] destruction" that pushed Salvador *el ingeniero* away from his profession (Café Tacvba, 1994, stanza 7, lines 3–4)?

We emphasize that the story we share here is not meant for reproduction in other classrooms. It is deeply contextualized in ways that make this impossible. Instead, we hope that examples like the photovoice activity, the cilantro design challenge, and the connection to chinampas inspire teachers to be creative and attuned to SEPs as one among many rich ways of knowing. The broad ways in which the NGSS frame engineering leaves space for positioning students as world-makers. Problem-posing pedagogy can support students in understanding how the present world was constructed without binding them to the pathologies of industrial development and its underlying ideologies of racism, colonialism, nationalism, and capitalism (Benjamin, 2016; Freire, 1970). When we, as adults, were cynical about Cervantes's response, Carlos, Ramona, Rocio, and their classmates remained proud of their work and hopeful about its impact. Students can develop clear-eyed, contextual views of their built worlds and realistic expectations for the role of scientific evidence in civic reasoning without becoming cynical. By creating experiences that develop capacities for analysis and critique that ask youth to consider *should we* before we ask *how*, while leaving space for speculative imagination and hope, we create education for ethical innovators and visionary world-makers, not just proficient engineers (Garcia & Mirra, 2021; Tzou et al., 2021).

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