Educator Resource: Students' Learning Progressions for the *Systems and Scale* Unit

The *Carbon TIME* curriculum is based on learning progression research. Learning progressions are descriptions of the informal and then successively more sophisticated (scientific) ways that students reason about phenomena. *Carbon TIME* researchers have investigated how students understand and learn to make sense of carbon-transforming processes. You will find many of our publications and presentations under the Research Tab on the *Carbon TIME* website. (See, for example, Learning Progressions and Climate Change, by Joyce Parker, et al.)

Here, we offer a brief overview of the specific learning challenges that your students are likely to face as they study the *Systems and Scale* Unit. We focus on students' practices associated with their roles as questioners, investigators, and explainers.

Students as Questioners

Some students are curious about flames and how materials burn and have lots of questions, other students less so. But even curious students must learn how to ask scientifically productive questions. Students' questions play an essential role as they work on the Expressing Ideas and Questions Tool and the Evidence-based Arguments Tool.

The Expressing Ideas and Questions Tool asks students for their questions, and consensus questions are an important outcome from this discourse routine. These questions will drive later activities and discussions. However, you will need to help students to identify and refine scientifically productive questions. The most productive questions for the unit ask about *mechanisms* (e.g., What's happening inside the flame?) and about *tracing matter and energy* (e.g., Why do fires need oxygen? What is in the ethanol that makes it burn?). In contrast, many students feel that they already understand flames pretty well or start with "wondering questions" about topics related to flames (e.g., How are flames like hydrogen bombs? What starts forest fires?).

Though you do not want to discourage students' "wondering questions," there are ways to help students identify scientifically productive questions on mechanisms and tracing matter and energy. For example:

- Many students mention that flames require oxygen or produce carbon dioxide, but for most students these ideas do not lead to questions to ask about how this process works. The facts about atoms that students study in Lesson 2 and the Three Questions that are introduced in Lessons 3 and 4 lead to questions about what happens to gases in flames: If atoms last forever, then O_2 can't just change into CO_2. Where did the carbon atoms come from?
- Students often share ideas about what goes into flames (fuel, oxygen) and what flames produce (carbon dioxide, smoke, heat, light) without making connections between what goes in and what comes out. You can encourage questions about connections that will lead toward students understanding these as reactants, products, and energy transformations in chemical changes.

Later in the unit, students completing the Evidence-based Arguments Tool generally need help identifying questions that result from limitations in their investigations and results. For example, the investigation provides evidence about matter and energy that go into or come out of the flame (macroscopic scale), but not about how the matter and energy are being changed inside the flame (atomic-molecular scale). Encouraging as-yet unanswered questions about how

matter and energy change inside the flame prepares students to answer those questions through the subsequent molecular modeling activities.

Students as Investigators

Students are naturally inclined to pursue "engineering investigations" about what burns and how to start, sustain, or extinguish fires, but not "matter-tracing investigations" about how matter and energy are moving through and transformed inside flames. In fact, it will be hard for many students to see how their investigations can answer questions about mechanisms or tracing matter and energy. It is especially important for students to figure out how their tools—the digital balances, BTB, and their senses—can be used to trace movements and changes in matter and energy.

- The digital balance is a *matter movement detection tool:* The rules on the Three Questions say that matter (solids, liquids, or gases) MUST be moving out of a system that loses mass and MUST be moving into a system that gains mass. Most students are pretty good at applying this reasoning to solids and liquids: They notice that the ethanol loses mass when it burns. But they struggle to interpret evidence about movement of gases: Where did the missing ethanol go and what happened to it?
- BTB is a *matter change detection tool:* If the amount of CO_2 in the air goes up, then it is probably coming from the flame and ultimately from the ethanol, so there must be a chemical change that is producing the CO_2.
- The students' senses are *energy change detection tools:* If they see flame produces heat and light, then since energy lasts forever, that energy MUST have been transformed from some other form into heat and light.

When students are using the Predictions and Planning Tool to plan their investigations, they need help to see how they can use the digital balance, BTB, and their senses to provide evidence that addresses the Three Questions about matter movement, matter change, and energy. And when they are using the Evidence-based Arguments Tool, they need help to see how their evidence provides them with partial, but not complete, answers to the Three Questions.

Students as Explainers

Our learning progression research shows three levels as students become more scientifically sophisticated in their explanations:

- F*orce-dynamic explanations* (Learning Progression Level 2) do not attempt to trace matter and energy at all. Instead, they treat flames as actors with needs, such as oxygen, to accomplish their purpose of burning. You will likely see students' Level 2 explanations on the Expressing Ideas Tool, where many students will write and talk about what the flame needs to burn, and on the Big Ideas Probe when students agree with Dad ("I think some of the gasoline just burns up and disappears.")
- *Incomplete matter-tracing explanations* (Learning Progression Level 3) try to trace matter and energy, but without following all the rules of the Three Questions. You will likely see students' Level 3 explanations on the Expressing Ideas Tool, where students describe the flame as converting O_2 to CO_2 without wondering where the carbon in CO_2 comes from, or suggesting that flames convert fuel into energy. On the Big Ideas Probe students show Level 3 reasoning when they agree with Marco ("I think some of the gasoline turns into energy that makes the car go. So you start with gasoline and you end up with motion and some heat.") or Mom ("I think the gasoline evaporates and becomes fumes that pollute the air.").

- *Complete matter and energy-tracing explanations* (Learning Progression Level 4) answer the Three Questions while following the rules. On the Big Ideas Probe, students who understand Level 4 explanations will agree ONLY with David ("I think some of the gasoline turns into carbon dioxide.") and Elena ("I think some of the gasoline ends up as water that goes into the air.").

The activities and tools in Lessons 3, 4, and 5, including the molecular modeling activities, the Explanations Tools, and the readings about different fuels in Lesson 5, are all designed to scaffold the students' explanations as they make the difficult progression from Level 2 to Level 4 explanations.