

Three-dimensional Learning in *Carbon TIME*

Carbon TIME assessments and units are organized around a fundamental goal of supporting teachers in *assessing and scaffolding students' three-dimensional engagement with phenomena*. This goal is based on a careful analysis of the *Next Generation Science Standards* and their source document, the National Resource Council's *Framework for K-12 Science Education*. A list of specific NGSS Performance Expectations for each unit is in the [NGSS Mapping](#) document in the Educator Resources Library. These performance expectations include:

- All eight science practices, organized into three clusters (see Figure 2 below).
- Crosscutting concepts, with a special emphasis on (a) scale, proportion, and quantity; (b) systems and system models; and (c) energy and matter: flows, cycles, and conservation.
- Disciplinary core ideas in the life sciences (LS1: From molecules to Organisms: Structures and Processes; LS2: Ecosystems: Interactions, Energy, and Dynamics); Earth and space sciences (ESS2: Earth's Systems; ESS3: Earth and Human Activity); and physical sciences (PS1: Matter and Its Interactions; PS3: Energy).

In this resource, we first discuss the challenges of addressing NGSS Performance Expectations in teaching materials. We then explain how each dimension of the NGSS is addressed in *Carbon TIME* units and assessments, including (a) the *Carbon TIME* model for three-dimensional learning, (b) how *Carbon TIME* resources assess three-dimensional learning, and (c) how the *Carbon TIME* instructional model scaffolds three-dimensional learning.

Challenges of Three-dimensional Learning

Many curriculum materials have lists of NGSS Performance Expectations that they “cover,” but what does “cover a performance expectation” REALLY mean? It SHOULD mean the students using the materials will master the Performance Expectations, but it usually means something less. Teaching for mastery of NGSS Performance Expectations is really difficult. Here are three reasons why.

NGSS Performance Expectations are difficult to master. Our learning progression research shows that many performance expectations describe major intellectual accomplishments for most students, requiring them to master new and unfamiliar forms of discourse (see the list of publications in the [Research Tab](#) of the *Carbon TIME* website). So it's not possible to create individual lessons or activities that are sufficient for students to master a Performance Expectation. Instead, *Carbon TIME* provides a tool kit for supporting the difficult process of helping students to achieve higher learning progression levels.

NGSS Performance Expectations are interconnected. Although performance expectations are listed individually, in fact our research shows that mastery of one requires mastery of others, and that our activities in the real world often involve multiple components of the NGSS three-dimensional framework. For example, students conducting an investigation are likely to ask questions (Science and Engineering Practice #1); plan and carry out an investigation (SEP #3); analyze and interpret data (SEP #4); use mathematics and computational thinking (SEP #5); engage in an argument from evidence (SEP #7); and obtain, evaluate, and communicate information (SEP #8).

NGSS Performance Expectations are difficult to assess. The National Research Council report [Developing Assessments for the Next Generation Science Standards](#) explains the many challenges involved in developing true three-dimensional assessments. The [Research Tab](#) of the *Carbon TIME* website includes publications and technical papers describing the



Carbon: Transformations in Matter and Energy
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development and validation of the *Carbon TIME* three-dimensional assessments and evidence of students' successful learning.

The Carbon TIME Model for Three-dimensional Learning

The NGSS assert that making sense of phenomena requires three-dimensional learning (science and engineering practices, crosscutting concepts, and disciplinary core ideas), represented by the multi-colored symbol on the left side of Figure 1. *Carbon TIME* represents the three dimensions and the connections among them in a more specific way, as shown on the right-hand side of Figure 1 (color coded to match the NGSS dimensions).

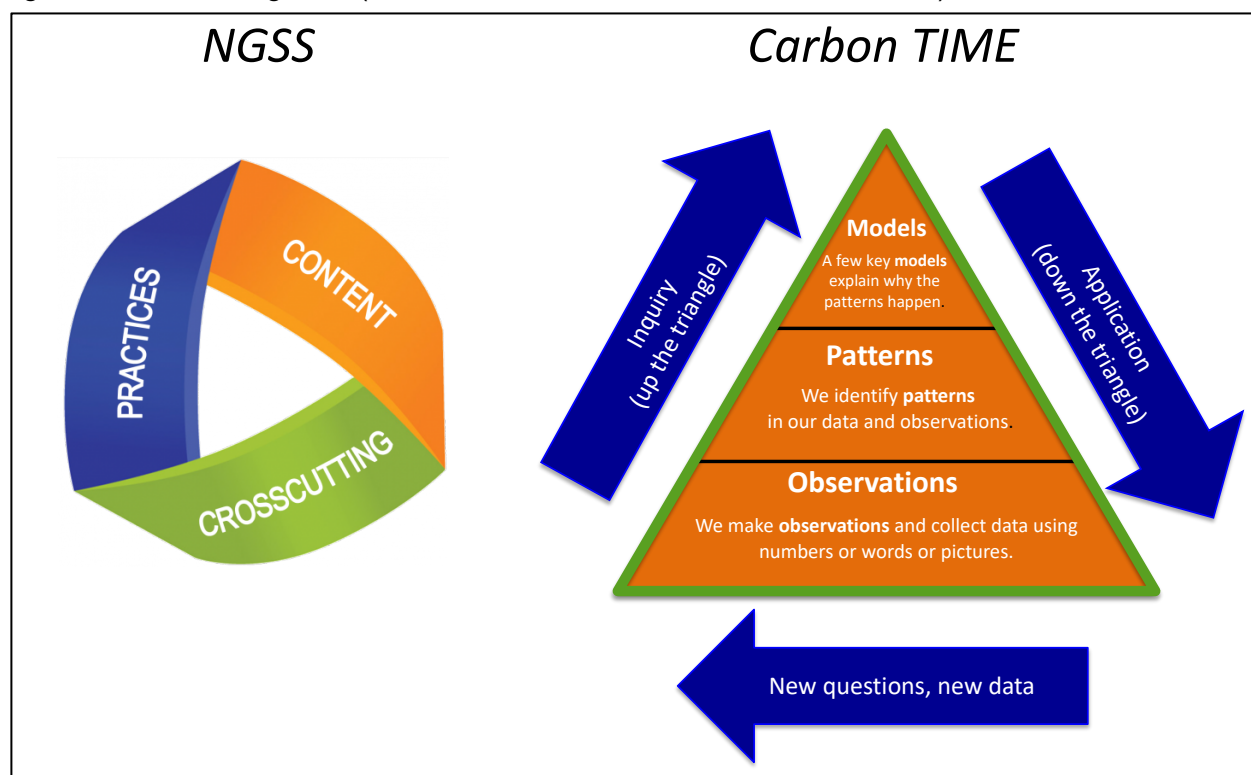


Figure 1: Comparing the three dimensions in NGSS and Carbon TIME

Here's an explanation of the *Carbon TIME* three dimensions.

1. The **orange triangle** represents the structure of scientific knowledge, which corresponds to the disciplinary core ideas (DCIs). The triangle has a wide base that narrows as you move upward, representing the many **observations of phenomena** that are used to identify **patterns in data**, which are then explained by a few key **scientific models or theories**. For more detail about these different types of scientific knowledge, see the [Carbon TIME Instructional Model](#) reading in the Educator Resources Library.
2. The **blue arrows** represent the science and engineering practices (SEPs). We group them into **inquiry practices** (making observations, analyzing data, developing arguments from evidence), **application practices** (using models, constructing explanations, designing solutions), **asking questions**, and general practices (literacy and mathematics).
3. The **green line** around the triangle represents the crosscutting concepts (CCCs) that work like "rules of grammar" to bound and constrain scientific ideas and practices. For example, **systems** are constrained by the CCC of conservation of **energy and matter**. For a more detailed discussion of the role of CCCs in *Carbon TIME*, see the short 2018

conference paper on [Crosscutting Concepts as Epistemic Heuristics](#) under the Research tab on the website.

How Carbon TIME Resources Assess Three-dimensional Learning

Figure 2 shows the same triangle and arrows as Figure 1, but this time with the relevant science and engineering practices (SEPs) listed beside each arrow (and with new color coding for the arrows). This figure suggests how *Carbon TIME* resources can be used to assess student progress for all SEPs (as well as their associated CCCs and DCIs).

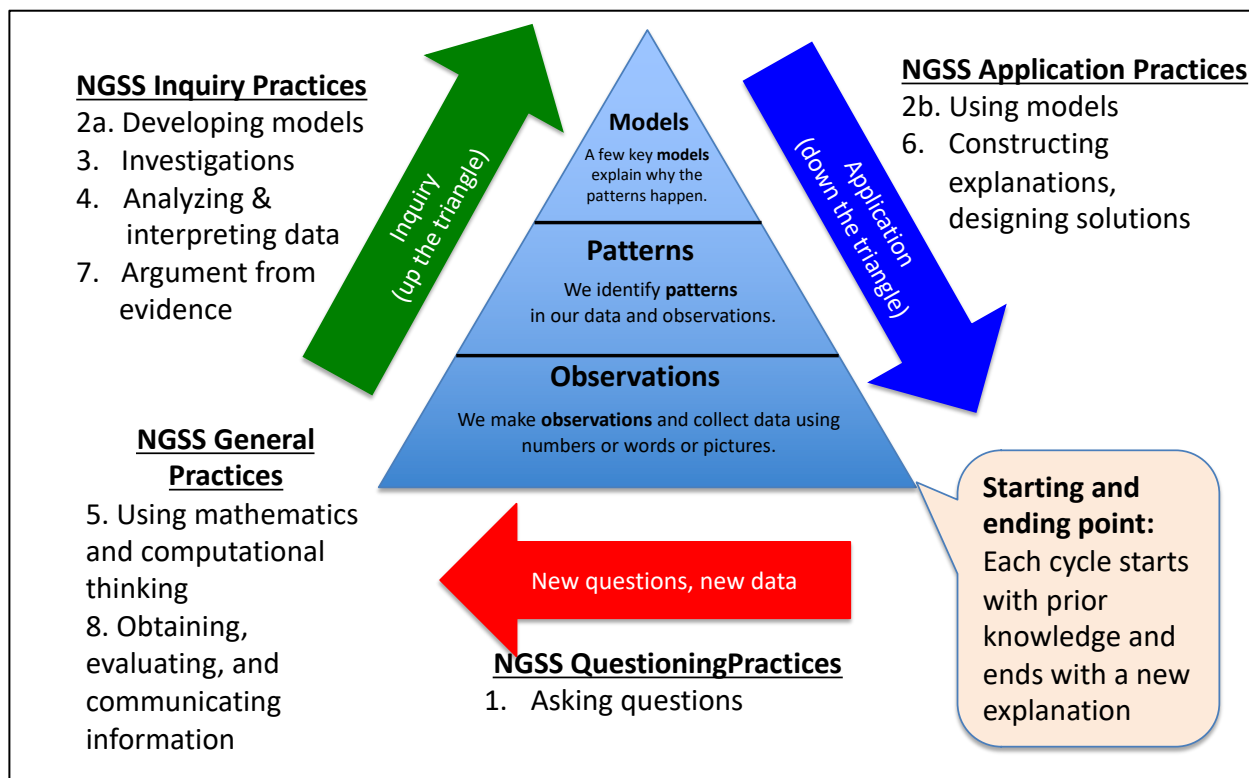


Figure 2: Students' three-dimensional engagement with phenomena

Figure 2 shows that whenever students successfully “figure out” a phenomenon (such as ethanol burning, mealworms growing and moving, radish plants growing, or bread decaying), they engage in all or part of a cycle of practices that potentially includes all of the SEPs. *Carbon TIME* provides many resources (see below) that engage students in each practice. Each resource is accompanied by an Assessing and Grading Tool that explains how you can use the resource for formative or summative assessment purposes.

1. **Asking Questions Practices:** Engaging students in asking questions and assessing their questions. We hope to see students progress from asking less focused “wondering” questions to asking questions that focus more on how systems at multiple scales transform matter and energy. Opportunities to elicit and assess students’ questions include:
 - a. Questions and accompanying discussions on the Expressing Ideas Tool
 - b. Unanswered questions on the Evidence-based Arguments Tool
 - c. Unanswered questions on the Learning Tracking Tool and Exit Tickets.
 - d. The last part of the investigation question in each pretest and posttest.
2. **Inquiry Practices:** Engaging students in inquiry and investigations and assessing their inquiry practices. We hope to see progress in students’ abilities to find patterns in data, interpret those patterns, formulate evidence-based arguments about transformations in

matter and energy, and recognize limitations in their data and conclusions. Opportunities to elicit and assess students' inquiry practices include:

- a. The Predictions and Planning Tool and the Evidence-based Arguments Tool that accompany each investigation.
 - b. A long question on each pretest and posttest that asks students to interpret data from an investigation and draw conclusions about transformations in matter and energy.
3. **Application Practices:** Engaging students in scientific model-based explanations. We hope to see students progress from offering force-dynamic explanations to offering explanations based on scientific models of how matter and energy are transformed in systems at multiple scales. Opportunities to elicit and assess students' explanation practices include:
- a. Big Ideas Probes engage students in discussing and evaluating different explanations for the same phenomenon
 - b. Explanation Tools both scaffold and assess students' explanations
 - c. Each unit ends with opportunities for students to develop model-based explanations of multiple phenomena
 - d. Several questions on each pretest and posttest assess students' explanation practices.

How the Carbon TIME Instructional Model Scaffolds Three-dimensional Learning

Each *Carbon TIME* unit follows the instructional model shown in Figure 3 below. For a more detailed explanation of the instructional model and how it plays out in each unit, see the [Carbon TIME Instructional Model](#) reading in the Educator Resources Library.

Our assessments and learning progression research show that very few students are initially successful at three-dimensional engagement with phenomena. They need support or *scaffolding* to be successful. Each unit includes many features, organized around the instructional model, that provide that scaffolding.

As Figure 3 shows, each unit is organized around a storyline that engages students in the three clusters of science practices described above. We first describe the basic sequence of practices, then the tools and recurring features that support those practices.

- **Students as questioners:** Each unit begins with a phenomenon and driving question. For example, in the *Systems and Scale* unit the teacher shows that ethanol burns but not water, and students consider the driving question, "What happens when ethanol burns?" Students use the Expressing Ideas Tool to record and discuss their ideas and questions. A key outcome of the discussion is a set of student questions about the phenomenon that they will answer during the unit.
- **Students as investigators:** In each unit the initial discussion leads first to a lesson providing students with foundational knowledge (scale, atoms, and molecules for *Systems and Scale*), then to an investigation in which students trace matter and energy through systems. Students use the Predictions Tool and the Evidence-based Arguments Tool to record and discuss their ideas. They reach evidence-based conclusions and record unanswered questions to be addressed later in the unit.
- **Students as explainers:** Each unit concludes with a series of activities where students use molecular models to model the phenomena, and then use the Explanations Tool to develop and discuss rigorous scientific explanations that answer the driving question. They then use what they have learned to explain other related phenomena (for example, burning methane, wood, gasoline, and propane in *Systems and Scale*).

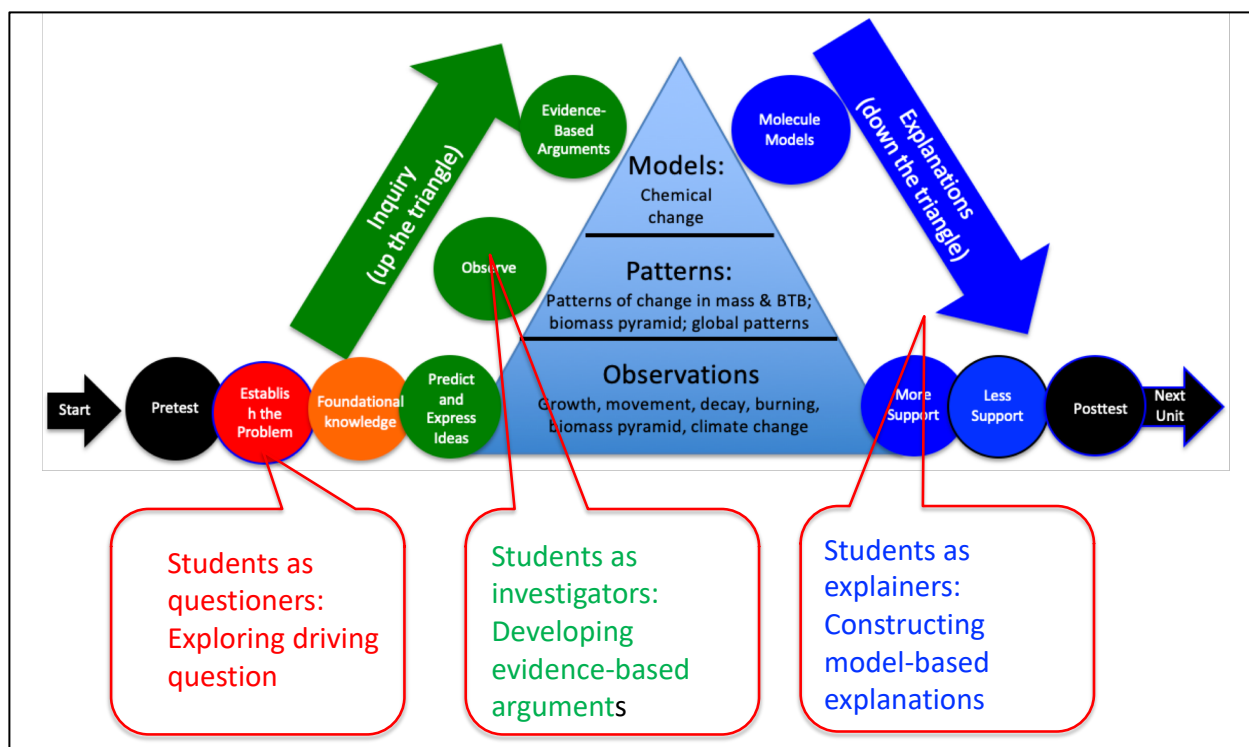


Figure 3: The Carbon TIME instructional model with student roles

Target performances play a key role in all *Carbon TIME* units. They connect the overall storyline and instructional model with each specific activity. The Front Matter for each unit includes a list of target performances for each activity. In general, target performances are challenging for students, so the [Carbon TIME discourse routine](#) can help student to achieve proficiency, particularly around the *Carbon TIME* Process Tools.