Educator Resource: Students' Learning Progressions for the *Animals* 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 *Animals* Unit. We focus on students' practices associated with their roles as questioners, investigators, and explainers.

Students as Questioners

Some students are curious about animals 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 may find few productive questions among the questions that students initially pose. The most productive questions for the unit ask about *mechanisms* (e.g., What's happening inside the child?) and about *tracing matter and energy* (e.g., How are food and other materials moved around and changed in the child's body?). In contrast, many students start with "wondering questions" about health and diet (e.g., Are fatty foods bad?).

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

- Almost all students mention O_2-CO_2 gas exchange as something that animals do, but students rarely identify questions to ask about how this process works. You can encourage students to refine their questions by thinking about the Three Questions and accompanying rules that they studied in *Systems and Scale:* If atoms last forever, then O_2 can't just change into CO_2. Where did the carbon atoms come from?
- Students often share diet, nutrition, health, and exercise information (healthy eating, nutrients, proteins, carbs, etc.). It can be helpful to draw students' attention to questions about what obviously must be chemical changes as food is transformed into the child's muscles, bones, etc., and waste.

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 mealworms' bodies (macroscopic scale), but not about how they are being changed inside the mealworms' bodies (atomic-molecular scale). Encouraging as-yet unanswered questions about how matter and energy change inside the mealworms' bodies prepares students to answer those questions through the subsequent molecular modeling activities.

Students as Investigators

Students are naturally inclined to pursue "engineering investigations" about how different conditions affect mealworms' growth, but not "matter-tracing investigations" about how matter and energy are moving through and transformed inside mealworms' bodies. 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 potato loses mass and the mealworms gain mass. But they struggle to interpret evidence about movement of gases: If the whole system (i.e., the mealworms, their food, and their wastes) loses mass, then gases MUST be leaving the system.
- 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 mealworms, so there must be a chemical change that is producing the CO_2.
- The students' senses are *energy change detection tools:* If they see the mealworms using energy to move, then since energy lasts forever, that energy MUST have been transformed from some other form into motion energy.

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:

- *Force-dynamic explanations* (Learning Progression Level 2) do not attempt to trace matter and energy at all. Instead, they treat animals as actors who have needs, such as food, water, and air, to accomplish their purposes—to move, grow, and be healthy. You will likely see students' Level 2 explanations on the Expressing Ideas Tool, where many students will write and talk about what the child needs to grow and stay healthy, and on the Big Ideas Probe when students agree with Kara ("I think that when I exercise my body burns the fat up. Then it's gone.")
- *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 child as converting O_2 to CO_2 without wondering where the carbon in CO_2 comes from, and on the Big Ideas Probe when students agree with Marco ("I think that when I exercise and lose weight I'm turning fat into energy.") or Mei ("I get so hot when I exercise. I think my body turns the fat into heat.").
- *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 Andre ("I breathe a lot when

I exercise. I think fat gets turned into stuff I breathe out.") and Lu ("I think when I exercise my body turns the fat into sweat and I sweat it out through my skin.").

The activities and tools in Lessons 4, 5, and 6, including the molecular modeling activities, the Explanations Tools, and the readings and worksheets in Lesson 6, are all designed to scaffold the students' explanations as they make the difficult progression from Level 2 to Level 4 explanations.