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Case Study Pedagogy in Disaster Education

Integrating Knowledge While Cultivating Epistemic Reflexivity

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Abstract
Research in cultural anthropology and the interdisciplinary field of science and technology studies (STS) has demonstrated that environmental disasters are not only techno-scientifically and socio-politically complex but also epistemically complex -- involving perspectival diversity; multiple, often conflicting forms of evidence; data gaps and disinformation; and role transitions and confusions. Disasters, this research has demonstrated, are highly fraught knowledge problems that nevertheless call for pragmatic response. In this article, we describe an approach to disaster education that stems from this premise, mobilizing an Environmental Injustice Case Study Framework that draws out multiple dimensions of disaster, foregrounding the need for interdisciplinarity while immersing students in the challenges and paradoxes of disaster knowledge production. We offer both an instructional approach and a theoretical perspective on what case study pedagogy in disaster education accomplishes, and can contribute to science education writ large. Our argument is that critical approaches to case study pedagogy can scaffold many kinds of learning in both disaster and science education, helping students integrate diverse kinds of data, analysis, interpretation, and judgment, while building metacognition and epistemic reflexivity.

1 Introduction

We have come to anticipate that many students in our undergraduate course, "Environmental Injustice," will, early on, be frustrated, even angry — because their assignment to build a case study of environmental injustice in a particular place is overwhelmingly complex, and — in some elements — impossible, because they cannot locate the information called for. This signals to us that the course goals are being met: students see for themselves that disaster knowledge is far from straightforward. The course shares with students many cases of environmental injustice and many concepts, data resources, and types of analysis needed to make sense of these cases. In doing so, the course draws students into critical thinking

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about disasters as knowledge problems, in process building their reflexivity about knowledge writ large.

The latter, we have learned, cannot be accomplished simply by telling our students that knowledge, especially knowledge about environmental disasters, is complicated and contested; they need to experience this hands-on. We scaffold this by mobilizing a ten-question Environmental Injustice (EiJ) Case Study Framework that guides the use and integration of distinct types of data and analysis to produce place-focused characterizations of environmental disasters. The framework extends both from anthropological research on environmental disaster and injustice in many settings, and from sustained engagement with the theories and practices of science and technology studies (STS), critical pedagogy, and case study pedagogy.

The framework supports analysis of the combined effects of three kinds of environmental disasters -- fast (requiring emergency response), slow (resulting from slow, cumulative pollution) and combo (occurring when hazards exacerbate each other, as when extreme weather increases the likelihood of toxic chemical leaks).

Our anthropological research has demonstrated that disasters — especially environmental disasters — are not only techno-scientifically and socio-politically complex, but also epistemically complex. Data detailing the impacts of disasters is always incomplete and reflects the bias of the organizations with the authority and resources to generate data, for example. Disaster data is also politically contested, reflecting different perspectives on what happened, why, and what should be done in response. Further, disasters involve many kinds of failures (of communication, transportation, and water supply systems, for example) and call for many kinds of action (water delivery, provision of trauma support services, and enhanced protections against gender violence, for example).

Understanding and responding to disasters thus require *cultural analysis*, alongside other kinds of analysis (Fortun, 2021). Cultural analysis recognizes that the ways people experience and understand problems, from their situated vantage points (as low-income residents, first responders, or city officials, for example), shape not only the experience of those problems, but also the shape of the problems themselves. Understanding and responding to disaster also calls for especially intensive epistemic reflexivity — recognizing both the many limits of knowledge and the many ways knowledge can be translated into action.[1]

In this essay, we describe an approach to disaster education that stems from this premise, mobilizing the EiJ Case Study Framework to draw out multiple dimensions of disaster while immersing students in the challenges of disaster knowledge production. We ask: How can case study pedagogy contribute to disaster and science education? In response, we offer both a practical approach and theoretical perspective on what case study pedagogy in disaster education — and in science education more broadly — can accomplish. Our argument is that critical approaches to case study pedagogy can scaffold many kinds of learning in both disaster and science education, helping students integrate different kinds of data, analysis, interpretation, and judgment, while building metacognition and epistemic reflexivity.

We first developed and began using the EiJ Case Study Framework (see Fig. 1, below) in a large social science general education course for undergraduates at the University of California Irvine. Since then, we have also used the EiJ Case Study Framework in high

[1] On the value of cultivating epistemic reflexivity among teachers, see Feucht et al. (2017).

1. What is the setting of this case? What are its assets? What opportunities and challenges will there be in this setting in coming years?
2. What environmental hazards are there in this setting, what is their source and what are their effects on the environment, health, and inclusive prosperity?
3. What intersecting factors -- social, cultural, political, technological, ecological -- contribute to environmental health vulnerability and injustice in this setting? What has produced historic disadvantage?
4. Who are the stakeholders? What are their characteristics, and what are their perceptions of the problems?
5. What have different stakeholder groups done (or not done) in response to environmental problems in this setting?
6. How have environmental problems in this setting been reported on by media, environmental groups, companies, and government agencies? Where has there been data divergence?
7. What local actions would reduce environmental vulnerability and injustice in this setting?
8. What extra-local actions (at state, national or international levels) would reduce environmental vulnerability and injustice in this setting and similar settings?
9. What kinds of data and research would be useful in efforts to characterize and address environmental threats in this setting and similar settings? What could be learned from qualitative research?
10. What intersecting injustices -- data, economic, epistemic, gender, health, infrastructure, intergenerational, media, procedural, racial, reproductive -- contribute to environmental injustice in this setting?

Fig. 1 Environmental Injustice Case Study Framework

school courses and research internship programs, in graduate seminars, and in adult community education. It also has become a critical frame for our ongoing research as cultural anthropologists.

In the first section that follows, we share how we have moved from research on environmental injustice across many settings to work in both critical and case study pedagogies. In the second section, we unpack the Environmental Injustice Case Study Framework, describing how we mobilize it in practice, reaching for diverse learning outcomes. Our conclusion highlights the "double movements" that case study pedagogy enables in disaster education — supporting explanatory pluralism and knowledge integration, while also foregrounding the epistemic paradoxes and limits of constituting "the case."

2 From Research to Critical and Case Study Pedagogy

Connecting research and teaching has long been recognized as both valuable and a challenge — and linked to the challenge of connecting research to action in institutions like the World Health Organization and the United Nations Office for Disaster Risk Reduction (United Nations, 2015). The urgency of addressing these challenges has been demonstrated

repeatedly in our own research, deeply motivating us to build bidirectional pathways between our research and teaching, and between knowledge and action. In short, we have come to see our teaching as an opportunity to prepare students for the work that we have learned that disasters call for — helping them develop both expertise relevant to disasters, and sustained reflexivity about disaster expertise, knowledge, and action. We recognize that this is not pedagogically straightforward so have engaged extensively with the theories and practices of both critical and case study pedagogy to support our efforts. This section describes these entwined endeavors.

2.1 Disasters Through the Lens of Anthropology and STS

There is a long tradition of disaster research in cultural anthropology, which foregrounds both the historical production of disasters and the ways disasters both expose and often re-entrench social hierarchies and structural violence (Fortun, 2001; Faas & Parreno, 2024; Farmer, 2004; Henry, 2011; Oliver-Smith, 1996; Taddei, 2019; Vaughn, 2012). Extended ethnography in disaster contexts, often working alongside especially vulnerable social groups, has been a key method. Disasters — and the failures of disaster mitigation, preparedness, and response — have been documented in gritty detail, showing, for example, how people with the most limited economic resources often have more trouble than others accessing the economic resources needed for disaster recovery. Anthropologists have also shown how a seemingly helpful concept like "resilience" can come to license abandonment of communities impacted by disasters (Barrios, 2014) and how even such a basic concept as "community" is variably understood and enacted in disaster contexts — and almost always contested (in the determination of who gets disaster relief, for example) (Hsu, 2016; Vaughan, 2014).[2]

Importantly, cultural anthropologists have worked with — and extensively debated the parameters of — ethnographic case studies, aware that they risk particularism at the expense of knowledge about patterns across cases (Yates-Doerr & Labuski, 2017). At their best, ethnographic cases are deeply particularistic, while also inviting comparisons and the development of generalizable knowledge. It is through a "thick description" of places, people, and their interactions that ethnographic insight is built (Geertz, 1973) — framed by and pointed toward other cases. A signature aspect of ethnographic cases of disaster is the provision of both emic and etic perspectives, at multiple scales.

Emic perspectives are the perspectives of the people studied — whether people impacted by disaster, or those responsible for disaster prevention, response, and long-term recovery. Etic perspectives seek to explain emic perspectives — describing, for example, how structural disadvantages, disciplinary frameworks, and entrenched social hierarchies shape the perceptions of differently situated people in disasters. This double-vision — examining both emic and etic (insider and outsider) approaches — both deepens holistic understanding of disaster and foregrounds their epistemic complexity.

STS enriches anthropological approaches to disaster research by extending attention to involved technical systems (and their failures) and to the kinds of knowledge produced and mobilized by experts of many kinds (including community experts). STS researchers have

[2] In describing disaster studies in anthropology and STS, we do not suggest that the type of analysis we attribute to them is only done in these fields. Our point is to convey the genealogies within which our work is situated.

Table 1 Epistemic reflexivity disaster education needs to cultivate

Research on environmental disasters and injustice in many settings points to the need to develop many types of epistemic reflexivity. Students need to build capacities to recognize: • Both the biases and value of different forms of expertise and knowledge • How knowledge embodies and enacts power • How places and disasters are both unique and productively comparable • Multiple stakeholders, and their experiential and perspectival diversity • Multiple, often conflicting forms of evidence (quantitative and qualitative) • The value of both insider and outsider perspectives on places and communities • (Sometimes purposeful) data gaps • Vested interests and the disinformation that often follows • How disasters often lead to role transitions and confusion, requiring people to think on their feet and innovate • Many forms of reparative action, and the ways different forms of knowledge can legitimate and direct action

studied, for example, how and why experts establish building and fire codes and how their reasoning changes over time (Knowles, 2013). STS researchers have also foregrounded what produces inattention, ignorance and "undone science"(Goldstein, 2017; Hess, 2015), explicating how established educational programs often reproduce knowledge silos (Park, 2020), how jurisdictional tangles can obscure sources of environmental harm (Howey & Neale, 2023), and how action to address one problem (HIV, for example) can distract attention from other problems (Benton, 2015). Environmental disaster, STS researchers have made clear, produces both toxic chemicals and "toxic truths" (Davies & Mah, 2020; Tirrell et al., 2020).

Our own disaster research in different settings — across California, on the US Gulf Coast, in post-Fukushima Japan, and in India in the wake of both the 1984 Union Carbide chemical disaster in Bhopal and the exceptionally hazardous air pollution in Delhi — has been situated at the nexus of cultural anthropology and STS, enabling us to produce detailed, theoretically framed and conclusive accounts of disasters that highlight how disasters are knowledge problems (Adams, et al., 2023; Fortun, 2001, 2012; Negi & Srigyan, 2021).

Disasters, we have found, are knowledge problems because they are produced through the interaction of many kinds of systems (geomorphic, ecological, socio-technical, political-economic, etc.), each requiring specialized knowledge to understand (Fortun, 2012). We also have found that disasters cascade across time, confounding ways disasters have often been conceptualized and responded to as relatively discrete "events" (Fortun et al., 2016). Our most frustrating finding has been the recurrence of disinformation in the wake of a disaster, often introduced by actors seeking to downplay their own responsibilities. Failure to recognize the knowledge challenges of disaster, we have observed, often exacerbates disasters, and their uneven effects on different social groups. Extensive epistemic reflexivity is urgently needed (see Table 1).

2.2 Disasters and Education — Critical and Case Study Pedagogies

Our research on environmental disasters and injustice has been sobering, while also prompting us to build especially tight ties between our research and teaching. We envision our students as next-generation disaster researchers and practitioners, working in many

fields, at many scales. One way we support our students is by sharing with them many case studies of environmental disaster and injustice drawn from our research and that of colleagues. Moving students through many different case studies — highlighting human dimensions and both variation and patterns across them — has proven an effective way to call them into concern about environmental disasters.

Preparing students for engagement with disasters cannot, however, be accomplished only through the building of new knowledge. It also requires the cultivation of new ways of thinking about knowledge, power, and the ways knowledge embodies and exercises power (Foucault, 1980). For this, critical pedagogy is crucial.

Critical pedagogy recognizes that students are often encultured *not* to see their own environments and associated harms -- partly because they experience their environments as "normal" and partly because there are many factors and forces propelling them into disbelief, cynicism, and resignation. Critical pedagogy also emphasizes that students' capacity to know themselves and their problems can be cultivated by providing them with analytic tools, case material to think with, and opportunities for dialogic exchange with people both similar to and different from themselves. In this, critical pedagogy aligns with "explanatory pluralism" (Keller, 1995), a concept foregrounded by feminist STS researchers to unsettle claims that there is one (right) way to see problems and answer questions.

Student-centered approaches to education lean in the same direction as critical pedagogy but often miss crucial aspects. Unlearning, for example, is as important as learning in critical pedagogy and is recognized as difficult to accomplish (Britzman, 2017). Students are socialized and caught within tangles of oppressions — based on class, race, gender, and educational attainment, for example, and on the privileging of "hard sciences" and generalizable knowledge over local, particularist knowledge garnered through interpretation rather than measurement.

Critical pedagogy also emphasizes that knowledge and expertise are double binds (Bateson, 1960). Double binds occur when two simultaneous values or instructions conflict — as when budding experts are encouraged to invest in and be proud of their expertise, even while being encouraged to recognize that their expertise is limited and needs to be supplemented with expertise of other kinds. As we show below, critical case study pedagogy enacts just such a double bind, helping students build and demonstrate expertise, while also experiencing the limits of expertise. We do this by reworking case study pedagogy by interlacing it with critical pedagogy.

2.3 Case Study Pedagogy Across Domains

Case study pedagogies facilitate movement between theory and practice in many fields (for extensive reviews across disciplines see Merriam, 1985 and Brown, 2008). In some disciplines, they even become a "signature pedagogy" (Shulman, 2005), mobilized to socialize students into professions like business and management (Contardo & Wensley, 2004; De Wilde et al., 2010; Merseth, 1990; Swiercz & Ross, 2003), law (Carter & Unklesbay, 1989; Kimball, 2021; Matsuura, 2021), and medicine (Bowe et al., 2009; Irby, 1994; Servant-Miklos, 2019).

Even though the definition, design, and instructional goals of case studies may differ (Lundberg et al., 2001), case study pedagogy often cultivates many skills: problem recognition and problem-solving (Jonassen & Hernandez-Serrano, 2002), interpretation and perspective-taking (Vinney et al., 2019), complex decision-making (Bagdasarov et al., 2013), knowledge transfer between disciplines (Thiel et al., 2013; Turk et al.,

Table 2 Guiding pedagogical questions

1. How can we *concern* students with both environmental disaster and science?
2. How can we *prepare* students for the combined techno-scientific, socio-political, and epistemic challenges of disaster?
3. How do we *scaffold* appreciation for both quantitative and qualitative data, and both particularistic and generalizable knowledge?
4. How do we *inspire* students to pursue knowledge about disasters, while also teaching them about the swirl of disinformation, bias, and ignorance that disaster knowledge always takes shape within?
5. How do we *build* students' confidence as disaster analysts, in ways strengthened — rather than undermined — by deep epistemic reflexivity and humility?

2019), and collaborative learning (Khosa & Volet, 2013), among other practical and metacognitive skills (Dutton, 2003). When applied to disaster education, case study pedagogy is reported to enhance the transfer of knowledge across contexts, facilitate executive decision-making, support crisis and trauma counseling (Aluisio et al., 2016; Greene et al., 2016; Slick, 2019), and reveal non-causal and non-linear links between cascading disasters (Feng & Xiang-Yang, 2018; Wang et al., 2020).

There are, however, important criticisms of case study pedagogy. Contardo and Wensley (2004), for example, write that while the case study model of the Harvard Business School advanced problem-based learning and case-based reasoning, it also reproduced ideas about American capitalism, institutionalism, and managerialism. Sprain and Timpson (2012) write that while case studies advance rigorous contextual knowledge, they often confine learners within the boundaries of the cases. This relates to the criticism that knowledge generalizations beyond the individual case are hard to arrive at through case studies (Corcoran et al., 2004; Slick, 2019).

In the next section, we describe how our development and use of the EiJ Case Study Framework integrates the pedagogical tactics described above — building on but also reflexive about case study pedagogy itself.

3 Mobilizing the Environmental Injustice (EiJ) Case Study Framework

We first developed and taught with the Environmental Injustice Case Study Framework in 2018, in a large (300+) undergraduate anthropology course, "Environmental Injustice" at the University of California Irvine. The course fulfills general education requirements so attracts students across disciplines. In the course, we introduce students to many cases of environmental disaster and injustice, in settings around the world. We also organize students into research teams (of about ten students) in which they develop their own case studies of environmental disasters and injustice focused on diverse settings across California. In designing the course, an initial goal (among others; see Table 2) was to help our students build and see the value of interdisciplinary approaches to problem characterization and response, highlighting the value of social science integration.

Since then, we have adapted the EiJ Case Study Framework for many audiences and contexts. We have taught the framework in interdisciplinary graduate seminars and run related training sessions for STEM graduate students and postdocs preparing for community-engaged research. We have adapted the approach and teaching material for

delivery in high schools across California, helping realize a statewide commitment to enhanced environmental education, in steps with Next Generation Science Standards (NGSS Lead States, 2013). We have also brought our approach into curriculum development for adult members of a community-based environmental justice organization and into an after-school science academy (for upper elementary, middle school, and high school students) that we coordinate for that organization.

In this section, we first unpack the EiJ Case Study Framework, highlighting how the framework is a knowledge integrator, a framework for comparison, and an animator of epistemic reflexivity. We then describe how we involve students in hands-on work with the framework, teaching them how to use a suite of analytic approaches ("sketches" that students work through, often in groups) that simultaneously build their analytic capabilities and their awareness of what analysis depends on, accomplishes, and can fail to accomplish. In the third segment, we describe the pedagogical power of having students write case studies themselves. In the fourth segment, we describe how we strive to build student reflexivity about case studies, disasters, and knowledge writ large.

3.1 The Environmental Injustice (EiJ) Case Study Framework as Knowledge Integrator and Comparative Framework: Reading Across Cases

Environmental injustice results from many factors and dynamics, including historical disadvantages, inadequate access to health monitoring and care, and ineffective environmental regulation. Environmental injustice also results from many types of pollution, involving many types of chemicals, which harm people and ecological systems in diverse ways, through different exposure pathways. Understanding and addressing environmental injustice thus require interdisciplinary approaches.

Reducing environmental injustice is also complex, depending on pollution reduction from many sources (cars and factories, for example), on supporting laws, implemented by many different government agencies, and on the mobilization of public pressure for legal accountability and substantive change. Reducing environmental injustice also depends on public education and opportunities for different groups (workers and residential communities, for example) to be involved in decisions that impact them. Reducing environmental injustice thus depends on many types of data and analysis, on the integration of these to build holistic understanding, and on the translation of knowledge gained for many audiences (city planners, community organizations, and businesses, for example). The goal is to move from knowledge to action. The Environmental Injustice Case Study Framework is designed to support this work. In focusing the framework on environmental injustice, we emphasize that understanding and responding to injustice is far from straightforward.

In reading across cases, students travel with us to to places like Louisiana's "Cancer Alley" (where residents live alongside hundreds of petrochemical plants), to Navajo Nation (where residents live alongside over a thousand abandoned uranium mines), and to North Carolina (where there are massive hog farms, now seen as engines for renewable energy projects). All these regions are also experiencing extreme climate change impacts.

The EiJ Case Study Framework helps students both zoom in on a particular place and build comparative perspective — recognizing that environmental disasters and injustice are both common and unique in the ways they take shape and play out. Questions in the EiJ Case Study Framework guide their analyses, allowing them to look at a case, and ask, "What is this a case of"? Gregory Bateson (1960) provides insight into this process

by theorizing learning as the reinterpretation of signals. According to Bateson, thought becomes stuck if mechanisms for reinterpretation are not available. Helping students use — and become increasingly at home with — a multi-factor analytic framework is thus a way to activate pathways that enable reinterpretation of received information, and continual, student-driven learning.

Instead of presenting a singular frame or categorical scheme for understanding environmental disasters and injustice, the EiJ Case Study Framework presents students with many frames and categorical schemes — each associated with one of the main questions in the framework. Through this, the EiJ Case Study Framework recognizes "explanatory pluralism" as both fact and value. Historian and philosopher of science Evelyn Keller, writing about the biological sciences and genetics, explains:,

> The central concern [here] … has been with the de facto multiplicity of explanatory styles in scientific practice, reflecting the manifest diversity of epistemological goals which researchers bring to their task. But I also want to argue that the investigation of processes as inherently complex as biological development may in fact require such diversity. Explanatory pluralism, I suggest, is now not simply a reflection of differences in epistemological cultures but a positive virtue in itself, representing our best chance of coming to terms with the world around us (Keller, 2002, p.300).

Knowledge production through explanatory pluralism and comparison widens rather than narrows what it is important to understand. For many students (and more senior researchers), this is hard to tolerate. They are deeply socialized to stay focused; prompts that encourage them to constantly bring in more layers of analysis are unsettling. No one type of scientific knowledge can answer all the questions in the EiJ Case Study Framework, and the answers, if they exist, cannot be found at the back of the textbook.

In reading across cases of environmental injustice, students repeatedly encounter dense complexity. Each case is dauntingly complex; together, the complexity is overwhelming. Learning to stay with this complexity is a key goal. This involves tolerating ambiguity, uncertainty, and even distress, which many learning theorists recognize as important learning outcomes (Banning, 2003; Rodness & Britzman, 2016). It also involves patience and confidence in the face of epistemic complexity, learning not to shut down in the face of knowledge gaps, divergences, and conflicts (Chinn et al., 2021).

Even more important is the way reading across cases of environmental disaster draws students into concern and even outrage, turning around habitual distraction and disinterest. The cases that students move through often stay with them, becoming stories that they know and tell, giving them a new vantage point for understanding the world and the possible roles they can play in it.

3.2 Analytic Sketching Toward EiJ Case Studies

The EiJ Case Study framework has ten core questions, each addressing a different aspect of environmental disaster and injustice. Further, each question in the EiJ Case Study Framework has many sub-questions, each requiring distinct types of data and many kinds of analysis. Structured research "sketches" support this work. Working on these sketches gives students the opportunity not only to learn about the EiJ Case Study Framework, but also to implement it. Sketches scaffold the researcher's work (Vygotsky, 1978), supporting interdisciplinary practice. These sketches can be done separately, focused on different cases (as

HAZARDS-TO-HEALTH PATHWAYS ANALYSIS			
POLLUTION SOURCE	**POLLUTION HAZARD**	**HEALTH EFFECTS**	**VULNERABLE GROUPS**

Fig. 2 The hazards-to-health pathway analysis helps students characterize the environmental health effects of environmental hazards

described above; in the section on reading across cases), or as a full set, focused on a particular place (as described in the following section).

Here, we will not provide a comprehensive explanation of the purpose and practice of each of the framework's ten questions — though all scaffold knowledge integration. Instead, we will highlight elements and sketches that animate epistemic reflexivity, pointing to specific sketches that integrate knowledge by prompting students to engage with diverse analytic frames.

Q1 of the EiJ Case Study Framework focuses on "setting," with sub-questions prompting descriptions of landscape, Native histories, demographics, political cultures, and community assets, among other features. Sketches supporting Q1 provide opportunities to begin exploring and critiquing data resources like the US Census and to learn how Native land acknowledgements are a response to erasure. Q1 also calls for information on what likely lies ahead in the setting focused on: hurricane or extreme heat intensification, for example, or loss of land and local control due to large-scale renewable energy projects — signaling how the place will continue to change, beyond what a case study can represent.

Q2 focuses on environmental hazards in the setting, their sources, health effects, and vulnerable groups — integrating perspectives from engineering, chemistry, biology, and public health. One sketch supporting the response to Q2 is adapted from a graphic widely used in environmental exposure assessment and public health to visually organize pathways from hazard exposures to environmental health effects (National Institute of Environmental Health Sciences, 2020). This sketch (Fig. 2) is a powerful referent in discussions about the methods available to understand environmental health harm, and the many reasons these have been controversial.

Q3 draws out factors that make people in the setting especially vulnerable to environmental hazards. In responding to Q3, students are exposed to many different indicators that directly or indirectly point to community vulnerability. Most but not all of these indicators are quantifiable. Asking students to think about the legacy effects of historic disadvantage and racism cannot only rely on metrics, for example. In answering Q3, students learn to think with both statistics and historical interpretation and about how different vulnerability indicators can help explain and address environmental injustice.

Q4 asks students to identify and analyze diverse stakeholders in environmental justice in the setting focused on. Stakeholders often include polluting businesses, workers, different government agencies, and people living, going to school, or working near

EiJ SKETCH: STAKEHOLDER POWER GRID		
CATALYSTS	**STAKEHOLDER GROUPS**	**CORROSIONS**

Fig. 3 The stakeholder power grid helps students recognize power dynamics in a setting and think about where change may be possible or difficult

EiJ SKETCH: STAKEHOLDER ACTIONS & INACTIONS		
STAKEHOLDER GROUP	**ACTION**	**INACTION**

Fig. 4 Charting stakeholder actions and inactions helps students recognize how inaction shapes problems as powerfully as action

pollution sources. In the "Stakeholder Power Grid" sketch that supports Q4 (Fig. 3), students are asked to list different stakeholder groups in the middle column. In the left column, "Catalysts," they list things that give that stakeholder group power — *catalyzing* their capacity to do and get what they want. In the right column, "Corrosions," they list things that undermine the power of that stakeholder group, *corroding* their capacity to do and get what they want. Catalysts might include wealth, reputation, knowledge, or political power. Corrosions might include lack of money or status, lack of organizational capacity, racism, or gender bias. The goal of this exercise is to draw out who has power and who lacks power — laying ground for thinking about where change might be possible, or difficult.

Q5 explores the different viewpoints and actions taken (or not taken) by different stakeholder groups (disinformation by polluting companies, for example). In one supporting sketch, students list stakeholder groups in environmental disaster and injustice in the setting they are focused on and then describe what actions that stakeholder group has taken and *not taken* (Fig. 4). Like in their explorations of available data resources for characterizing environmental injustice in a particular setting (in Q6), students learn to recognize inaction and omission as meaningful and consequential.

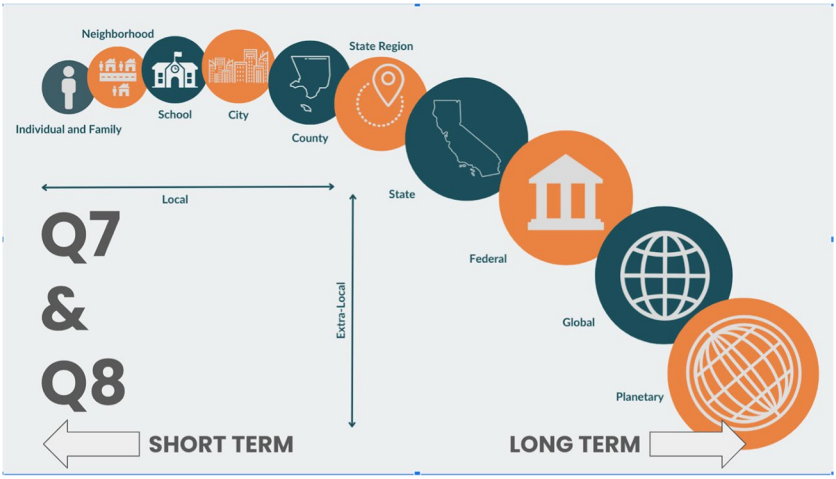

Fig. 5 We scaffold student sketching work with many learning tools such as this visual that helps students propose action at relevant scales. This visual was made by Margaret Tebbe, a member of the EiJ Teaching Team

Q6 asks students to describe ways environmental harms in the setting have been researched and reported on by news agencies, government agencies, NGO, and academics — noting where there is "data divergence" (when the same data is interpreted in different ways or different data is used in problem characterization, resulting in difference interpretations). One sketch supporting this question is simple: it instructs students to go to the Wikipedia page for the setting they are focused on. By this point, they are aware that the setting is subject to many environmental hazards and harm. Wikipedia pages often do not mention this at all.

Q6 also asks students to think back through all the other questions that they have worked to answer — recalling what information they could *not* find or make sense of. Often, they have much to share. Work to address Q3 — focused on both particular and cumulative hazards in the setting focused on — almost always provides examples. The discussion can then turn to questions about data and procedural justice (questions they return to in Q10).

Q7 and Q8 ask students to describe possible corrective actions at the local level (by households, neighborhood associations, cities, and counties) and at the extra-local level (by state and national governments, and by international organizations) (Fig. 5). Given the prompt response required during disasters, students need to move quickly from problem characterization to proposals for action and change.

Q9 asks students to identify research that needs to be done going forward to better characterize environmental hazards and harms in the setting. They are asked to propose quantitative research (having learned through other cases about air pollution monitoring, biomonitoring, and epidemiology, for example). They also are asked to develop their own proposal for qualitative research, guided by a sketch for "Rapid Qualitative Research Design." We remind students that qualitative research does not focus on something that can be measured or counted; qualitative research examines people's experiences, observations, perceptions, and social positions.

Q10 wraps the case up, providing space to draw out the intersecting injustices that combine to produce environmental injustice in the setting focused on. Q10 asks, "What

intersecting injustices – data, economic, epistemic, gender, health, infrastructure, intergenerational, media, procedural, racial, reproductive – contribute to environmental injustice in this setting"? Students might document the epistemic injustice that occurs when information about environmental hazards is only available in English, for example, when most members of impacted communities are Spanish-speaking. To address the injustice, they could propose survey research to learn both about linguistic diversity in impacted communities, about where people get their news, and about the sources of news that community members most trust.

The sketches that support work with the EiJ Case Study Framework serve many purposes. They teach questions rather than answers, helping build students' analytic capabilities and confidence. They help students move through and organize complex details and many kinds of analysis. They also make space for the unexpected, as in laboratory and field notes (Clifford 1990; Shankar, 2007).

3.3 Building Case Studies

The sketches that we have created to support work with the EiJ Case Study Framework allow students to zoom in and out, moving through various kinds of analyses to see "the case" from different angles. Importantly, through repeated engagement with the same sketch, students learn not only new content, but also about the sketch itself, and the type of analysis it supports. This, in turn, makes students more analytically independent and empowered — an important learning outcome.

Writing full case studies, individually or in a group, accomplishes something different — and poses its own difficulties. Producing a full, richly detailed case study is challenging for all researchers, especially those schooled to expect very delimited problem sets. There is a lot going on in a case study analysis, and a key part of the learning is holding it together. At its best, case study development helps students recognize and appreciate the interrelation of all elements of the case study. Building a full case study can also prompt recognition of the limits of the case study framework and about ways to reinterpret or extend its questions. This is yet another important type of learning — to pay attention to details that do not yet have a place within established epistemic frames, recognizing that those frames ("paradigms") may need to shift.

The case studies that student research groups develop are extensive, often reaching seventy or more pages, including many photographs, data visualizations, and graphics, all with explanatory captions. Case studies are evaluated (by students themselves and by the teaching team) partly through an itemized checklist that includes more than a hundred items. Managing complexity is a key challenge and goal.

Importantly, case studies — because they are "peopled" — are a way to stimulate student interest and investment in STEM as a social resource. Because they are focused — often on one place — case studies also give students the opportunity to work with many kinds of data and knowledge, appreciating how they are more than the sum of their parts. In building their cases, students move through different orders of thinking — sense-making, emplotting argument and narrative, and reinterpretation, for example.

Case studies, through the depth of engagement they allow, can also provide time and space to build student expertise and confidence. When writing their own case studies, students will come to know more about their cases than their teachers, helping them unlearn deeply entrenched hierarchies of authority. If produced collaboratively, case studies can

Table 3 Learning objectives

1. Students should be interested in and concerned about environmental disasters and injustice
2. Students should be able to identify multiple factors and dynamics that contribute to environmental disaster and injustice, integrating diverse data and forms of knowledge
3. Students should be able to draw out both similarities and differences across cases of environmental disaster and injustice, appreciating both particularistic and general knowledge, and both insider and outsider perspectives
4. Students should be able to identify and evaluate divergent data and perspectives on environmental disasters without expecting a singular, correct perspective
5. Students should gain confidence in their capacities to both analyze environmental disasters and translate complex knowledge into action pathways

also empower students by giving them experience with collective action, while also deepening their experience with explanatory pluralism.

Perhaps most important is the way case study pedagogy — if it foregrounds the *making* of the case — can build substantive expertise, capacity for interdisciplinary analyses, capacity for knowledge translation, *and* deep epistemic reflexivity — with the latter understood as the capacity to make and use knowledge without the arrogance and blindness to limitations that recurrently compromises both the production and use of science. It requires a double movement, both forward and always doubling back to reassess, and both confidence and constant questioning. This is an enduring pedagogical challenge — that case study pedagogy can be leveraged to address.

3.4 Building Case Study and Knowledge Reflexivity

The learning that happens through case studies is not straightforward. As described above, case study pedagogy has been motivated by a need for modes of learning that immerse students in a particular problem space, guiding them through problem response, attuned to the dynamics of multiple stakeholders and multiple scales of action. An important critique of case studies, however, is that cases are often bounded in ways that leave some issues and groups of people out. Critics point out that the presentation of case studies as a holistic description of a problem space is necessarily misleading, obscuring the way construction of the case itself is both epistemically biased and never complete.

A key challenge in interdisciplinary disaster education is to mobilize case study pedagogy to take advantage of its integrative and immersive potential while also encouraging deep epistemic reflexivity. This is especially important in disaster education given that what counts as "the disaster" is always deeply politically and weighted by established social and knowledge hierarchies. Disasters should never be approached as uncontested knowledge objects.

We work within this double bind (Bateson, 1972; Fortun 2001) through the use of a case study framework that problematizes problem characterization itself — by drawing out different stakeholder experiences, perspectives, and actions, and by asking directly about missing information and "undone science" (Frickel et al., 2010). Further, all questions in the case study framework are open-ended, helping users recognize that the bounds of "the case" can be constantly expanded.

Table 4 Learning outcomes

1. Students are stimulated to be concerned about environmental disaster and injustice, unlearning STEM teaching that cuts out social implications, and the apathy that often flows from disempowerment
2. Students gain experience as interdisciplinary researchers, unlearning STEM in disciplinary silos, learning to recognize and appreciate many forms of expertise (including social science expertise), and the value of explanatory pluralism
3. Students gain experience comparing cases of environmental disaster, appreciating both particularistic and general knowledge, and both insider and outsider perspectives
4. Students gain experience working with incomplete and questionable data, recognizing associated challenges and conflicts while also proposing action pathways

Despite the multi-directionality of our approach, there are clear learning objectives (Table 3), with supporting learning activities. The learning activities include reading across case studies to build comparative perspective, analytic sketching that integrates different kinds of data and analysis, and the writing of case studies. Reading across cases of environmental injustice pushes against disinterest by drawing students into the often-urgent, human dimensions of environmental disaster. Analytic sketching gives students hands-on experience with complicated and contested information landscapes, prompting them to locate information that is not easy to find and to organize it under myriad analytic frames. As a step between reading and building case studies, analytic sketching is where knowledge infrastructures (and their limitations) — so important for disaster education — come alive.

Writing and building case studies allows time for students to both invest in a place and create knowledge resources useful to people in that place. Since case studies are both descriptive and prescriptive, moving from analysis to proposals for action at local as well as extra-local scales, they build students' sense of their own agency. Moving through many components of building a case study collaboratively, students gain an appreciation for the need for interdisciplinarity and collaboration. Taken together, students feel a deep sense of accomplishment even though part of what they document are knowledge gaps and structural barriers to positive change. Their confidence in part derives from having learned concepts that allow them to name and analyze many types of injustice that combine to produce environmental disaster and injustice — each of which points to an action pathway.

It has taken time and much revision to figure out these learning objectives and they will no doubt be revised again as we continue to track back and forth between our field research and classrooms. Disaster education, in our view, strongly calls for this. We also have complicated learning outcomes (Table 4) — articulated to remind ourselves and our students of the need for double movement that we argue here to be critical. In short, we teach with case studies in a way that foregrounds their analytic production.

4 Conclusion: Double Movements: Case Study Pedagogy in Disaster and Science Education

Environmental disasters result from tangles of socio-political and techno-scientific problems, which together create complex and fraught knowledge problems. In this article, we describe an approach to disaster education that stems from this premise, mobilizing an Environmental Injustice Case Study Framework that draws out multiple dimensions of disaster (and the need for interdisciplinarity) while immersing students in the paradoxes and challenges of disaster knowledge production.

In conclusion, we return to our main research question: How can case study pedagogy contribute to disaster and science education? Our overarching argument is that critical approaches to case study pedagogy can scaffold many kinds of learning in both disaster and science education, helping students integrate diverse kinds of data, analysis, interpretation, and judgment, while building metacognition and epistemic reflexivity.

Our use of case study pedagogy — and the EiJ Case Study Framework — draws students not only into disaster knowledge, but also into critical thinking about disasters as epistemic problems. Environmental disasters, we know from our own research, involve perspectival diversity; multiple, often conflicting forms of evidence; (sometimes purposeful) data gaps; disinformation; role transitions and confusion, etc. Understanding and responding to environmental disaster thus require the capacity to recognize and analyze perspectival differences and many forms of evidence. It also requires the capacity to work within knowledge limitations and conflicts — recognizing that paralysis in the face of conflicts has consequences.

Cultural analysis, which draws out perspectival differences, is thus critical, as is epistemic reflexivity — recognition that all forms of knowledge, and supporting modes of analysis, are partial, biased, and best evaluated and used in concert. This points to (and gives students experience with) both the fact and value of explanatory pluralism (Keller, 2002). It also demonstrates the limitation of any "case," no matter how thoroughly researched and presented. The EiJ Case Study Framework itself points students beyond it, in multiple ways — by asking (Q1) how the setting focused on is likely to change, for example (thus calling for ongoing analysis,) and by asking (Q9) about the many kinds of research that remain to be done to adequately understand "the case."

It is in such double movements — recognizing what case study analysis and development accomplishes while also recognizing the epistemic paradoxes and limits of constituting "the case" — that we see the potential for case study pedagogy in disaster education and in science education more generally. Case study pedagogy can immerse science students at all levels in diverse, richly detailed and peopled cases, helping them see both variation among them and patterns across them — prompting concern, recognition of the need for complex analyses, and the urgency of moving knowledge into action. Case study approaches can also stimulate metacognition of knowledge, power, and their interrelations, empowering students by cultivating epistemic reflexivity.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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