The Importance of Phenomena in Science and Engineering

I grew up in Biddeford, a small town in Maine next to the Saco River, where a waterfall used to power large textile mills. On the other side of the river was our twin city, Saco. When I was in middle school I walked to school every day. The first mile was nearly flat. Then I came to an abrupt downhill slope for the last quarter mile to my school, which was near the river. If I wanted to visit my cousin in Saco and couldn’t get a ride, I’d have to cross a bridge and walk up a steep hill, where again the terrain became nearly flat for some distance.

I remember reading in our middle school science book about river valleys, including “V-Shaped” young valleys that were etched deeply into the ground by rapidly flowing water, and “U-Shaped” mature valleys that formed as the walls of the valley gradually eroded. But it was not until many years later that it occurred to me that our school was in a river valley. In hindsight, our science teacher might have used our daily journeys to school, from different parts of the city, as an interesting phenomenon to kick off a unit about the role of erosion in sculpting geological formations.

Enabling students to explain phenomena has always been a goal of science education, but in the era of NGSS, engaging students in science and engineering practices and crosscutting concepts in order to learn about phenomena requires a new approach. A brief on the role of phenomena on the Next Generation Science Standard* (NGSS) website explains that: “Phenomena are observable occurrences. Students need to use the occurrence to help generate the science questions or design problems that drive learning.” The brief describes two kinds of phenomena: anchoring phenomena that provide the overall focus for a unit or lesson, and investigative phenomena that students explore in the course of a coherent series of activities.” Phenomena can either refer to occurrences in the natural world of the traditional sciences, or in the designed world of technology and engineering.

Choosing the right phenomenon to anchor a lesson is critical. The phenomenon needs to be both familiar to the students and sufficiently interesting to stimulate their curiosity. It also needs to lead to investigations that target core ideas, crosscutting concepts, and practices that form the objectives of the lesson, while leaving room for genuine student inquiry or creative design processes.

"HMH Into Science™ begins each lesson with an anchoring phenomenon designed to capture students’ interest. A driving question about the phenomenon elicits their initial ideas, and launches a series of further questions and activities in which students explore related investigative phenomena. At the end of the lesson, and perhaps once or twice during the lesson, students revisit the anchoring phenomenon and offer new explanations in light of what they’ve learned so far.

FIFTH-GRADE EXAMPLE: Plants Transform and Use Energy and Matter

In this first lesson of a unit on energy and matter in organisms, students are confronted with a phenomenon that is likely to be quite surprising—a thriving lettuce garden that uses no soil. This phenomenon was selected to help counter a common misconception, that plants derive most of their mass from soil. In fact, it is carbon from carbon dioxide in the air combined with water and

energy from sunlight that allows plants to grow through the process of photosynthesis. Even huge trees are composed almost entirely of carbon from the air, with trace nutrients dissolved in water.

After a couple of questions to get students thinking about lettuce growing without soil, they are asked the question that drives the lesson: **How do these plants get the energy and matter they need to grow without soil?** Students share their initial ideas without guidance from the teacher at this stage.

The first investigative phenomenon that students address is that plants need sunlight. To introduce this idea, students are asked to think about why rainforests, that have thick canopies, have few young trees growing in them. Students then devise a fair test of their ideas. For example, testing the idea that young trees may not grow in shade might involve comparing the growth of two recently sprouted seeds that are similar in all ways, except that one is kept in shade, and the other in sunlight.

In order to maintain interest on the driving question, students next perform an experiment to see if the mass of a growing plant comes from the soil. They weigh a seed or seedling. They also weigh a pot of dry soil. They then plant and water the seed or seedling. After six weeks they remove the plant from the soil and weigh it. They also dry the soil and weigh it again. They then have evidence that although the plant has gained a measurable amount of mass, the soil has lost little or none.

Continuing their investigation of what plants need to grow, students discuss what happens to plants that do not receive water regularly. They also learn about nutrients dissolved in water that plants take in through their roots.

If plants are grown without soil, it is important to be sure that the proper nutrients are dissolved in the water.

Next students see magnified views of the underside of a leaf, noting tiny holes where air enters and leaves the leaf. These tiny holes provide evidence that plants also need air to grow.

Students are then shown an illustration of how plants combine sunlight, air, and water with nutrients to produce food for the plant. They then apply what they learned to the driving question: How do these plants get the energy and matter they need to grow without soil? To further reinforce the idea that plants can indeed grow without soil, the students see an image of a potato that has been left in water for several days, which now has roots and is beginning to sprout.

The phenomena in the unit are diagrammed below. Notice that there are two overarching investigative phenomena that are needed to answer the driving question. The first is that plants combine water, air, and sunlight to produce food (sugar) to grow. Although this idea is introduced at the end of the lesson, it depends on understanding of three phenomena that students investigated earlier in the lesson: that plants require sunlight, water with nutrients, and air. The other overarching investigative phenomenon is that plants do not get their mass from the soil. This second phenomenon is important to counter a common misconception. Although students are not expected to develop a full understanding of photosynthesis at this level, including the idea that plants utilize the carbon dioxide in air for most of their mass, these preliminary phenomena help students prepare for that more complex understanding later on.
Criteria for Using Phenomena to Drive Instruction

The NGSS Early Implementers Initiative in California is a multi-year effort to implement new science education standards in ten pilot districts, involving hundreds of teachers and tens of thousands of students. Experience from the first four years of the effort led to the following criteria for selecting the most useful phenomena to drive instruction. These criteria offer an excellent summary of the way phenomena are chosen and applied in the examples cited above:

• Can students observe and/or investigate the phenomenon, either through firsthand experiences (e.g., directly in a classroom, lab, or outdoor environment) or through someone else’s experiences (e.g., through video presentations, demonstrations, or analyzing patterns in data)?

• Do students have to understand and use science and engineering practices, disciplinary core ideas, and crosscutting concepts to explain how and why the phenomenon occurs?

• By making sense of the phenomenon, are students building understanding toward grade-level performance expectations?

• Would student explanations of the phenomenon be grade-level appropriate?

• Is the phenomenon relevant to real-world issues or to the students’ local environment?

• Will students find making sense of the phenomenon interesting and important?

• Does the potential student learning related to the phenomenon justify the financial costs and classroom time that will be used?

To the extent possible, teachers are also encouraged to think about ways that the anchoring phenomenon of the unit might relate to local phenomena. Perhaps a suggestion of that sort, given to my own middle school science teacher decades ago, might have helped him realize that our lesson on river valleys could be far more meaningful and memorable if he started out by asking us to think about the phenomenon of walking down a steep hill to our school, near the Saco River, and then led us to explain that phenomenon by thinking about how water shaped the entire Saco River Valley over thousands of years.