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Teaching Science in the Natural World

By: Mike Marvel, PhD, Manager of Product Management

What Are Phenomena?

The Next Generation Science Standards (NGSS) emphasize the practice of science rather than the learning of disciplinary facts alone, isolated from the context of the natural world. Phenomena, which enable this kind of science education, are often classified as two types: anchoring, which typically serve as foci for an entire unit, and investigative, which serve as foci for a single lesson or short instructional sequences. We can observe phenomena in the natural world and use the **Disciplinary Core Ideas (DCIs)** of the physical, life and earth sciences to provide explanation. In NGSS, the seven **Crosscutting Concepts (CCCs)**, such as Patterns and Energy and Matter, are shared across the different disciplines and are also used to explain phenomena. The application and unpacking of the **DCIs** and **CCCs** requires the use of one or more of the eight **Science and Engineering Practices (SEPs)**, which include Planning and Carrying out Investigations and Analyzing and Interpreting Data.

The "Thinking Like Scientists" example detailing Rutherford and Chadwick's investigation is an example of NGSS in action. Rutherford began with an **observation of a phenomenon (scattering of alpha particles by gold foil)** and, working with a **DCI** in mind **(matter was made up of atoms)**, questioned the nuclear composition of the atom. He determined through **experimentation and data analysis (SEPs)** that there must indeed be a small, dense nucleus. He further questioned the ability of the nucleus to maintain stability if only protons were present. From there, James Chadwick conducted a series of investigations with a new **DCI** in mind **(the existence of a stable nucleus)** and determined that a heavy, uncharged neutron was present in the nucleus and responsible for nuclear stability. Present throughout this entire process were the **CCCs** Cause and Effect and Energy and Matter.

Thinking Like Scientists: *Studying Phenomena at University of Cambridge's Cavendish Laboratory*

The NGSS provide a framework in which students are meant to think like scientists. To help conceptualize this idea, imagine being present in the University of Cambridge's Cavendish Laboratory during the early part of the 20th century when Ernest Rutherford and James Chadwick were investigating the nuclear constitution of the atom. At this time, scientists agreed that **matter was made up of atoms.** Rutherford knew there was more to learn about the atom and directed two of his students, Hans Geiger and James Marsden, to bombard gold foil with alpha particles, expecting that they would observe high-angle scattering (i.e., alpha particles that bounced off the gold foil as opposed to passing directly through it). **Geiger and Marsden did indeed observe small amounts of such scattering**, which led Rutherford to hypothesize that **most of the mass of the atom was contained in a small, dense nucleus that held protons**. This hypothesis led Rutherford to question why the nucleus did not break apart because of the repulsive interactions between protons.

With this in mind, James Chadwick **bombarded beryllium atoms with alpha particles** to study the radiation emitted by the beryllium as a result. When that radiation interacted with paraffin wax, it dislodged protons from the paraffin and the protons subsequently moved at a high velocity. At the time, scientists thought that the radiation emitted by the beryllium atoms must be high-energy photons, but Chadwick felt that this could not be the case because photons had no mass and could not be expected to knock anything loose from a target. As a result, he believed the emitted species was something relatively heavy and uncharged. He called this particle a neutron, owing to its ability to penetrate deep into a target without being repelled by positive protons or negative electrons.

Thinking Like Scientists—in a K–12 Classroom!

Of course, the Cavendish Laboratory and the K–12 classroom are two very different environments. Teachers must develop leading questions and phenomena with time and resource constraints in mind; they cannot devote as much time to the atom's nuclear constitution as Rutherford did! Teachers must devise phenomena that engage and expose students to a larger set of disciplinary core ideas (facts) than those pertinent only to the atom. In addition, teachers face the challenge of having to rigorously manage the paths students follow as they construct explanations of phenomena. In a university lab, scientists can liberally pursue unexpected results because they are not required to "cover" a specific set of **DCIs**. In contrast, K–12 teachers must manage the sequence of investigations that students engage in so they have been adequately exposed to the NGSS by the end of the process.

> **Teachers must develop leading questions and phenomena with time and resource constraints in mind."**

5 Characteristics of NGSS Phenomena

- Phenomena must be **relatable** (i.e., they must hold some significance for students, culturally or otherwise).
- Phenomena and leading questions should be **open-ended** and not easily explained with "yes" or "no" answers. Instead, their explanations must push students beyond what is readily accessible from perusing the Internet or a textbook.
- Phenomena should, through their explanation, expose students to a desirable set of **DCIs**, **CCCs** and **SEPs**. In other words, phenomena should be **pertinent** to a practical number of NGSS so students do not miss out on important elements.
- Phenomena should be **mapped out** prior to their use with students. Teachers should spend time constructing their own explanations of phenomena in advance so they can be prepared to answer expected and unexpected student questions. Unexpected questions can occur when students harbor misconceptions. Effectively addressing misconceptions requires some thought by the teacher prior to introducing the leading question or phenomena so the leading questions do not elicit answers based on misconceptions.
- Phenomena do not need to be flashy; they only need to generate good questions that lead students to further **inquiry** and application of **DCIs**.

Phenomena are not as useful if students are required to know target knowledge ahead of time. This leads to a more prescriptive, less student-generated science experience.

Lightning is one of many natural phenomena that leads to driving questions.

Framing the Investigation

The following are some examples of phenomena/anchoring questions:
- Why does nail polish remover evaporate more quickly than water?
- Why are some bacteria so difficult to kill with antibiotics?
- How is it possible for a huge oak tree to grow from a tiny acorn?

Phenomena such as these provide focal points and coherence to instructional sequencing. Student explanations require them to apply a predetermined set of **DCIs** and **CCCs** through engagement with the **SEPs**. For example, the scientific explanation of the phenomenon based on tree growth is unlikely to require the application of a **DCI** related to atomic structure, so if a teacher wants to cover that **DCI**, the phenomenon will need modification or replacement. Alternatively, a teacher can choose to focus on student lines of inquiry that lead to the investigation of chemical reactions in photosynthesis and subsequently to the reactivity of the oxygen molecule as it relates to the atomic structure of a single oxygen atom. Regardless of the direction, the explanation of a phenomenon requires students and teachers to generate compelling questions, unpack and bundle **DCIs** and use **SEPs** and **CCCs** to meet performance expectations, all while learning that science is an endeavor within the NGSS framework.

NGSS Implementation: One Size Does Not Fit All

There are many different perspectives on what implementation of the NGSS should look like in the K–12 classroom. Some teachers exclusively rely on anchoring phenomena to form the basis for months-long units while others choose to implement investigative phenomena that can be explained in the course of days or weeks. Regardless, most seem to agree that NGSS implementation is a challenge.

Don't be afraid to start small with a single lesson or unit. This can help build confidence as you get a feel for the things that help your students go from phenomena to explanations. Recognize that your implementation will be a process that will look a lot different as you and your students gain experience. "Real" scientists' work is often characterized by equal parts frustration and reward. For example, most chemists who work in pharmaceutical labs go their entire careers without working on molecules that ever make their way into a single person's body. However, along the way they advance the discipline so one day a different scientist might arrive at a viable medication. Your NGSS journey may feel both rewarding and frustrating at times. When this happens, you will know you are on the right track.

> **"Don't be afraid to start small.**

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