Earth Science Education for Community Preparedness: Place-Based Approaches to Climate, Water, and Natural Hazards in K-12 Schools

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Abstract

This manuscript presents a K-12 Earth science education framework that connects place-based geoscience learning with community preparedness. Earth science education is positioned as a practical pathway for helping students understand weather, climate, water systems, landforms, natural hazards, and human interactions with Earth systems. Drawing on scholarship and guidance from geoscience education, Earth science literacy, natural hazards education, science education policy, and climate assessment literature, the manuscript argues that students benefit when Earth science instruction begins with local phenomena and moves toward broader Earth system explanation. The proposed framework includes four instructional moves: observing local phenomena, explaining Earth system processes, analyzing community risk, and communicating preparedness decisions. The discussion emphasizes that community preparedness should not replace disciplinary science learning; rather, it should deepen students' use of evidence, data interpretation, modeling, spatial reasoning, and responsible communication. The manuscript also identifies practical K-12 activities, including schoolyard runoff investigations, weather data analysis, community hazard mapping, and preparedness communication projects. Finally, the manuscript addresses equity, implementation, and ethical cautions so teachers and curriculum leaders can use Earth science learning to support scientifically accurate, standards-aligned, developmentally appropriate, and locally meaningful preparedness education.

Keywords: Earth science education, geoscience education, K-12 science, place-based learning, natural hazards, climate literacy, water systems, community preparedness

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Introduction

Earth science education is a public education priority because students live in communities shaped by weather, climate, water systems, landforms, natural hazards, resources, and human interactions with Earth systems. The National Research Council (2012) described Earth and space science as a major domain of K-12 science learning, and the Next Generation Science Standards connect Earth systems content to practices such as analyzing data, developing explanations, and evaluating evidence (National Research Council, 2013). Earth science literacy is also connected to public decision-making because students and families must interpret information about storms, flooding, heat, drought, water quality, land use, and environmental risk (Earth Science Literacy Initiative, 2010; Geological Society of America, n.d.).

The purpose of this manuscript is to present a K-12 Earth science education framework that connects place-based learning with community preparedness. This argument is grounded in geoscience education scholarship showing that local places can support Earth systems learning and in national science education guidance emphasizing meaningful, equitable, evidence-based science learning (National Academies of Sciences, Engineering, and Medicine, 2021; Semken et al., 2017). The framework positions Earth science content as the foundation for student inquiry, evidence-based reasoning, and developmentally appropriate preparedness learning.

This manuscript is a review and curriculum framework paper rather than an empirical study. It synthesizes scholarship on geoscience education, place-based learning, natural hazards education, climate literacy, and K-12 science learning to propose practical design principles for teachers and curriculum leaders (Boyd et al., 2022; Monroe et al., 2019; National Research

Council, 2012; Semken et al., 2017). The goal is to keep Earth science at the center while showing how K-12 schools can use Earth science learning to strengthen community understanding and preparedness.

Earth Science Literacy and Community Preparedness

Earth science literacy involves more than learning isolated terms about rocks, weather, or landforms. The Earth Science Literacy Initiative (2010) organized Earth science around major ideas such as Earth's history, Earth systems, the geosphere, water, resources, natural hazards, and human impacts. These ideas matter in K-12 education because students need to understand Earth processes that shape daily life and community environments (Earth Science Literacy Initiative, 2010; National Research Council, 2012).

Community preparedness provides a concrete context for applying Earth science literacy. Natural hazards such as floods, droughts, hurricanes, landslides, wildfires, earthquakes, severe storms, and extreme heat are connected to Earth system processes, while community risk also depends on exposure, vulnerability, infrastructure, and preparedness (Boyd et al., 2022; Crimmins et al., 2023; Federal Emergency Management Agency, 2017). For K-12 students, these topics can be taught through age-appropriate questions about local patterns, historical events, evidence, uncertainty, and responsible action.

Natural hazards education remains an implementation challenge in schools. Boyd et al. (2022) surveyed Colorado teachers and found that natural hazards were more commonly taught than community resilience, with barriers including limited time, curricular alignment concerns, and teacher background knowledge. Those findings indicate that teachers may need standards-aligned materials, data tools, and professional learning to connect hazard science with preparedness in ways that preserve disciplinary science learning (Boyd et al., 2022; National Academies of Sciences, Engineering, and Medicine, 2021).

Place-Based Geoscience Education

Place-based geoscience education is a strong fit for K-12 Earth science because Earth systems can be observed, measured, mapped, and discussed through local examples. Semken et al. (2017) described place-based education in geoscience as a context-rich approach that connects learning to places that people know, experience, and value. A schoolyard, stream, neighborhood, road, watershed, coastline, urban heat island, or stormwater system can therefore become an entry point for disciplinary science learning (Semken et al., 2017).

Place-based learning should not remain only local; it can begin with nearby phenomena and then connect those observations to regional, national, and global Earth systems. For example, temperature patterns on school grounds can be connected to weather systems, land cover, urban heat, and climate trends, while a local flooding concern can be connected to watershed processes, land use, precipitation intensity, soil infiltration, and stormwater management (National Research Council, 2012; Semken et al., 2017). This movement from local observation to broader Earth system explanation is central to strong geoscience learning.

Place-based Earth science education can also improve relevance because it helps learners see how geoscience informs environmental and community decisions. Metzger (2024) argued that geoscience education should be reimagined so learners understand the role of geoscience in sustainability challenges related to climate change, water resources, natural hazards, and human-Earth interactions. Climate education research similarly suggests that learning is stronger when instruction is personally relevant, uses active engagement, addresses misconceptions, and connects to scientific process or community action (Monroe et al., 2019).

Climate, Water, and Natural Hazards as K-12 Earth Science Anchors

Climate, water, and natural hazards can serve as anchors for standards-aligned Earth science instruction. National science education guidance emphasizes scientific practices, crosscutting concepts, disciplinary core ideas, and equitable opportunities for students to engage in meaningful science learning (National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012, 2013). These anchors can help teachers connect Earth systems content to inquiry, data analysis, modeling, explanation, and evidence-based argumentation.

Water is a useful anchor because it connects Earth science content to local experience. Students can investigate precipitation, runoff, infiltration, groundwater, surface water, watersheds, water quality, erosion, and flooding, all of which connect physical Earth processes to human decisions about land use, infrastructure, agriculture, recreation, and public health (Earth Science Literacy Initiative, 2010; National Research Council, 2012). A water-centered unit can also connect science practices to authentic data sources such as rainfall records, stream gauge information, flood maps, land cover maps, or water quality reports.

Natural hazards provide another strong anchor because they require students to understand both Earth processes and human exposure. Earth science instruction should help students distinguish between a natural process and the risk that emerges when people, buildings, infrastructure, or ecosystems are exposed to that process (Boyd et al., 2022; Crimmins et al., 2023; Federal Emergency Management Agency, 2017). Teaching this distinction helps students move beyond fear-based disaster lessons toward evidence-based hazard understanding.

An Instructional Framework for Earth Science and Preparedness

A practical K-12 framework can help teachers connect Earth science learning to community preparedness without sacrificing academic rigor. The proposed framework includes four instructional moves: observe local phenomena, explain Earth system processes, analyze community risk, and communicate preparedness decisions. Each move should be aligned to grade-level standards, disciplinary core ideas, science and engineering practices, and developmentally appropriate expectations (National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012, 2013).

The first instructional move is to observe local phenomena. Students begin with something they can see, measure, map, or describe, such as standing water after a storm, temperature differences between paved and shaded areas, erosion near a sidewalk, cloud patterns before a storm, sediment in a stream, or evidence of drought stress in vegetation. Observation supports place-based geoscience learning because it helps students generate questions from familiar places and examine local evidence (National Research Council, 2012; Semken et al., 2017).

The second instructional move is to explain Earth system processes. Students use disciplinary concepts to explain what they observed, such as watersheds, runoff, infiltration, soil saturation, precipitation intensity, streamflow, energy transfer, surface materials, albedo, land cover, air masses, pressure systems, moisture, fronts, and forecast uncertainty (Earth Science Literacy Initiative, 2010; National Research Council, 2012). This move keeps preparedness learning rooted in Earth science rather than general awareness alone.

The third instructional move is to analyze community risk. Students examine how Earth system processes interact with human systems, including infrastructure, land cover, building location, drainage, vegetation, and preparedness practices. This analysis should remain evidence-based and age-appropriate, and it should connect hazard science to community resilience without asking students to draw unsupported conclusions about individual households or private property (Boyd et al., 2022; Federal Emergency Management Agency, 2017).

The fourth instructional move is to communicate preparedness decisions. Students use evidence to explain what individuals, families, schools, or communities can do before, during, or after a hazard, using products such as posters, brief reports, maps, classroom presentations, family information sheets, or school preparedness recommendations. Preparedness communication should be grounded in credible science, local conditions, and responsible risk communication rather than safety slogans alone (Federal Emergency Management Agency, 2017; Geological Society of America, n.d.; Monroe et al., 2019).

Practical K-12 Learning Activities

Teachers can apply the framework through manageable activities that fit within existing science courses. One activity is a schoolyard runoff investigation in which students compare how water moves across grass, soil, gravel, and pavement after rainfall or a simulated water application. Students can measure infiltration, observe flow paths, identify low areas, and explain how land cover affects runoff, which supports Earth system thinking about water, erosion, flooding, and stormwater management (Earth Science Literacy Initiative, 2010; National Research Council, 2012).

A second activity is a local weather data investigation. Students can collect or access data on temperature, precipitation, humidity, wind, or air pressure and compare patterns across days or seasons. This activity aligns with science practices because students analyze data, develop evidence-based claims, and consider uncertainty rather than only memorizing weather vocabulary (National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2013).

A third activity is community hazard map analysis. Students can examine publicly available maps such as floodplain maps, watershed maps, elevation maps, land cover maps, or heat maps and ask how physical geography and human development shape risk. Teachers should structure this task so students do not identify private homes or vulnerable individuals, while the instructional focus remains on Earth science concepts, spatial reasoning, data interpretation, and responsible communication (Boyd et al., 2022; Federal Emergency Management Agency, 2017; Semken et al., 2017).

A fourth activity is a preparedness communication project. Students can identify an Earth science hazard relevant to their community, gather credible information, and create a brief evidence-based communication product for a school or family audience. This activity should be evaluated for scientific accuracy, evidence use, clarity, and audience appropriateness, which aligns with research emphasizing active, relevant, inquiry-based climate and environmental learning (Monroe et al., 2019; National Academies of Sciences, Engineering, and Medicine, 2021).

Equity and Access in Earth Science Learning

Equity matters in Earth science education because students do not all have the same access to high-quality science learning, and communities do not experience environmental risks in identical ways. The National Academies of Sciences, Engineering, and Medicine (2021) called for better and more equitable science education across K-16, including attention to opportunity gaps and science learning experiences that prepare students for civic and career participation.

Earth science education can contribute to that goal by giving students access to meaningful learning about the Earth systems that shape their communities.

An equity-oriented Earth science classroom should avoid treating students as representatives of a single neighborhood, culture, language, income group, or hazard experience. Some students may have direct experience with flooding, evacuation, housing instability, extreme heat, or disaster recovery, while others may not. Teachers can invite student voice without requiring students to disclose personal or family experiences, a caution that aligns with place-based education's attention to local context and with national guidance on inclusive science learning (National Academies of Sciences, Engineering, and Medicine, 2021; Semken et al., 2017).

Equitable Earth science education should include multiple ways for students to participate, including observation, mapping, drawing, measuring, discussing, writing, modeling, graphing, and presenting. English learners and students with disabilities may benefit from visual data, structured sentence frames, collaborative investigations, and multimodal products, while academic expectations remain rigorous (National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012). These access points support evidence-based reasoning without lowering the disciplinary demands of Earth science learning.

School Leadership and Implementation Considerations

Curriculum leaders play an important role in helping Earth science and preparedness learning move from isolated teacher effort to sustainable practice. Schools can begin by identifying where Earth systems, weather, climate, water, natural hazards, and human impacts already appear in the curriculum. This type of curriculum audit can help teachers locate natural points of integration and align Earth science learning with disciplinary core ideas, crosscutting concepts, and science and engineering practices (National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012, 2013).

Professional learning is also necessary. Boyd et al. (2022) found that teachers identified barriers to natural hazards and community resilience instruction, including limited alignment, time, and background knowledge. School leaders can respond by supporting teachers with standards-aligned resources, local data sources, collaboration time, and partnerships with science agencies, emergency managers, universities, museums, and environmental organizations (Boyd et al., 2022; Federal Emergency Management Agency, 2017; Geological Society of America, n.d.).

Implementation should protect academic neutrality and scientific integrity. Earth science instruction should help students evaluate evidence, understand uncertainty, and distinguish credible scientific sources from unsupported claims, which is consistent with national science education guidance and climate education research (Monroe et al., 2019; National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012). The strongest approach is inquiry-based, evidence-informed, and developmentally appropriate.

Cautions for Earth Science Preparedness Education

Several cautions are important when connecting Earth science education to preparedness. First, teachers should avoid reducing Earth science to emergency tips because preparedness messages are most meaningful when they are built on disciplinary understanding. A lesson on tornado or flood safety should therefore connect to weather systems, forecast evidence, watershed processes, precipitation, runoff, land cover, and topography (Federal Emergency Management Agency, 2017; National Research Council, 2012).

Second, teachers should avoid presenting natural hazards as isolated disasters disconnected from Earth systems. Hazards become scientifically understandable when students examine processes, patterns, timescales, exposure, vulnerability, and human decisions. Earthquakes, floods, droughts, landslides, wildfires, hurricanes, and heat events each require scientific explanation, credible evidence, and age-appropriate analysis (Boyd et al., 2022; Crimmins et al., 2023; Earth Science Literacy Initiative, 2010).

Third, teachers should use care when discussing climate change. Climate learning should be grounded in credible scientific sources, evidence, models, and age-appropriate instructional design. The Fifth National Climate Assessment synthesizes climate impacts, risks, and responses across U.S. regions, and climate education research suggests that effective instruction should be personally relevant, engaging, deliberative, and connected to scientific process (Crimmins et al., 2023; Monroe et al., 2019).

Fourth, teachers should avoid unsupported local claims. A school may have a history of flooding, severe storms, heat concerns, or water quality questions, but students should be taught to verify claims with credible data before drawing conclusions. This distinction helps students develop scientific literacy and protects the credibility of Earth science instruction (Geological Society of America, n.d.; National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2012).

Conclusion

K-12 Earth science education can strengthen community preparedness when students learn to connect Earth systems, local data, natural hazards, and evidence-based decision-making. This manuscript proposed a place-based instructional framework built around four moves: observing local phenomena, explaining Earth system processes, analyzing community risk, and communicating preparedness decisions. The framework is consistent with geoscience education research, Earth science literacy guidance, natural hazards education research, and national science education guidance (Boyd et al., 2022; Earth Science Literacy Initiative, 2010; National Academies of Sciences, Engineering, and Medicine, 2021; Semken et al., 2017).

Earth science education should not be limited to vocabulary, textbook diagrams, or isolated hazard safety messages. It should help students understand water systems, weather patterns, climate processes, landforms, natural hazards, resources, and human interactions with Earth systems (Earth Science Literacy Initiative, 2010; National Research Council, 2012). The literature on place-based geoscience education, climate education, natural hazards education, sustainability, and K-12 science learning supports the value of connecting science instruction to local phenomena, credible data, and authentic problems (Boyd et al., 2022; Metzger, 2024; Monroe et al., 2019; Semken et al., 2017).

For teachers and curriculum leaders, the practical task is to design Earth science learning that is scientifically accurate, locally meaningful, standards-aligned, and accessible to all students. When implemented carefully, place-based Earth science education can help students understand their environments, evaluate evidence, communicate risk responsibly, and participate more thoughtfully in school and community preparedness. In this sense, Earth science education can function as both a disciplinary learning priority and a practical contribution to resilient communities (Federal Emergency Management Agency, 2017; National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2013).

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