Cause and effect as a lens and thinking tool to observe and make sense of two puzzling phenomena.

By Lindsey Mohan, Emily Harris, and Candice Guy-Gaytán

A circle of fourth-grade students sit around Mrs. Ray, who shows videos and images of two natural events: large rocks that have fallen from a cliffside and large rocks in the middle of a dry stream near a road. She asks, “What caused these events to happen? How do we think the changes caused by these events affected the land, waters, and living things?” Her students share their initial ideas. For the first event, a student suggests, “a big gust of wind pushed on a weak rock.” A second says, “maybe there was an earthquake and it shifted.” Mrs. Ray records students’ ideas on an initial class model. Then she focuses students on potential effects. Students share concerns about drinking water for animals, blocked waterways causing flooding, and “cracked trees” that are homes to birds and small critters. Mrs. Ray points to the second event and asks students to consider its causes and effects. A student says, “maybe the rocks were on the side of the river and the river flooded and the rocks went into the river and smashed together.” For possible effects, students share that maybe, “the road got blocked” and “cars got stuck on the road.” Mrs. Ray asks, “How sure are we about our ideas? Do we have any questions we’re wondering about?”

This classroom example demonstrates the rich conversations that can unfold when a crosscutting concept (CC), in this case, cause and effect, is used to support students in making sense of phenomena. A Framework for K–12 Science Education explains that CCs help students to develop “an organizational framework for connecting knowledge” (NRC 2012, p. 83). Since CCs transcend any one science discipline, they enable students to connect knowledge across school years, between science disciplines, and across other disciplines, like the social sciences and language arts. Such connected knowledge better prepares students to use science to make sense of what they experience in their lives, especially outside the classroom walls (Anderson et al. 2019).

While CCs were once backgrounded in the national standards (Goggins et al. 2019), the Next Generation
Science Standards (NGSS Lead States 2013) integrate them with the science and engineering practices (SEPs) and disciplinary core ideas (DCIs) to form three-dimensional standards. This integration pushes educators and curriculum developers to think more deeply about how to support the regular use of CCs alongside the other dimensions of science learning. This article offers examples of how we designed learning experiences to intentionally integrate one CC, cause and effect, with science and engineering practices (SEPs) to support students in observing, investigating, and making sense of phenomena.

Cause and Effect as a Core Unit Crosscutting Concept

Cause and effect is a central CC in science. In science, we look to uncover causal mechanisms to explain how or why something happens, making it essential to scientific work. Young learners engage with causal reasoning even before kindergarten and as learners investigate increasingly complex phenomena in schooling, their causal reasoning should expand and grow to make sense of that complexity (Grotzer and Tutwiler 2014). This growth in causal reasoning requires carefully designed learning experiences during elementary years to lay a solid foundation.

We as science curriculum developers partnered with upper elementary teachers to develop a fourth-grade storyline unit focused on weathering and erosion. The unit is composed of eight lessons that span four to six weeks depending on instructional minutes per week. The unit integrates ESS2.A: Earth Materials and Systems with cause and effect as students engage in asking questions and defining problems, developing and using models, planning and carrying out investigations, and engaging in arguments from evidence. We share how we integrated our core crosscutting concept, cause and effect, in two ways across the unit. First, as a lens when making observations about phenomena (Duncan and Cavera 2015), and second, as a thinking tool to support sensemaking about phenomena.

Using Cause and Effect as a Lens to Observe Phenomena

Our unit begins with students making observations about two locations where large rocks appeared in a new place quickly. In the first location, students observe large rocks in Yosemite Valley and watch a video of rocks breaking off a rock wall above the valley. In the second location, students observe large rocks next to a road in Glen Canyon. Students use Google Earth to look closely at the area where the rocks are located and notice a dry streambed and desert landscape. As students make observations, the teacher prompts them to think about: “How did these rocks and dirt end up in new places and how did this affect the area?” This immediately cues students to think in terms of causality.

From the beginning of the unit, students interrogate the anchoring phenomena through the lens of cause and effect. Rivet et al. (2016) explain that when a CC is used as a lens, it can be “a means of observing and seeing salient features of phenomena” (p. 971). Framing observations with a CC affects what students pay attention to. After making initial observations, one student shared, “The big question for me was how it all happened. How it caused … like, what made the rock fall or this one fall or mudslide or rockslide happen?” Imagine if another CC, like patterns, had been used as a lens instead. Students may focus on when the events happen, where they happen, and how often they happen. With a different CC as a lens, other features of the same phenomena become more salient. In the unit we describe, students are consistently cued to pay attention to causal mechanisms (“how” and “why”) and causal relationships. The choice of CC to guide observations of phenomena impacts the kinds of investigations and sensemaking that follow.

Using Cause and Effect as a Thinking Tool to Make Sense of Phenomena

Using a CC as a thinking tool for sensemaking can focus students’ attention and engagement with science and engineering practices (SEPs) as they investigate and explain phenomena. By thinking tools, we mean structures and techniques built into the materials or used by the teacher to guide and support students. We integrated cause and effect thinking tools with four SEPs, resulting in the following kinds of learning experiences:

• Having students develop and revise models to explain the causes and effects of phenomena
• Prompting students to ask cause-and-effect questions
• Comparing observed effects and their causes through planning and carrying out investigations
• Having students construct arguments about likely causes of phenomena

Developing and Revising Models to Explain the Causes and Effects of Phenomena

Throughout the unit, students iteratively develop and revise a conceptual class model to explain (1) what could have caused the rocks to break apart, (2) what could have caused the rocks and dirt to move to new places, and (3) what effects these events have on the land, water, and living things. To support students in sharing their initial ideas, in the first lesson, students use a template to help them model the causes and effects of the Yosemite and Glen Canyon phenomena. The template contains prompts for students to use a zoom-in bubble to depict how one potential cause could break or move rocks (see Figure 1). Students also record written ideas for possible causes and effects. The zoom-in bubble on the template is a scaffold to help students get started, which is particularly valuable for students who may be overwhelmed by starting a model on a blank page.

Students use their individual models to collectively develop an initial class model to capture multiple possible causes and effects, as shown in the opening vignette (see Figure 2). The class modeling process cues students to brainstorm and represent a range of ideas for causes first, followed by effects. Eliciting a range of possible causes for the initial class model invites participation from all students and communicates that there are no single right answers as we begin our learning together. The class model is revised at the end of subsequent lessons when students can draw on evidence from investigations to revise it. For example, following the investigations, students revise the class model with their new understanding of mechanisms that can break apart and move rocks and the impact of these processes. To support productive discussions for all students, establish norms for equitable participation, such as norms that value everyone’s ideas and ones that help the class see themselves as a community learning together.

Prompting Students to Ask Questions with Cause and Effect

After students generate initial ideas for causes and effects of the two puzzling phenomena, they identify areas of uncertainty in their explanations. They use these areas of uncertainty to pose questions. The questions are posted to the class Driving Question Board (DQB). A DQB is a tool used across the unit to track student questions. Questions are usually organized into clusters of related questions (see Figure 3). These questions from students are used to motivate investigations and become the class mission to figure out during the unit.

To support students in turning their uncertainties into questions, the teacher uses cause and effect to guide students in asking questions. The teacher prompts students to first write questions about the possible causes of the two phenomena. Students are cued to draw upon their initial models for causes and turn their ideas into questions they can investigate. Students are then cued to write and post questions about the possible effects. Intentional teacher prompting first around possible causes and next around effects focuses students’ attention as they write questions. Table 1 summarizes example teacher prompts and the resulting student questions generated through this process. Cause and effect is the core crosscutting concept around which subsequent investigations are designed,
so it is essential for students to generate cause and effect questions that will motivate the rest of the unit. Teachers can provide cause-and-effect question starters to students who need additional support. This is especially beneficial to emergent multilingual students. Questions starters may include:

- How did ___? Why did ___?
- How can ___ cause a rock to ____?
- What happens if we test ____?

**Comparing Observed Effects and Their Causes Through Planning and Carrying Out Investigations**

To investigate their questions, students use physical models to test potential causes. In one investigation, students use model rocks made of plaster with cracks in them. Students use these model rocks to test if seepage of water in the cracks combined with the weather conditions in Yosemite could explain the rocks breaking apart. In a second investigation, students test how the slope and amount of water affect the movement of rocks. Using a model landscape of Glen Canyon—a gutter with sand at the top—students first gather baseline data. To do this, they pour one cup of water through the gutter and observe how the sand moves, how far it moves, and how quickly it moves. Next, they change their setup to conduct a fair test. They add either more water or adjust the slope.

Before using the physical models, teachers can create an analogy map to help students connect the parts of the physical model to the real world. For example, the water poured on the gutter represents rainfall and runoff in the real world.

**TABLE 1**

<table>
<thead>
<tr>
<th><strong>Example teacher prompts</strong></th>
<th><strong>Example student questions</strong></th>
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<tbody>
<tr>
<td><strong>Cause</strong></td>
<td></td>
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<tr>
<td>What questions do you have about what causes rocks to break apart?</td>
<td>How could a storm cause it to break?</td>
</tr>
<tr>
<td>What questions do you have about what causes rocks and dirt to move to new places?</td>
<td>Was there an earthquake?</td>
</tr>
<tr>
<td>It looks like we have questions about ___ and ___ as possible causes. Are there other possible causes we haven’t asked a question about yet?</td>
<td>How did they (rocks) get weak?</td>
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<tr>
<td></td>
<td>Can ice break rocks?</td>
</tr>
<tr>
<td></td>
<td>Was there water that moved the rocks?</td>
</tr>
<tr>
<td></td>
<td>Can a windstorm pick up a boulder?</td>
</tr>
<tr>
<td></td>
<td>Did water make the rocks move faster?</td>
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<tr>
<td><strong>Effect</strong></td>
<td></td>
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<tr>
<td>What do you wonder about the effect these changes have on the land, water, and living things?</td>
<td>How many trees did it knock down?</td>
</tr>
<tr>
<td>Have we asked questions about the potential positive and negative effects of these events?</td>
<td>Did anyone get hurt?</td>
</tr>
<tr>
<td></td>
<td>Did the rocks dry the water up?</td>
</tr>
<tr>
<td></td>
<td>Why was the dirt wet?</td>
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Analogy mapping can help some students better understand how the test they are conducting in the classroom will help them figure out the phenomena in the world. Students are provided an investigation template to guide how they set up investigations to test different causes and document observations. Students are heterogeneously grouped
and select different roles (e.g., a technician measures gutter height) to facilitate the small-group investigation process. The template they use includes an if-then thinking tool to compare results. The if-then tool makes explicit cause and effect by cueing students to pay attention to the cause (if we do ____) and the observed effect (then we see ____). This tool helps students compare the observed effects from the experimental setup compared to the baseline setup to draw cause-and-effect conclusions from their investigations (see Figure 4).

**Constructing Argument From Evidence About Likely Causes**

Geologists cannot always determine with certainty what causes different geologic events. Instead, they may say there are several contributing factors and articulate some of the obvious ones. Our unit takes a similar approach. Students make claims about likely causes and support their claims with evidence. After the investigations, students make arguments to answer the question, *How did the boulders, rocks, and dirt end up in these places?* Students are guided through the argumentation process with a thinking tool that scaffolds their writing. The tool first cues students to write a claim about a likely cause(s). Students are then prompted to support their claim with evidence from investigations (see Figure 5). The tool pushes students to articulate evidence they have observed connected to the cause they identify in their claim. If students have had practice writing claims supported by evidence and no longer need the scaffold, it can be removed from the handout. Those students who still need support in writing arguments can continue to use the scaffold.

This argument prepares students for the final unit assessment in which students observe new phenomena in a community park. Students receive a park map with images of five different locations that show cracked sidewalks and sediments on pathways as well as annual average temperature and precipitation data for the park. Their task is to identify two different places—one where weathering is happening and one where erosion is happening—and develop an argument for what likely caused weathering or erosion supported by evidence (see Figure 6 for example of one student’s argument about what caused weathering at the park steps location). Assessment guidance focuses on looking for students supporting claims using evidence from what students observe in the images, the data, and investigations they’ve done throughout the unit (see Table 2).
Conclusions

In this article we share a unit that integrates the crosscutting concept of cause and effect. Unit materials help students use cause and effect as a lens to observe phenomena and as thinking tools to support sensemaking. The materials coupled with teacher facilitation strategies, guide students toward developing evidence-based mechanisms to explain phenomena. The consistent use of cause and effect across the learning activities helped students to use the CC more independently. One teacher reflected that at the end of the unit, “I’ve noticed that my students are using that language [cause and effect] in their conversations especially when we did our argument activity.” Students needed support to achieve this kind of success. Students not only demonstrated a deeper understanding of the causal relationship in the phenomena they investigated but repeated practice with the CC indicated students were using it more autonomously over time.

Final unit assessment guidance for question 1 about weathering.

Three-dimensional learning goal for the final unit assessment:
I can develop an argument for what likely caused weathering and erosion at two places in the park.

In Question 1 responses, look for:
Students supporting claims about one or more likely causes of weathering with evidence from what they observe in the images, the weather data, and investigations throughout the unit. Pay attention to students’ claims and evidence to see if they demonstrate their understanding of how water, ice, living organisms, and/or gravity break apart earth materials.

<table>
<thead>
<tr>
<th>Possible claims</th>
<th>Examples of evidence</th>
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| Freezing ice expanded and caused park steps (#2) or a pathway in the park (#5) to crack. | • In the weather data for the park, I observed the temperature go below and above freezing.  
• In the Lesson 2 investigations and optional readings, I saw that pushes from expanding ice can create larger cracks and break rocks or concrete. |

Weathering is not obvious in all of the images. However, it is happening at a zoomed-in scale. Students may correlate what caused weathering here with the evidence from previous lessons. If they support their example with evidence, you can follow up by asking what it might look like if we zoomed in.
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Supplemental Resources

PeBLES2 Project Website: https://sites.google.com/mmsa.org/pebles2/about-the-project

REFERENCES


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