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STEM education for transformative hazard literacy: from technological fixes to slow learning

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Abstract

While education is widely recognized as a key component of disaster prevention and response, the broader educational visions that underpin disaster education have received limited attention. This article critiques prevailing approaches to disaster and hazard education, which are frequently shaped by economic and technocratic values. Although minimizing economic loss and ensuring personal safety are undeniably important, when driven by these values, education tends to prioritize short- and mid-term outcomes, obscuring the sociopolitical and systemic factors that enable hazards to escalate into disasters. Focusing on disaster vulnerability and justice-centered science, technology, engineering, and mathematics (STEM) education, I examine how learning about disasters can serve the transformative goals of STEM education by empowering students to recognize, analyze, and critically engage with issues of equity and justice in the context of disasters. Drawing on the case of the 2023 Türkiye-Syria earthquakes that claimed over 55,000 lives and left millions homeless, I argue for a shift in the purpose of disaster and hazard education: from minimising economic losses to cultivating democratic citizens who understand the social roots of disasters and actively work to challenge injustice and transform society.

Keywords: disaster justice, hazard literacy, justice-centered science education, STEM education

Introduction

Education is deeply influenced by the ways in which phenomena are understood and framed within society [1]. From an educational point of view, the 'frame' through which a phenomenon is viewed can determine the curriculum, the methods of teaching, and even who is considered a legitimate authority on the topic. Mitchell highlighted how disasters can be framed in strikingly different ways after Hurricane Katrina:

> … a hurricane like Katrina may be simultaneously regarded as a disaster, a natural experiment, an aesthetic spectacle, a manifestation of divine power, an indicator of anthropogenic climate change, a mechanism of societal differentiation, a test of societal resilience, a device for redistributing economic and political resources [2].

To explore how framing can influence how we teach and learn about disasters, consider two high school lessons on earthquakes:

In Ms. Smith's lesson, students begin by watching a video depicting earthquake destruction, sparking discussion about their observations and prior knowledge. She then outlines the learning objectives: understanding the causes of earthquakes, seismic waves, and measurement methods. Using a diagram and foam blocks, she explains plate tectonics, illustrating how colliding plates generate seismic activity. She then introduces the different types of seismic waves, guiding students through a hands-on activity where they analyze seismograms to identify P-wave and S-wave arrivals and relate their time differences to distance. Ms. Smith follows with an introduction to the Richter and Moment Magnitude scales, using real-world earthquake data to compare magnitudes and their impacts.

A month later, in a lesson led by Mr. Simms, students develop, test, and refine an earthquake emergency response plan for their school. They begin by identifying early warning signs and distinguishing between an emergency response plan and a drill. Using school maps, they assess structural and non-structural hazards, outline evacuation routes, and devise response strategies—including shelter-in-place measures where necessary. Working in teams, they create, compare, and refine earthquake response plans tailored to their school's risks. They also discuss preparedness, including assembling safety kits and understanding basic first aid. The lesson culminates in a practical earthquake drill, where students test their plans, evaluate their responses, and identify areas for improvement. Finally, they present their plans to school authorities, reinforcing the role of preparedness and community engagement in disaster response.[1]

These two hypothetical lesson scenarios illustrate two of the most common approaches to education about hazards and disasters. The first, a conventional high school science lesson, focuses on the geophysics and seismology of earthquakes, introducing students to concepts such as seismic waves, data interpretation, and engineering solutions for earthquake-resistant structures. The second, in contrast, emphasizes the practical and personal implications of earthquakes, centring on preparedness and emergency response rather than scientific causation. Let us call these approaches the 'scientific cause' and 'personal safety' models of hazard and disaster education.

To consider the implications of these approaches, consider a student, Sean, who has attended both lessons. After watching a news report about a recent magnitude 7.4 earthquake in a Caribbean island that claimed thousands of lives, he begins to reflect on what he has learned. From Ms. Smith's lesson, he understands that the earthquake was caused by movement along a fault line beneath the island. From Mr. Simms's lesson, he reasons that the high death toll might be due to inadequate emergency preparedness and weak building structures. However, when he later reads that the mortality rate in the disaster was four times higher for Black women than for White men, neither lesson offers an explanation. What he has learned so far does not account for why and how earthquakes disproportionately affect certain groups of people. This gap in Sean's understanding reflects what Park describes as the 'two cultures' in hazards and disaster education—two dominant approaches that leave critical socio-economic dimensions of disasters that put people at risk of hazards unaddressed [4].

[1] This case was informed by lesson examples from Nature Education [3].

Extending the Concept of Hazard and Disaster Literacy

The concept of *hazard literacy,* and *disaster literacy*, has been used to refer to individuals' ability to understand, assess, and respond to natural and technological hazards. In much of the disaster and risk communication literature, hazard and disaster literacy is defined in terms of awareness, preparedness behaviors, and knowledge of warning systems or evacuation procedures [5], although in a small number of sources these terms refer to knowledge of specific historical disasters [6]. While these perspectives can be useful in promoting individual and community-level readiness, they often remain focused on behavioral change and technical understanding. Less attention has been paid to how hazard and disaster literacy might also include critical engagement with the political and historical conditions that shape risk exposure and disaster response.

In this paper, I extend the concept of hazard and disaster literacy to include the capacity to interrogate the structural factors that render certain populations more vulnerable, and to act on this understanding through democratic, ethical, and collective action. This justice-oriented framing draws from critical science education and vulnerability studies to reimagine hazard literacy not just as a technical or behavioral outcome, but as a transformative educational goal. Specifically, I examine how education about disasters, and hazards can look like in an age characterized by a 'risk society' [7]—one in which the process of modernization not only generate unprecendented, often invisible hazards but also distributes these risks unevenly across society, as well as disasters are caused by human choices [8]. The risks and impacts of disasters are disproportionately borne by socioeconomically marginalized groups, who also face unequal access to support and resources, thereby raising a host of social justice and equity issues [9–11].

In the following, I first examine two possible reasons why social justice and vulnerability have been sidelined in disaster and hazards education, in relation to the overemphasis on economic returns for educational input and the resilience paradigm in disaster research. I then explore how a justice-centered STEM education can help learners move forward from the technical explanation and solution to addressing the root causes of disasters. I use the example of the 2023 earthquakes in the border between Türkiye and Syria to illustrate the potential of such an approach.

Beyond Economic Returns

Over the last few decades, education about hazards and disasters has seen a notable growth in scale, across the formal [12,13] and informal learning environments [14], and at all stages of education. A major international agency that makes significant efforts related to hazards and disasters is the United Nations Office for Disaster Risk Reduction[2] (UNDRR). UNDRR was created in 1999, towards the end of the international decade for natural disaster reduction. The education of young people was recognized as a core mission of the organization from the outset:

> … It is therefore important for future generations, as the leaders of tomorrow, to learn about the long-term aspects of such a protection [of earth], and to provide them with the necessary early education for a better understanding of both natural hazards and the way to prevent their disastrous impact on societies … Young people should be given the chance to ensure

[2] It was originally launched as the 'UN International Strategy for Disaster Reduction' (UNISDR) and then renamed as its current name in 2019.

> their own protection and the protection of their world, through appropriate education and level of responsibility in the decision-making process [15].

The UNDRR delivers and supports education and training across the world, including the establishment of its Global Education and Training Institute located in Incheon, South Korea, to promote education of emergency responders and the general public. Since 2016, they have been running a 'School Safety Program' to support the following priorities of the Sendai Framework for Disaster Risk Reduction 2015–2030: (1) understanding disaster risk; (2) strengthening disaster risk governance to manage disaster risk; (3) investing in disaster risk reduction for resilience; and (4) enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation and reconstruction.

The learning objectives of the School Safety Program is stated as: (a) understand the meaning of a disaster, (b) develop awareness of hazards around them, (c) learn what they can do to prevent disasters, and (d) develop capacities to save their own lives and people in the community. These objectives are justified within the broader goal of UNDRR, as stated in their website:

> It pays to invest in reducing the risks posed by disasters. Every dollar spent doing this can save fifteen in post-disaster recovery costs. Every dollar invested in making infrastructure disaster-resilient saves four that would otherwise have to be spent rebuilding [16].

While disaster education is implemented in diverse ways across national and local contexts, global frameworks—such as those promoted by the UNDRR and the Sendai Framework—often frame education in terms of economic returns and resilience as exemplified by this example. These framings carry significant weight in shaping international policy discourse and the development of national curricula. The quote above is just one of the myriad examples where reducing, understanding and teaching about disaster risk are predominantly driven by economic interests and framed in economic terms. In this 'utilitarian' model, education is ultimately seen as an investment to reduce social and economic losses. The implication here is that an education policy or intervention about hazards and disasters can be justified or rejected mainly based on cost-benefit analysis [17]. Of course, few people would want to invest in education programs that are proven to be ineffective and fails to save lives and prevent damages. However, this sole focus on financial returns often undermines the fact that education has many outcomes that are difficult to measure and quantitatively compared. Another negative consequence of this financial focus is a myopic approach to hazard and disaster education overshadowing the long-term, transformative potential of education that are often unmeasurable and not manifest in immediate outcomes.[3] This kind of education can grow people and communities that are resilient to disasters in the short term, but it does not go so far as cultivating people who recognize the underlying social causes that turn hazards into disasters, and are empowered to transform the social, political, economic conditions that allow this process.

Learning about disasters often unfolds outside the classroom, through what some scholars describe as 'public pedagogies' [18]. These include movies, documentaries, museum exhibits, and the literary and performing arts, all of which can offer richer, more nuanced perspectives that

[3] This is not to suggest that justice-centered education cannot be assessed in principle. A number of methods can be used to capture and track students' justice-oriented learning, such as group projects and reflective journals. However, these outcomes often unfold over long periods of time, are highly contextualized, and do not lend themselves easily to standardized assessment or comparison. The challenge, then, lies less in the absolute impossibility of measurement than in the mismatch between the goals of justice-oriented education and the dominant metrics valued in contemporary education systems, which tend to favor short-term, quantifiable outcomes.

address the broader societal implications of disasters. The 2020 Netflix docuseries *Challenger: The Final Flight* describes the Space Shuttle Challenger disaster in the U.S. in 1986, that broke apart 73 seconds into its flight, engulfing all seven crew members in flame, including a school teacher from New Hampshire. The documentary first introduces the crew and NASA's Teacher in Space Project, highlighting Christa McAuliffe's selection. It then reveals the engineering concerns about the O-ring seals in cold weather conditions that were raised by Morton Thiokol engineers but ultimately dismissed by management under launch schedule pressures. Through archival footage and interviews with NASA personnel, astronauts' families, journalists, and engineers involved, the series chronicles the tragic launch day, the national mourning that followed, and the subsequent Rogers Commission investigation. The docuseries exposes the institutional failures and communication breakdowns that led to the disaster, while honoring the crew's legacy and examining how the tragedy transformed NASA's approach to safety and organizational culture.

Seeing this as a public pedagogy of nuclear disaster risk, what learning outcomes can be expected from it? There will be some historical details and technological details about the disaster that might be measured and assessed before and after watching it, but these would be hardly the main learning goal. Also, it would be impractical to expect watching the documentary would produce any 'quantifiable' improvement in individuals' capacity to respond to space shuttle accidents; or at least there would be many better ways for that. On the other hand, students' reflection on the moral dilemmas faced by engineers who identified potential problems but were overruled by management, or how NASA's institutional culture, pressure to maintain launch schedules, and communication breakdowns contributed to the accident, could be key learning goals but this is not something that can be easily assessed in the short term properly. There are important aims of disaster education that should not be disregarded only because they are not compatible with the measurement culture and cannot be reduced to quantifiable outcomes.

Bringing the 'Social' Back in How We Think (and Teach) about Hazards

In recent decades, significant progress has been made in integrating disaster risk reduction in school curricula [19], particularly following the Hyogo Framework for Action (2005–2015) and the Sendai Framework for Disaster Risk Reduction (2015–2030). However, as discussed earlier, these initiatives have placed limited emphasis on the social dimensions of disasters. This omission aligns with the growing focus on quantifiable outcomes in disaster risk reduction (DRR) interventions. Students' understanding of the scientific causes of disasters and their ability to respond effectively can be relatively easily measured through traditional assessment methods, whether in the form of paper-and-pencil tests or scenario- and performance-based evaluations, and these assessments are widely used to evidence the effectiveness of educational interventions [20,21]. In contrast, assessing students' learning about the social justice aspects of disasters – e.g., the way that people are exposed to a lesser or greater degree of disaster risk and what influences their vulnerabilities – tend to call for long-term engagement and iterative reflection. These aspects are challenging to capture through conventional quantitative metrics [22], which are increasingly emphasized in an era of accountability-driven education worldwide.

The increasing emphasis on measurement has coincided with a paradigm shift in disaster research. At the start of the 21st century, disaster researchers shifted their attention from hazards and vulnerability to resilience, and over time, fostering resilience became the official narrative of disaster prevention and mitigation. This involved the idea that we can increase individuals' and communities' capacity to counter hazards and 'bounce back' by, for example, improving early warning systems, strengthening infrastructure, conducting regular emergency drills, developing community-based disaster management plans, and promoting household emergency preparedness measures. Van Bavel et al. point out that the shift to the resilience paradigm moved the focus away from power relationships, agency, values and knowledge, only giving them subordinate roles, and resilience is often even seen as 'handmaid of neoliberalism, strengthening its discourse on personal responsibility, but this is a "responsibility without power"' [23].

The danger of the sole reliance on the resilience approach is that it can shift the way human actions are held responsible for challenges within socio-ecological systems. The concept of resilience is centered around the extent to which human actions enable a system to persist, recover, or reach a tipping point [23]. In this way of understanding and framing disasters, it is easy for education to be viewed as instrumentalist and technocratic remedy to disasters without exposing and deliberating on the root causes that make people vulnerable, which often only become apparent over long periods of time and requires a broader examination of nature, technology and society. By emphasizing resilience and ecosystems, there is a possible erosion of the idea that socio-economic systems themselves create and distribute risks unevenly. In contrast, the concept of vulnerability explicitly frames risk as a condition shaped by economic and political forces, highlighting how individuals experience varying degrees of exposure. While vulnerability centres on individuals and communities at the grassroots level, highlighting how their exposure to risk results from social processes, the resilience approach risks shifting towards interventions that absorb political and economic factors into a neutral framework of ecosystem management. This shift often leads to depoliticizing the underlying causes that contribute to placing people at risk [24].

Miyazawa's examination of education in Fukushima after the 2011 nuclear accident [25] provides a telling example of how societies can produce disaster injustices and how a focus on reconstruction and resilience can hinder justice-oriented education about hazards and disasters. In the aftermath of the nuclear accident, educational responses in Fukushima were closely aligned with broader national 'reconstruction' and 'revitalization' campaigns. Just weeks after the disaster, the Fukushima Prefectural Board of Education released the *Fukushima Reconstruction Plan for Education*, which prioritized addressing learning losses, especially in relation to national academic achievement tests. As Miyazawa documents, this plan was underpinned by a discourse of 'normalization', aimed at helping students quickly overcome their fears of radiation and reintegrate into everyday school life as contributors to the region's recovery. Such an approach reflects the logic of the resilience paradigm, which often privileges adaptation and return to 'normality' over sustained critical engagement with the socio-political conditions that gave rise to the disaster. Education, in this framing, becomes a vehicle for stabilizing society and restoring productivity, rather than a means to question the injustices and systemic inequalities that left certain communities more exposed than others.

What is notably absent from this educational response was a reckoning with the political economy of energy production and environmental risk in Japan. The Tōhoku region, which includes Fukushima, has long functioned as an internal periphery or 'energy colony', supplying electricity, food, and cheap labor to more urbanized and affluent regions. As national energy policy increasingly turned to nuclear power, the region was disproportionately targeted for the siting of nuclear facilities, incentivized through subsidies, promises of local employment, and infrastructural investment [25]. This asymmetrical relationship – and the silencing of anti-nuclear dissent that accompanied it – formed a critical part of the conditions that made the disaster possible. Yet these historical and structural dynamics were excluded from the post-disaster educational strategy. The opportunity for students to critically examine how state policies, regional inequalities, and environmental governance contributed to their community's vulnerability was largely absent.

This case highlights the limitations of a resilience-focused educational response that treats disasters primarily as technical challenges to be managed, rather than as social phenomena rooted in systems of power and inequality. By centering resilience without a parallel emphasis on vulnerability and justice, there is a risk of depoliticizing disaster education and foreclosing opportunities for young people to develop a deeper understanding of how and why certain populations are more at risk, and how societies create injustices and, let disasters happen [26]. If we are to bring the 'social' back into how we think and teach about hazards, education must move beyond instrumentalist framings and create space for critical inquiry into the structural conditions that produce disaster risk. This involves not only integrating knowledge of STEM into learning about disasters and hazards, but also engaging students in ethical, historical, and political questions about responsibility, accountability, and the unequal distribution of harm.

From Technological Fixes to Slow Learning

From the perspective of STEM education in particular, the mainstream approaches to hazard and disaster education, with their economic focus, seem to leave little room for the inclusion of STEM subjects. While understanding the scientific and technical aspects of phenomena like earthquakes can inform protective measures and emergency decision-making, this approach is often deemed less cost-effective than direct safety training. As Selby and Kagawa rightly observe, "understanding the science of a hazard alone does not develop the propensity for pro-action, while focusing exclusively on safety without examining prevention and mitigation implies the inevitability of what is to happen" [27]. Addressing this disconnect requires more than a mere refocusing of disaster education; it calls for a fundamental reimagining of STEM education. Such reimagining should transcend the traditional transmission of knowledge and skills to embrace broader social justice objectives.

In response to recent calls for science learning environments that consider historicity, culture, and power, researchers have proposed pedagogical approaches which critique dominant forms of science and situate learning within broader justice movements [28,29]. This paradigm challenges traditional methods that portray science as a neutral, apolitical activity, instead highlighting that scientific knowledge and practice are inherently intertwined with social, political, and historical contexts. By utilizing students' existing funds of knowledge and embracing multiple epistemologies in classroom settings [30], these approaches actively challenge epistemological hierarchies and create space for diverse, lived interpretations of scientific phenomena. For instance, educators are integrating environmental justice case studies, where learners investigate the historical exclusion of marginalized groups from environmental decision making, and engaging students in community-based participatory research that addresses local issues such as air quality, water contamination, food justice or public health disparities [31–33]. In these activities, students can identify, critique, and tackle societal problems drawing on diverse sensemaking and cultural resources, in addition to science and engineering knowledge [29].

These justice-centered pedagogies position young people as transformative intellectuals, equipped to perceive and utilize STEM as a catalyst for change [29]. In a justice-oriented science classroom, students are encouraged to explore the intersections between scientific issues and social, cultural, and ethical dimensions. This approach repositions them as active participants and creators of knowledge, rather than passive recipients [34]. They are invited to critically explore how scientific knowledge is produced and deployed, and how it may both reflect and perpetuate societal inequalities. Within such a framework, students are urged to engage with socio-scientific issues that bear personal and communal significance. As Grunewald observes, justice-oriented pedagogy "aims to identify, recover, and create material spaces and places that teach us how to live well in our total environments (reinhabitation), [and] identify, and change ways of thinking that injure and exploit other people and places (decolonization)" [35]. This approach aims to not only nurture critical thinking, environmental understanding, and compassion but also foster collaborative ethical action.

Putting the concept of vulnerability at the centre of hazard literacy can be a powerful way to implement justice-centered STEM education. Such an approach recognizes that vulnerability to hazards is not randomly distributed, but follows patterns of historical marginalization and structural inequality. It can combine STEM knowledge with an examination of who is most vulnerable to specific hazards, how social structures create and maintain these vulnerabilities, and whose knowledge and experiences are valued and whose are excluded in preparing societies and communities for disasters. To learn about these aspects of disaster justice, students can utilize various forms of scientific and social data, such as data from the Global Assessment Report on Disaster Risk Reduction (https://www.undrr.org/gar), the FEMA National Risk Index (https://hazards.fema.gov/nri/map) and the Climate Just Interactive Map (https://www.climatejust.org.uk/map.html). A vulnerability-centered hazard literacy can complement learning focused on hazards and resilience and therefore serve as key to addressing the 'two cultures' problem raised by Park [4] (Table 1).

Although investigations may begin with locally relevant and urgent community issues, justice-centered learning about hazard and disaster can and ideally, should, extend beyond students' immediate contexts. Education should progress from enhancing personal and community preparedness to fostering empathy and care for people beyond one's immediate circle. This approach aligns with the notions of cross-cultural sensitivity and global citizenship, encouraging learners to "understand the world around them and work together to fix the big problems that affect everyone, no matter where they're from" [36]. Through this expanded aim, STEM education for hazard literacy can become transformative, equipping students not only with scientific knowledge but also with the critical awareness and ethical commitment needed to create more just communities and societies.

Such an approach also resonates with recent STEM education frameworks that increasingly emphasize addressing social injustice and vulnerability as a core aim of education. The Programme for International Student Assessment (PISA) 2025 Science Framework from proposed "demonstrating hope and respect for diverse perspectives in seeking solutions to socio-ecological crisis" as one of the three 'Anthropocene competencies' that all 15-year-olds should posess. Specifically, it suggested that:

> A 15-year-old student who uses an ethic of care and justice, and demonstrates resilience, hope, efficacy, and a respect for diverse perspectives in seeking solutions to social and environmental challenge can:
>
> 1. Evaluate actions drawing on an ethic of care for each other and all species based on a worldview where humans are part of the environment rather than separate from it (being ecocentric).
> 2. Acknowledge the many ways societies have created injustices and work to empower all people to contribute to community and ecosystem well-being.

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Table 1. **Disaster paradigms and the focus of STEM research and STEM education**

	Hazard-centered	Resilience-centered	Vulnerability-centered
STEM research focus	• Modeling and forecasting geodynamic and hydrometeorological phenomena • Developing technologies for early warning • Engineering structural solutions	• Developing community-based warning systems • Designing resilient infrastructure • Building adaptive capacities	• Examining structural inequities in disaster impacts • Researching power dynamics in recovery processes • Developing equity-centered interventions
STEM education focus	• Training technical experts • Building specialized disaster engineering skills • Developing technological solutions	• Learning STEM content and methods in personally relevant contexts of disaster and hazards • Connecting STEM to everyday life • Making decisions under uncertainty • Nurturing information literacy	• Acknowledging social injustices • Fostering transformative scientific literacy • Developing empathy and relational ethics • Promoting solidarity and collective action
Possible pitfalls	• Overlooks social dimensions of disasters • Downplays root causes of vulnerability • Depoliticizes disaster processes • May reinforce existing power structures	• Often narrowly defines 'personal relevance' • May obscure systemic failures by focusing on adaptation • Risks normalizing disaster conditions rather than challenging them.	• May be challenging to implement within discipline-focused STEM curricula • Requires institutional commitment to justice • Demands deeper engagement with ethical dimensions

STEM, science, technology, engineering, and mathematics.

3. Exhibit resilience, hope, and efficacy, individually and collectively, in responding to socio-ecological crises.
4. Respect diverse perspectives on issues and seek solutions to regenerate impacted communities and ecosystems [37].

A similar position was put forward in the National Academies of Science, Engineering and Medicine's recent concensus report where it was stated that:

- Children learn about the connection between the natural world and human actions and decision making.
- Children investigate how Black, Indigenous, and other communities of color experience disproportionate effects of food deserts, natural hazards, and environmental pollution.
- Curricular materials invite children, families, and teachers to examine issues from historicized lenses, and understand how contemporary scientific practices or concepts may have deep roots in racist or other oppressive histories [34].

These examples demonstrate that by broadening the aim of STEM education we see strong resonance and overlap with transformative hazard literacy that centers structural issues and social vulnerability, that is, the 'social roots' of environmental and technological disasters.

The approach I have articulated thus far can be characterized as a form of 'slow learning' about disasters and hazards in two distinct senses. First, it shifts the understanding of disasters from rapid, short-term, and sudden events to slow-unfolding, historically rooted, and ongoing processes. Second, it advocates for civic aims of STEM education whose cultivation and impact necessarily take time to realize. Unlike conventional disaster education which often emphasizes preparedness drills or technical knowledge that are easy to quantify, slow learning encourages students to grapple with complex historical, political, and moral dimensions of disasters. This may involve historical investigations, iterative dialogue, and community-based exploration. As such, slow learning aligns closely with justice-centered education by fostering the kind of critical consciousness and sustained ethical commitments necessary to address the root causes of vulnerability and social injustice.

In the following section, I examine a recent disaster in Türkiye and Syria to illustrate what STEM education for transformative hazard literacy might look like, and how it can move beyond the limitations of dominant 'scientific cause' and 'personal safety' approaches to hazard education introduced earlier.

The 2023 Türkiye-Syria Earthquake and STEM for Social Justice

On February 6th, 2023, two powerful earthquakes, each of magnitude 7.8 and 7.5, struck south-eastern Türkiye and northern Syria. It occurred in a region where several tectonic plates—including the Anatolia, Arabia, Africa, and Eurasia plates—are constantly interacting, creating significant strain and resulting in powerful quakes. This natural process, however, turned into a widespread human catastrophe due to a series of human failures. Countless buildings collapsed, leaving thousands homeless, trapping many under debris, and killing more than 55,000. The disaster was particularly severe in southern Türkiye's 10 affected provinces, home to large Syrian refugee populations, while Syria itself was already reeling from more than a decade of civil war.

In the immediate aftermath, President Recep Tayyip Erdogan attributed the disaster to fate, stating that such events were "part of destiny's plan." [38]. This echoed his remarks just months earlier following a deadly explosion at a state-run coalmine in Amasra, on the northern Black Sea coast, where he similarly blamed "fate's design" for the deaths of at least 41 miners [39]. By framing these tragedies as acts of destiny, Erdogan's response diverted attention from the role of government decisions and regulatory failures in transforming a natural disaster into a preventable catastrophe.

This fatalistic framing starkly contrasts with subsequent findings by engineers, which pointed to systemic negligence and lapses in oversight. According to the post-earthquake investigation, one main reason for the severe destruction was so-called soft storey bulidings. Soft-storey buildings are structures where the ground floor has significantly less stiffness and strength than the floors above it, making the building particularly vulnerable to collapse during earthquakes. In an earthquake, the weak lower level may fail, causing the upper floors to collapse onto it, often called 'pancake collapse', which happened during the 2023 earthquakes (Fig. 1) [40]. Most of the buildings in the regions with strongest ground shaking such as Hatay and Kahramanmaraş collapsed in this mechanism.

The buildings that experienced such failures were mostly constructed before 2000 and were not entirely compliant with the building codes in effect at the time. Additionally, prior to 2000, concrete was traditionally mixed on-site without strict consideration of the required concrete strength. The post-earthquake investigation by an international group of engineers revealed that the disaster was far from a mere act of nature, let alone destiny. They identified critical human failures in urban planning and construction supervision, including: (a) urban planning that ignored disaster risk data, resulting in buildings constructed on unstable agricultural land and soft soils; (b) the promotion of illegal construction through zoning amnesties that allowed buildings to be erected without adhering to proper safety codes; and (c) a marked shortage of qualified professionals and effective supervision during the construction process [42].

As Ertas emphasizes [43], these failures were not random but stemmed from systemic, deep-rooted issues within Turkish politics. From the perspective of STEM, what was lacking in this disaster was not the scientific and engineering knowledge about earthquake-resistant

Fig. 1. **Pancake collapse in Iskenderun, Hatay, Türkiye.** Copyright: Doga Ayberk Demir/Shutterstock. Used with permission.

construction and the impact of seismic activity on buildings and infrastructure. Türkiye is located in a highly seismically active zone where tectonic plates interact continuously beneath the Earth's surface, making earthquakes a frequent occurrence. Many of the collapsed structures were constructed using concrete that lacked sufficient seismic reinforcement. Despite the existence of seismic building codes in this region, which are designed to ensure that structures can endure strong ground motion (characterized by ground acceleration of approximately 30% to 40% of gravitational acceleration) without catastrophic failure, these buildings appear to have been unable to meet those standards.

Years before the earthquake, policies were enacted that prioritized rapid development and economic growth over strict adherence to safety standards [43,44]. Legislation that granted property owners 'amnesty' for construction violations—despite the known seismic risks—exemplified a government approach that ultimately compromised public safety. The investigators concluded that:

> ... This demonstrates that seismic resilience is not only a technical problem in Türkiye but one that requires a multi-sectoral and interdisciplinary dialogue scrutinizing the regulatory system, bureaucratic hierarchy, legal/political backdrop against which the construction sector operates in Türkiye, work ethics and the "social contract", economic and professional pressures and risk perception, among others [42].

The Türkiye-Syria earthquake case provides a compelling example of how disasters emerge not solely as natural events but as outcomes of deeply rooted social, political, and economic factors. Rather than accepting disasters as inevitable, unfortunate, and 'natural', students are prompted to critically assess the societal structures that exacerbate such events. By engaging with the intersection of policy and engineering, students can develop a more nuanced understanding of social justice, recognizing that public safety is not merely a technical challenge but a reflection of broader civic responsibility.

From a justice-oriented perspective, this case study can be used to develop critical citizenship,

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inspiring students to become lifelong learners and advocates who question established norms and push for reform based on a critical understanding of STEM. For example, students could investigate the tectonic dynamics of the fault system in the region (science), calculate ground acceleration using seismic data (mathematics), model building stability under seismic load (engineering), or assess the distribution of hazard information through early warning systems (technology). These investigations can then be connected to critical questions about building code enforcement, zoning amnesties, and infrastructure disparities across socioeconomic groups, which requires historical and political consciousness. The learning objectives would include both disciplinary outcomes—such as analyzing structural failure using engineering principles—and justice-oriented goals, such as identifying how systemic neglect and unequal access to safe housing exacerbate disaster impacts.

To help learners understand, evaluate, and challenge the conditions that create and perpetuate disaster vulnerability, educators can prompt open and reflective discussions. Some useful prompts include:

- What are the seismic and geological characteristics of the Türkiye-Syria region, and how do they compare to other earthquake-prone areas?
- Who were most affected by the earthquakes?
- What data are there to investigate the cause and impact of the earthquakes?
- What engineering measures and technological systems were implemented before the earthquake to mitigate seismic risks, and how effective were they?
- What building regulations and safety standards were in place, and how did policies like the construction amnesty influence their enforcement?
- How did the specific seismic activities and geological conditions contribute to the scale and impact of the earthquake?
- What were the immediate and long-term infrastructural and environmental impacts of the disaster?
- Which demographic and socioeconomic groups were most affected by the earthquake, and what factors contributed to these disparities?
- What lessons can we learn from this disaster for future disasters?

Engaging with these questions helps students understand that the social causes of disasters—such as unregulated construction practices and insufficient governmental oversight—are crucial for redressing historical and ongoing injustices preventing future tragedies. While this example focuses on unethical management of technological hazards by policymakers, various disasters present distinct justice and equity issues that can be explored through the lens of justice-centered STEM education, incorporating disciplines such as engineering, technology, seismology, as well as the sociopolitical perspectives, to examine issues of race [45], gender [46], social class [47] and disability [48,49]. By examining these complex intersections, students can appreciate how systemic inequities shape both technical solutions and the broader outcomes of disasters. Ultimately, a justice-oriented STEM approach equips students with the tools to become informed and conscientious citizens, capable of bridging the gap between technical expertise and social accountability.

Conclusion

In this article, I have argued that learning about hazards and disasters should embrace

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the transformative aims of STEM education, extending beyond understanding the scientific mechanisms of disasters and learning how to stay safe. By emphasizing the role of the 'social' in researching and teaching about disasters, I have highlighted how events often perceived as 'natural' disasters are, in fact, deeply rooted in social and political structures that have hindered the application of scientific and engineering knowledge to risk reduction. Recognizing disasters in this way—rather than as divine acts or purely natural processes—empowers learners as STEM-literate democratic citizens capable of driving positive change. While learners' abilities to recognize social injustices and their willingness to contribute to societal transformation may be difficult, if not impossible, to quantify or measure, these 'slow' learning goals are essential to the broader social purpose of STEM education.

While this article has critiqued the dominance of resilience framings in DRR and disaster education, this is not to suggest that resilience and recovery should be excluded from educational aims. Rather, they should be seen as complementary to justice-oriented approaches. A narrow focus on resilience can risk decontextualizing and depoliticizing disasters, but resilience itself is not inherently at odds with social justice. Indeed, resilience education can and should incorporate equity goals—for example, by ensuring that access to disaster relief, early warning systems, and hazard information is distributed fairly across different communities. A more holistic and critical approach to hazard education would bring these strands together: supporting learners not only to adapt and recover, but also to question and transform the conditions that render some communities disproportionately at risk. In this light, resilience can become part of, rather than a substitute for, a broader vision of justice.

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