Chapter 12
Mechanistic Reasoning In-School Versus Mechanistic Reasoning In-Life

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12.1 Introduction

Recent reforms in science education have centered our field's attention on the need to move beyond accumulation of science knowledge and toward engaging in scientific practices (Schwarz et al., 2016; The National Research Council, 2012). The idea—now nearly universally accepted in standards (NGSS Lead States, 2013), curricula (Cooper & Klymkowsky, 2013; Shwartz et al., 2008), and assessments (National Research Council, 2013)—is that students need to know not only what scientists know but also what scientists do to construct that knowledge. Underlying this idea is the assumption that if students can construct and critique knowledge in the way that scientists do, then they can be successful at navigating issues of a scientific nature that emerge in their daily lives (The National Research Council, 2012).

One scientific practice that has received substantial attention in the literature is that of developing and using models (Passmore et al., 2014; Schwarz et al., 2009). The Next Generation Science Standards (NGSS) describes this practice as a way to make sense of scientific phenomena, processes, or relationships (NGSS Lead States, 2013). For example, to explain why they can smell paint at a distance, students might construct and use representations of particles traveling from the paint bottle to their nose. Inherent in NGSS's view of models is the notion that these models are causal—they describe scientific phenomena in terms of how one object or process leads to a change in some other object or process.

To highlight the causal nature of modeling, here we explore the related scientific activity of mechanistic reasoning. Russ et al. (2008) proposed that mechanistic reasoning is an important part of school science in that it allows students to draw on

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their existing resources for causal reasoning to build robust accounts of phenomena consistent with those constructed by professional scientists. In that work, the authors defined mechanistic reasoning as made up of a variety of steps from Describing Target Phenomena, to Identifying Entities and their Properties, to Chaining together multiple steps in a causal process.

In the time that has elapsed since Russ et al. (2008)‘s definition of mechanistic reasoning, many scholars have explored student capabilities for such reasoning (Dood et al., 2020; Russ et al., 2009) and designed curricula and classroom practices to support it (e.g., Bachtiar et al., 2021; Cooper et al., 2016). This and related work on mechanistic reasoning tacitly assumes that such reasoning is inherently valuable. Underlying this assumption are two justifications. First, mechanistic reasoning is inherently good because it resembles the way scientists reason about the physical and natural world (Glennan, 2002; Machamer et al., 2000; Westfall, 1986). Second, as Russ (2014) argues, it is good irrespective of what scientists do because it is a productive way to construct knowledge about the world around us (Ahn & Kalish, 2000; Koslowski, 1996). The latter argument echoes claims elsewhere that science education prepares students to reason about science in their everyday lives (Rudolph, 2023; The National Research Council, 2012).

In this chapter, we unpack the latter assumption about the value of mechanistic reasoning in school science. Specifically, we question the claim that mechanistic reasoning in-school prepares learners for mechanistic reasoning in-life. Instead, we suggest that mechanistic reasoning as it has been defined in the literature, and realized in classrooms, does not resemble how individuals and communities productively construct knowledge in their everyday lives.

12.2 Flint Water Crisis

To contextualize our arguments, we focus attention on the Flint water crisis that began in 2014 and continues to affect residents of Flint, Michigan. Specifically, we will contrast school activities contextualized by the crisis in Flint with ways in which members of the Flint community constructed and critiqued mechanisms to hold state regulators accountable. To enable this discussion, we must first sketch the contours of the Flint water crisis.

12.2.1 The Water Switchover

Prior to 2014, Flint received its water from the Detroit Water and Sewer Department (DWSD). The DWSD drew water from a massive nearby lake (Lake Huron) and treated this water at a plant near the shoreline. Treated water was then pumped through a series of pipelines to the people of Flint. Water from the DWSD was both safe and expensive. Flint was the farthest flung of the communities the DWSD served, and the DWSD charged more for delivering water further distances. The city, saddled with managing ancient and sprawling infrastructure with decreasing tax revenue, was motivated to find a cheaper source of water (Clark, 2018).

The Karegnondi Water Authority (KWA) was billed as an answer to Flint's water cost woes. The KWA would pump raw water from Lake Huron to the communities it served, and this water would be treated at local plants. Moving to KWA-supplied water was sold as a cost-savings measure and approved by both the emergency manager and city council. However, the KWA was merely an idea in the mid-2000s; no pipes were yet constructed and it would be several years before the new infrastructure was ready to distribute lake water to Flint and surrounding communities (Clark, 2018). Additionally, Flint's local water treatment plant had been idle since the 60 s and needed re-tooling to treat raw lake water. Renovations to this treatment plant, according to Flint's utilities administrator at the time, would take some time (Fleming, 2018). Flint was not ready to treat and distribute raw water.

Despite the misgivings of Flint's utilities administrator, the decision was made to temporarily draw raw water from the nearby Flint River, and treat it locally, rather than continue to make use of the DWSD's service while KWA infrastructure was built. In the spring of 2014, Flint shut off the water supply from the DWSD and began using river water (Clark, 2018).

12.2.2 Toxic Water

Flint residents soon began noticing something off about their water. Bethany Hazard, a retired cancer survivor, noticed that water from her tap seemed murky and foamy. She elected to buy bottled water rather than consume what flowed from her faucet. Lathan Jefferson contacted the Environmental Protection Agency (EPA) office in Chicago to report rashes he believed were due to changes in his water. These experiences were common enough that local news reported, approximately a month after the water switchover, that residents were "avoiding the tap" and "drinking bottled water instead" (Clark, 2018, p 33).

As it happens, there was a serious problem with the water in Flint in the summer of 2014. The new water treatment program implemented by the city did not include corrosion control. The Michigan Department of Environmental Quality (MDEQ) told staff at the treatment plant that such measures were not necessary at the present time (Flint Water Advisory Task Force, 2016). Corrosion control keeps the metal pipes in America's vast water infrastructure from degrading. Specifically, chemical species such as orthophosphates react with metals in pipes to form a mineral-like crust that prevents the pipes from leaching metal into the water. In the absence of corrosion control, metals like lead are able to dissolve in water flowing through the pipes and be distributed to residents all over the city (Clark, 2018).

Lead is a well-known toxin that is especially harmful to children. It accumulates in teeth, bone, and soft tissues and can cause a broad spectrum of issues (e.g., brain swelling, anemia, abdominal pain, kidney failure, reduced attention spans, seizures, coma; Clark, 2018). There is no safe level for lead in water. As such, when it was found that LeeAnn Walter's water contained alarmingly high levels of lead, and that members of her family had correspondingly high concentrations of lead in their bloodstream, concern was more than warranted. Over 270 samples from around the city, carefully collected by residents of Flint in collaboration with researchers from Virginia Tech, showed that LeeAnn's experience was not an aberration. Samples had an average of 26.79 parts per billion of lead in them, nearly three times the safety standard set by the World Health Organization (10 ppb; Clark, 2018). The highest tested sample came in at 1051 ppb (Edwards et al., 2015).

This is the crux of the Flint water crisis, which poisoned a city and took heroic efforts from the Flint community, tenacious reporters, and collaborating scientists to resolve (at least insomuch as the crisis is resolved). We will discuss the ways in which mechanistic reasoning was used by members of the Flint community to legitimize their experiences in Sect. 4. First, however, we turn to school science, which has produced a number of chemistry activities contextualized by the Flint water crisis (e.g., Buckley & Fahrenkrug, 2020; Terry, 2017; Yu & Linden, 2022). In unpacking one of these activities, we ask: what aspects of mechanistic reasoning does this activity communicate as most valuable? We will then explore how/whether mechanistic reasoning emphasized in school maps onto mechanistic reasoning engaged in by members of the Flint community.

12.3 Mechanistic Reasoning in-School

The Flint water crisis—with its contested knowledge about chemicals both in the water from the pipes and in the bodies of members of the surrounding community—seems to be precisely the sort of science that people encounter in their daily lives for which science education could be useful. It shares several features with topics like climate change or vaccination that are often cited as socio-scientific issues that science education can prepare people to solve. Specifically, like climate change or vaccination, the Flint water crisis involves a relatively limited amount of scientific knowledge and is seen as inherently interesting because it has a substantial impact on how people live and thrive (or not) in the world. Given these features, it is not surprising that the American Chemical Society's ChemMatters magazine states that:

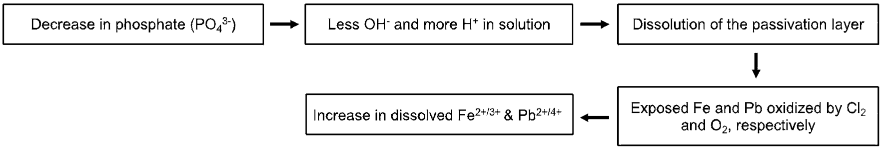
> Through knowledge of chemistry, including the formation of precipitates, the pH scale, and the redox chemistry of half-reactions, scientists were able to solve the Flint water mystery. The crisis was stopped before it became worse, and Flint's water supply was made safe—all thanks to chemistry. (Dingle, 2016, p 8)

This quote suggests that it is chemistry knowledge—precisely of the sort that can be taught and explored in school science classrooms—that "saved the day" for the residents of Flint. As a result, it implies that if lay people could just understand and engage in science *as it is taught in school* then they could solve problems such as this in their lives.

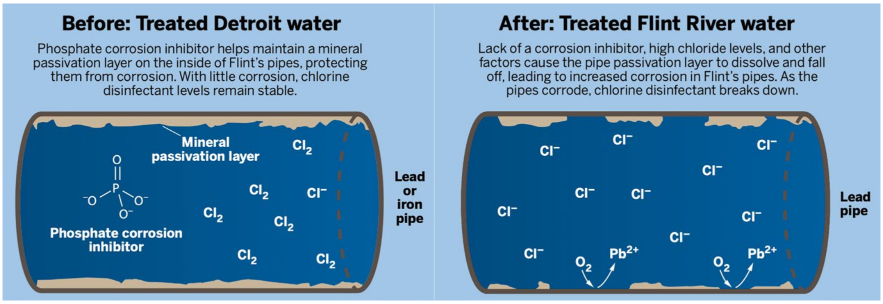
Given claims like the one above, it is not surprising that several different school activities have been designed around "solving" the Flint water crisis (Buckley & Fahrenkrug, 2020; Terry, 2017; Yu & Linden, 2022). To see what sorts of science learning students engage in during these activities, we focus our attention on a high school chemistry lesson meant to introduce the topic of chemical reactions (Terry, 2017). We chose this lesson because it encourages students to engage in mechanistic reasoning to support their understanding of the Flint water crisis. The features of school mechanistic reasoning we pull from this lesson are shared by other high school and college chemistry lessons contextualized by the crisis in Flint (e.g., Buckley & Fahrenkrug, 2020; Yu & Linden, 2022).

Students are meant to begin learning about chemical reactions in the context of the Flint water crisis by reading their textbook and a news article about the chemical processes involved in the contamination of Flint's water due to corrosion in the metal pipes (Torrice, 2016). In the lesson, students are led through exercises and content about various types of chemical reactions and solubility rules. They are then given a variety of compounds that were present in the Flint water pipes and water both before and after 2014 and asked to predict the precipitates for the different chemical reactions that occurred.

With all of this chemical knowledge, students are then asked to reason mechanistically by balancing chemical equations and assessing the relative amount of different compounds present in the water. In the language of Russ et al. (2008)'s coding scheme for mechanistic reasoning, students identify several *entities* involved in the process including PO_4^{3-}, Pb, OH^-, Fe, and Cl_2. They are further asked to reason about the *properties of those entities*—namely their net charges, and associated ions. These entities and their properties are *organized* in differing relative amounts inside the pipe and water that flowed through it. Finally, students *chain* those entities with those properties in that organization together using solubility, solution pH, and electron exchange as the *activities* to produce the following mechanism, where "→" means "leads to":



Images of the stages in this mechanism (what some might call models) are presented both in the lesson and in the news article (Terry, 2017; Torrice, 2016). Those images (see Fig. 12.1) show students the entities and organization as well as the processes by which lead entered water from the pipes in Flint after 2014.



Before: Treated Detroit water

Phosphate corrosion inhibitor helps maintain a mineral passivation layer on the inside of Flint's pipes, protecting them from corrosion. With little corrosion, chlorine disinfectant levels remain stable.

After: Treated Flint River water

Lack of a corrosion inhibitor, high chloride levels, and other factors cause the pipe passivation layer to dissolve and fall off, leading to increased corrosion in Flint's pipes. As the pipes corrode, chlorine disinfectant breaks down.

Fig. 12.1 Snapshots of a mechanism explaining high levels of lead in Flint water. (Reprinted with permission from *Chemical & Engineering News,* copyright © 2016 the American Chemical Society. This article was first published on Feb. 11, 2016 in volume 94, issue 7)

By understanding this mechanism and making predictions about its outcome, students are directly shown how the water in Flint became toxic and harmful to its residents. In doing so, this lesson represents a robust way to integrate chemistry and mechanistic reasoning into the exploration of the injustice of the Flint water crisis.

However, what we also see in this lesson is that the mechanistic reasoning about chemistry that students do is only valued insofar as it is correct. The questions at the end of the lesson (e.g., What led to the dissolution of the passivation layer, exposing of the metal (Pb and Fe) pipes?) ask individual students to select mechanistic answers (e.g., If X, then Y) but they are only given credit for those answers if they match the canonical mechanism presented in class. This suggests an "all or nothing" approach to mechanistic reasoning in which any deviation from normative mechanistic connections indicates that students fail to understand the chemical reactions that led to the Flint water crisis. As its designers describe:

> The goal [of this lesson] is to have students learn how to identify [oxidation/reduction, acid/base, and precipitation] reactions and understand their importance in a real-world setting with significant consequences. (Terry, 2017)

This quote demonstrates that the goal here is to center the content of chemistry—the various rules and reactions that gave rise to the problems in Flint. While the designers certainly encourage the use of mechanistic reasoning to understand that content—the content itself is what is most important in the lesson.

We propose that, although this lesson asks students to engage in sophisticated mechanistic reasoning (as defined by Russ et al. (2008)) about a socioscientific issue, its ultimate goal of having students reach canonical correctness through canonically correct (and pre-specified) mechanistic components limits its potential for supporting students in using mechanistic reasoning in their daily lives. Specifically, this lesson allows individual students to reason about only a very narrow set of *entities*, *properties*, *organizations*, and *activities* that are provided by the teacher. Only those mechanistic components introduced by the teacher or the reading are available for students to consider in their mechanistic reasoning. Students have no agency in investigating or determining possible mechanistic components to include. Further, that reasoning occurs in the service of understanding something that has already been determined by an authority.

Given that this lesson supports a relatively constrained form of mechanistic reasoning in which students attempt to match their knowledge to existing, established knowledge, we can ask ourselves whether and how that type of reasoning might be useful for explaining something in daily life for which the answer is not known. We suggest that this pattern-matching-style mechanistic reasoning does little to prepare students to grapple with complex and often unbounded problems such as those faced by the community in the Flint water crisis. In what follows we articulate how the Flint community grappled with mechanisms and demonstrate that this grappling bears little resemblance to the kind of pattern-matching students engage in during this lesson.

12.4 Mechanistic Reasoning In-Flint

The concerns about water safety voiced by LeeAnn Walters, Lathan Jefferson, and many other Flint residents were not initially taken seriously by those with authority. Contrary to what the ACS and the examined school activity suggests, stringing together science facts into a normative mechanism often does not immediately win the day. Here, we will describe instances where some collection of Flint residents, scientists, and authorities critiqued, negotiated, and constructed working mechanisms related to the water in Flint. In doing so, we aim to illustrate that how and why this work was undertaken is distinctly different from what is typically done in schools. Figure 12.2 shows how the events we discuss in this chapter are temporally related. This timeline is far from comprehensive. Those who would like a more complete picture of the Flint water crisis are advised to read Anna Clark's *The Poisoned City* (Clark, 2018).

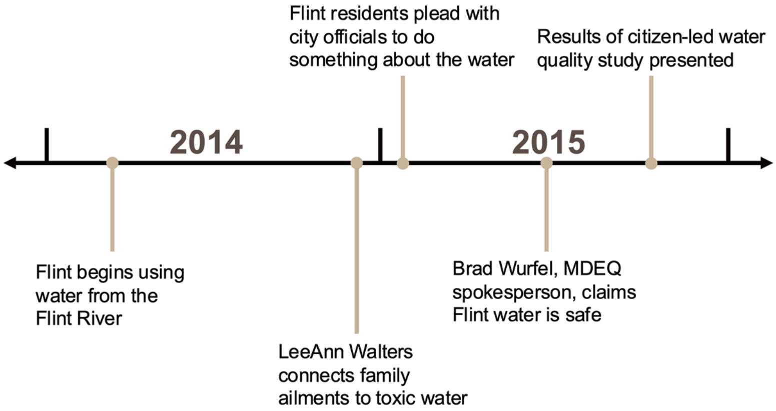


Fig. 12.2 Timeline illustrating the temporal relationship between episodes of the Flint water crisis discussed in this chapter

12.4.1 Critiquing Officials' Mechanisms

Flint residents' mechanistic reasoning started with considering the reasonableness of official mechanistic accounts. State and local officials in Flint claimed that water taken from the Flint river and treated locally was just as safe as Lake Huron water treated and transported by the DWSD (Clark, 2018). This suggests that the composition of water from the two sources is similar (and similarly safe) at the tap. Mechanistic reasoning underlying official claims would be something like: water flows from a natural source to a treatment plant, harmful things are removed and good things are added. This water is then distributed via pipes to various sectors of the city and does not appreciably change during this journey—the pipes do not add or subtract anything of consequence from the water as it flows through. One can then safely consume and use this water.

Two phenomena are the focus of mechanistic reasoning of this sort: water treatment (i.e., removing bad things and adding good things), and water transit from the treatment plant to the tap. In both cases, we can think about lower-scale entities involved (or not) in the phenomenon—these include water particles, particles of good or bad things (which become better specified as the crisis unfolds), and particles that make up the various pipes that comprise Flint's water infrastructure. These entities might take part in a variety of activities—they might be removed (bad particles), added (good particles) or be unaffected by the passage of water (pipe particles). Coordination of entity activities in a particular direction lets us "run" the mechanism (i.e., chaining).

By early 2015, many Flint residents were not buying the tacit mechanism underlying official claims of water safety—these claims were inconsistent with residents' lived experiences. For example, LeeAnn Walters began observing rashes on herself and her family shortly after the water switchover. These became worse over time. By fall of 2014, a whole host of ailments beset the Walters family, including hair loss, cognitive impairment, and abdominal pain. LeeAnn began connecting these symptoms to the water when, near Christmas, brown water started spurting from her tap (Clark, 2018). At around the same time, city officials notified residents that water contained unsafe concentrations of carcinogenic trihalomethanes. This notice stated that steps were being taken to fix this problem at the local treatment plant and "this is not an emergency" (City of Flint, 2015). Despite these official assurances, it was becoming clear to many Flint residents that *something* had changed about the water coming from their tap. In the language of mechanistic reasoning, we could say that the residents chained backwards from their health problems, to the water, to the pipes and infrastructure that held and moved the water.

The people of Flint told those in power about the issues with their water. For example, at a rowdy meeting in January 2015, residents demanded that the city's emergency manager account for the brown, toxic water flowing into their homes. These concerns were summarily dismissed. LeeAnn got city officials to inspect her water only after she presented a doctor's note about how badly her immune-compromised son was reacting to the water. The results of this inspection showed extremely high levels of lead and iron in the water. Rather than use this as evidence to revise their tacit mechanism of water treatment and transport throughout the city, officials constructed an alternative mechanism and attributed LeeAnn's issues to faulty indoor plumbing and agreed to replace the service line that connected her house to the water main (Clark, 2018). The implication here was that LeeAnn's issues were a one-off and the water infrastructure overall was basically fine.

12.4.2 Epistemic Injustice

The January 2015 meeting in city hall is an example of when city officials undermined residents' credibility as knowers and shapers of knowledge. Stated differently, we might say that interactions at this meeting were instances of epistemic injustice (Fricker, 2007). Rather than use residents' lived experiences as an outcome that required drastic changes to their existing mechanism and an impetus for widespread investigation of Flint's water quality, officials opted to dismiss concerns as uncredible—LeeAnn recalls the emergency manager telling her the brown water in the bottle she brought was, "not your water." If some subset of knowers in a community are regularly silenced, that community may "develop epistemological resistance in that these communities do not allow the knowledge and ideas of those perceived as 'non-knowers' to shift the collective perspectives and understandings" (Miller et al., 2018, p 1068). Those with power clearly developed epistemological resistance to the residents of Flint; although the residents appropriately questioned the mechanisms being presented to them, officials rejected their concerns.

Epistemic injustice is a consistent thread throughout the Flint water crisis. Time and again, those with authority undermined community members' status as knowers. In response to the epistemic injustices they experienced, residents collaborated with scientists and journalists to refine and elaborate on their mechanistic accounts—with the goal of having their lived experiences recognized and legitimized by those in power. Therefore, a mechanism was useful if it led to further investigations and, ultimately, to changes in water quality. Stated more generally, mechanistic reasoning during the Flint water crisis was undertaken with the goal of civic action, not for the purpose of matching some predetermined, expert-like drawing on an answer key.

The different goals motivating mechanistic reasoning in-class and in-Flint are likely to manifest in different ways of thinking and acting. Students engaged in the high school activity mentioned earlier would revise their reasoning only if their knowledge product conflicted with the authority-defined answer. By contrast, Flint residents continued to revise their own mechanism (e.g., by further specifying properties of entities, by checking consistency with available evidence) until it served to persuade authorities there was a crisis that demanded immediate action. We illustrate this sort of mechanism refinement below with a concrete example of residents collaborating with Virginia Tech scientists.

12.4.3 Elaborating Mechanisms for the Purpose of Legitimizing Lived Experiences

Let me start here—anyone who is concerned about the lead in the drinking water in Flint can relax.

Brad Wurfel, Michigan Department of Environmental Quality spokesperson, July 2015 (Clark, 2018, p 118)

In mid-2015, city and state officials buttressed their claims that "everything is fine" with the results of a 169-sample test of lead levels across the city. These tests showed an average lead level of 11 ppb, which is within acceptable limits. There were many issues with this study, including omission of two data points showing high lead levels, the practice of pre-flushing water lines prior to testing, and concentrating sampling around areas with newer water infrastructure (Clark, 2018). Additionally, claims made by officials were not consistent with the lived experiences of Flint residents like LeeAnn Walters.

To investigate the reasonableness of the official "everything is fine narrative", Flint residents built connections with scientists who had experience investigating drinking water safety. Supported by a grant from the National Science Foundation, Marc Edwards of Virginia Tech and his graduate students worked with the Coalition for Clean Water—a community advocacy group formed in 2015—to collect and analyze hundreds of water samples from around Flint. The testing protocol used in this study remedied many of the issues with the earlier city tests. For example, lines were not pre-flushed, water was to be collected from the cold tap at high flow, and multiple samples were collected from each site. Analysis of 277 community-collected samples revealed an average of 26.79 parts per billion of lead—almost three times the WHO safety standard (Clark, 2018; Edwards et al., 2015). Contaminated water was found throughout the city, validating the residents' understanding that LeeAnn's experience was not a one-off.

The results of the Virginia Tech study allowed Flint residents to elaborate their mechanistic accounts of how their water became toxic. "Good things" (i.e., corrosion control) were not added as part of water treatment and so "bad things" (i.e., lead, iron) were able to leach into the water. There are a few key characteristics of the resident's mechanistic reasoning that are worth highlighting here. First, this reasoning was not an individual activity but rather one that involved a community of concerned residents making connections with knowers whose expertise was thought useful to that community (Virginia Tech scientists). This is what Feinstein and Baram-Tsabari would call "curating an epistemic network" where an "epistemic network" is "a set of people who support sensemaking by providing new information and by aiding in the interpretation and reconstruction of scientific knowledge in context" (Feinstein & Baram-Tsabari, 2024, p 2050). Second, the purpose of elaborating the community's mechanistic account was to prompt action from those with authority. Specifically, members of the Coalition for Clean Water sought a return to the DWSD water supply. A mechanism achieved its purpose if it moved officials toward taking meaningful action.

12.5 How Can We Support (Potentially) Useful Mechanistic Reasoning?

We claim that, to support learners in using mechanistic reasoning in their post-school daily lives, mechanistic reasoning emphasized in-class should more closely resemble mechanistic reasoning useful in-life. That is, student communities should construct and critique mechanisms for reasons that are sensible beyond the bounds of the classroom. We suspect few would disagree with this intuitively plausible premise. Unfortunately, many standards documents (NGSS Lead States, 2013), curricula, and research projects (Dood et al., 2020) emphasize a vision of mechanistic reasoning in which individual students are to string together science facts and pictures to construct normative mechanisms for the purpose of pleasing the teacher. This sort of activity is meaningfully different from the ways in which communities construct and use mechanisms to promote just outcomes. Specifically, as we see in the cases of Flint residents' mechanistic reasoning, communities tend to construct and critique mechanisms over days, weeks, or months to gain traction on a goal that matters to them. A particular mechanism, and how/whether it maps onto what a professional scientist might construct, is not "the point" of such reasoning. Flint community members continued to refine their mechanisms until meaningful action was taken.

Although our argument has focused chiefly on how a community reasoned mechanistically, we acknowledge that a person may also employ mechanistic reasoning to address more-or-less individual questions or concerns. For example, an espresso machine technician might construct, and critique causal mechanisms related to scale buildup in solenoid valves to diagnose and repair a broken machine. There are likely to be important differences in what constitutes productive individual and community mechanistic reasoning, and how school might support such reasoning. Unpacking these in-detail is beyond the scope of this chapter. However, whether we aim to support individuals in making traction on their goals or communities in affecting policy change, our work should be informed by empirical accounts of people using mechanisms in real-world contexts. We should not assume that connecting science facts in an "expert-like" way to please an authority will somehow benefit individuals or society.

So how might we make formal learning spaces that enable reasoning such as what we saw among Flint residents? While acknowledging there are no simple answers to this question, here we put forward three design principles synthesized from relevant literature. Learning spaces with the potential to support mechanistic reasoning useful in-life should: (1) engage students in work rooted in the concerns/interests of their communities, (2) open space for students to grapple with complex, uncertain problems to which no obvious “right answer” exists, and (3) communicate the potential value of a variety of ways of knowing and learning. We briefly sketch each of these design principles below:

Our first design principle follows from the argument that students should engage in mechanistic reasoning for a purpose that is sensible and/or useful to them and their communities. That is, the motivation to construct mechanistic accounts cannot simply be, “I want to better understand this science concept because I (or more likely, my teacher) think it is interesting in its own right.” While this sentiment might seem benign, many scholars have argued that decontextualized science learning upholds the Western modernity narrative that scientific knowledge exists outside of time, place, and culture (Bang & Medin, 2010; Popkewitz, 2022), and that all science represents progress (Morales-Doyle, 2024; Sanchez, 2023). Teaching students to view science as objective, universal, and neutral directly diminishes our capacity to develop socially, civically, or environmentally responsible students. Instead, Sanchez (2024) proposes that we connect science learning to “matters of consequentiality—sociopolitical and socio-ecological concerns facing and impacting students’ communities, pasts, presents, and futurities” (p. 130). Morales-Doyle (2024) recommends that we teach science as a “catalyst for alternative futures” by orienting learning around social justice science issues (p. 149). While it is no small task to identify issues that are consequential to our students, or to center curriculum around these issues, we believe this is key to making mechanistic reasoning useful and valuable outside of a school setting.

Our second design principle is derived from the observation that mechanistic reasoning is often most useful when grappling with complex, uncertain scenarios where there is no obvious or known “right answer.” For example, LeeAnn and other residents of Flint built and refined mechanistic accounts, in part, to manage “complexity, confusion, or doubt” (Dewey, 1910, p. 12; Engle, 2011) encountered when considering (mis)alignment between official accounts and lived experiences. Doing so let this community focus attention on the activities of specific entities in order to understand their experience and advocate for infrastructural changes. If we want classes to see mechanistic reasoning as a useful way of managing uncertainty, then class activities need to be structured around making sense of messy, uncertain phenomena, such as the adverse health effects experienced by the people of Flint. It is likely that classes will not have the time or expertise to arrive at an elaborated, canonical explanation for such phenomena. However, so long as we are focused on the utility of mechanistic reasoning itself and not fixated on “right answers,” incomplete/partially working mechanisms are not a problem. Indeed, one could persuasively argue that, to the extent we use mechanistic reasoning in daily life at all, we are often working off of (over)simplified mechanisms that domain experts would take issue with. This is fine for most people most of the time.

Our third and final design principle is an attempt to foreground epistemic justice (Fricker, 2007) in how we imagine useful in-class mechanistic reasoning. Specifically, we claim that epistemically just engagement in mechanistic reasoning requires that classes adopt an expansive perspective on what and whose knowledge counts (Bang & Medin, 2010; Bang & Vossoughi, 2016). In practice, this means that learners should experience authority to negotiate criteria for useful mechanisms, including what knowledge should inform mechanistic accounts. Such a class would not impose a canonically correct knowledge product as the only or best mechanism. Indeed, there may be occasions in which mechanisms that diverge from a Western scientific understandings are experienced as useful by the class. For example, one could imagine a useful mechanism in which the class worked to understand how and why the Flint river became sick and what might be done to make this waterway well. Past scholarship has shown that de-settling Western perspectives on life and non-life can open new and powerful approaches to meaning-making (Bang et al., 2012). As such, exploring what makes a river unwell may be a generative approach to constructing mechanisms that support civic action. An epistemically just classroom would celebrate a mechanism of this sort and treat Indigenous knowledge (as well as other knowledge traditions) as powerful and valid.

Overall, these three principles are designed such that content and canonical ways of reasoning should not be experienced by the class as goals unto themselves. Instead, specific knowledge and ways of reasoning should be experienced as potential tools (Russ & Berland, 2019) that can help communities understand and possibly take action on issues that affect them.

In closing, we would like to acknowledge that supporting mechanistic reasoning that has potential utility in-life would require major structural changes to school and schooling. Collectively making sense of a local issue to advance more just social conditions is not compatible with systems designed to rank individual students according to who mimics "experts" with highest fidelity. Curricular, assessment, and interactional messages about what and whose knowledge counts (Russ, 2018) would have to shift from "knowledge is justified by aligning with an authoritative source" and "class is the only useful source of knowledge" toward messages like "knowledge is justified by peer consensus" and "knowledge from a variety of sources, including lived experience, is useful here." Much theoretical and empirical work remains to be done before we can claim we are supporting mechanistic reasoning that is useful in daily life.

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