A Learning Progression-based System for Promoting Understanding of Carbon-transforming Processes (*Carbon: Transformations in Matter and Energy*)

Charles W. (Andy) Anderson

DRK-12 PI Meeting

August 5, 2104
Focus on Carbon-transforming Processes in Socio-Ecological Systems

Photosynthesis

- Matter: CO$_2$, H$_2$O, and minerals
- Matter: Organic matter & O$_2$
- Energy: Sunlight
- Movement of CO$_2$, H$_2$O, and minerals
- Biosynthesis, digestion, food webs, fossil fuel formation
- Energy: Chemical potential energy
- Combustion, cellular respiration
- Energy: Work & heat
NGSS Focus for this Work

• Three key practices: interpreting and analyzing data, engaging in arguments from evidence, and constructing explanations.

• Two crosscutting concepts: systems and system models, and energy and matter: flows cycles, and conservation.

• Disciplinary core ideas in the life sciences (LS 1: From molecules to organisms: Structures and processes; LS 2: Ecosystems: Interactions, energy, and dynamics), Earth sciences (ESS 2: Earth’s systems; ESS 3: Earth and human activity), and physical sciences (PS 1: Matter and its interactions; PS 3: Energy)
Learning Progressions Include:

- A **learning progression framework**, describing levels of achievement for students learning (Model of cognition)
- **Assessment tools** that reveal students’ reasoning: written assessments and clinical interviews (Observation and interpretation)
- **Teaching tools and strategies** that help students make transitions from one level to the next (Empirical validation)
What Progresses?

• **Discourse:** “a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group” (Gee, 1991, p. 3)

• **Practices:** inquiry, accounts, citizenship

• **Knowledge** of processes in human and environmental systems
Learning Progression Levels of Achievement for Carbon Accounts

**Level 4: Coherent scientific accounts:** Students successfully trace matter and energy through carbon-transforming processes at multiple scales in space and time (generally consistent with current national science education standards and with the draft framework for new standards).

**Level 3: Incomplete or confused scientific accounts:** Students show awareness of important scientific principles and of models at smaller and larger scales, but they have difficulty connecting accounts at different scales and applying principles consistently.

**Level 2: Elaborated force-dynamic accounts:** Students’ accounts continue to focus on actors, enablers, and natural tendencies of inanimate materials, but they add detail and complexity, especially at larger and smaller scales.

**Level 1: Simple force-dynamic accounts:** focus on actors, enablers, and natural tendencies of inanimate materials, using relatively short time frames and macroscopic scale phenomena.
Levels 1 and 2: Actors Using Enablers to Accomplish Purposes

- **Actors**
  - people
  - animals
  - plants
  - flames

- **Enablers**
  - food
  - sunlight
  - care
  - match

- **Events**
  - growth
  - weight loss
  - fire
Level 3: Nutrient, Energy and $O_2$-$CO_2$ Cycles

- **Nutrients**
  - Plants
  - Decay
  - Energy sources for plants: sunlight, nutrients, water

- **Energy sources for animals: food, water**
  - Food chains
  - Carbon dioxide
  - Decomposers don’t need energy

- **Oxygen**
  - Animals
  - Plants

- **The oxygen-carbon dioxide cycle**
  - Sunlight
Level 4: Carbon Cycling and Energy Flow

- Matter: CO$_2$, H$_2$O, and minerals
- Matter: Organic matter & O$_2$
- Energy: Sunlight
- Photosynthesis
- Movement of CO$_2$, H$_2$O, and minerals
- Biosynthesis, digestion, food webs, fossil fuel formation
- Energy: Chemical potential energy
- Combustion, cellular respiration
- Energy: Work & heat
Carbon TIME Curriculum (available on National Geographic Website, 2015)

### Systems and Scale

**Teacher’s Guide**

How our systems depend on **Carbon** and chemical energy: Finding chemical change in life and lifestyles.

- The Environmental Literacy Project
- Carbon: Transformations in Matter and Energy (Carbon TIME) 2011-2012

### Plants and the Carbon Cycle

How seeds grow to trees and plants transform **Carbon**.

- The Environmental Literacy Project
- Carbon: Transformations in Matter and Energy (Carbon TIME) 2011-2012

### Animals and the Carbon Cycle

How animals use and change **Carbon** and chemical energy.

- The Environmental Literacy Project
- 2011-2012

### Processes

- **Powers of 10**
- Combs;on
- Photosynthesis
- Biosynthesis
- Cellular respiration
- Digestion
- Biosynthesis
- Cellular respiration
Decomposers and the Carbon Cycle

How decomposition changes Carbon and chemical energy

The Environmental Literacy Project 2011-2012

Ecosystems Teacher's Guide

How ecosystems store and cycle Carbon and chemical energy

The Environmental Literacy Project Carbon: Transformations in Matter and Energy (Carbon TIME) 2011-2012

Human Energy Systems Teacher's Guide

How humans use chemical energy stored in Carbon bonds

The Environmental Literacy Project Carbon: Transformations in Matter and Energy (Carbon TIME) 2011-2012

Processes

Digestion
Biosynthesis
Cellular respiration

All processes except combustion in ecosystems

Combustion of fossil fuels for energy
Activity Sequences in a Carbon TIME Unit

**INQUIRY**
- Activity sequence:
  1. Predict
  2. Explain
  3. Observe
  4. Explain

**APPLICATION/CITIZENSHIP**
- Activity sequence:
  1. Establishing the problem
  2. Modeling
  3. Coaching
  4. Fading
  5. Maintaining

**MODELS**
A few key models

**PATTERNS**
Dozens of patterns in experiences

**EXPERIENCES**
Millions of experiences and observations of material world
Inquiry Sequences Include:

Hands-on PEOE sequence

Video investigations. For example:

http://education.nationalgeographic.com/preview/education/media/burning-ethanol/?ar_a=1
Cognitive Apprenticeship Application Sequences

• Establishing the problem: Unanswered questions from inquiry sequence
• Modeling and coaching: Animations and molecular models, writing a chemical equation
• Coaching and fading: Other problems involving plant growth
• Maintenance: revisiting photosynthesis in other units (especially Ecosystems and Human Energy Systems)
Plants Lesson 2, Activity 2: Using Molecular Models to Explain Photosynthesis

Answering the Three Questions for plants in the light
The Movement Question

Where are atoms moving **from**?

Where are atoms moving **to**?
Which atoms and molecules move so that plants can do photosynthesis?

- Water
- Carbon dioxide
- Oxygen
- Glucose
How do glucose, water, carbon dioxide, and oxygen move for a plant leaf to photosynthesize?
Plants make glucose from carbon dioxide and water in their leaves.
What happens inside the leaf cell as it photosynthesizes?
Comparing photos of reactant and product molecules
Compare the atoms and energy units on the reactant and products sides.

Remember: **Atoms last forever** (so you can rearrange atoms into new molecules, but can’t add or subtract atoms). **Energy lasts forever** (so you can change forms of energy, but energy units can’t appear or go away).
Chemical change

Reactants

Glucose

Water

Products

What happens to atoms and energy in photosynthesis?

Carbon Dioxide

Light

energy

Oxygen

Water

Chemical change

Carbon Dioxide

Glucose

Oxygen

What happens to atoms and energy in photosynthesis?
What happens to carbon atoms in photosynthesis?

Carbon atoms in carbon dioxide become part of glucose molecules.

Reactants:
- Carbon Dioxide
- Water
- Light energy

Products:
- Glucose
- Oxygen
What happens to oxygen and hydrogen atoms in photosynthesis?

Oxygen and hydrogen atoms become part of glucose and oxygen gas molecules.
What happens to light energy in photosynthesis?

Light energy is transformed into chemical energy.

Reactants:
- Glucose
- Oxygen
- Light energy
- Carbon Dioxide
- Water

Products:
- Oxygen
- Water
- Glucose
What happens to atoms and energy in photosynthesis?

Reactants:
- Carbon Dioxide
- Water
- Light energy

Products:
- Glucose
- Oxygen
- Carbon Dioxide
- Water
- Light energy

Atoms last forever!
Energy lasts forever!
Writing a Chemical Equation

• Writing in symbols: Chemists use an arrow to show how reactants change into products:
  \[\text{[reactant molecule formulas]} \rightarrow \text{[product molecule formulas]}\]

• Saying in words: Chemists read the arrow as “yield” or “yields”:
  \[\text{[reactant molecule names]} \text{ yield(s)} \text{ [product molecule names]}\]

• Equations must be **balanced**: Atoms last forever, so reactant and product molecules must have the same number of each kind of atom.

• Try it: can you write a balanced chemical equation to show the chemical change for **photosynthesis**?
Chemical Equation for Photosynthesis

$6\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

(in words: water and carbon dioxide yield glucose and oxygen)
Percentages of Level 4 Responses

Blue: Comparison groups: Middle school, high school, college science majors
Red: Carbon TIME middle school: baseline, pre, post
Green: Carbon TIME high school: baseline, pre, post
Baseline, pre, and post achievement for Cohort 1 and Cohort 2 students. Error bars represent 95% confidence intervals. Dashed lines are mean thresholds for learning progression Levels 3 and 4.
Comparing Student Learning for Different Teachers

Student learning for Cohort 2 teachers. Error bars represent 95% confidence intervals. Dashed lines represent (a) no learning and (b) average learning gain for all teachers.
Hypotheses about Important Differences among Teachers

• Purpose: Conveying a consistent sense of purpose across lessons and units

• Principles: Consistent focus on tracing matter and energy and connecting scales

• Talk moves (cf., Michaels and O’Connor): Using a repertoire of strategies to elicit students’ ideas and discuss them critically

• Curiosity: Actively exploring scientific data and models and students’ ideas
TEACHER 30: How does the tree use sunlight to grow?
STUDENT: Sunlight helps it in photosynthesis and photosynthesis is how the leaves make their food which helps them to continue to grow so the sunlight helps the tree.

TEACHER 30: Just a second ago I thought I heard you said that the soil provides nutrients which is like its food and now you’re saying that the tree ... the sunlight comes from ... so could you clarify that, I’m a little ... could you clarify that for me?

STUDENT: The sunlight mainly helps with the growth of the leaves but the nutrients in the soil help with the growth of the trunk and the leaves so mainly but it takes time for the tree to get to the point where it’s growing leaves so while it doesn’t have leaves any more it’s still using the nutrients from the soil.
STUDENT: The sunlight gives ... I think it helps with the tree’s life cycle.

TEACHER 6: The sunlight helps with the tree’s life cycle? Okay. Is water giving it any energy?

STUDENT: It helps it grow more.

TEACHER 6: Okay. Do you know how it helps it grow or how do you think it helps it grow?

STUDENT: It’s kind of like the tree’s food.

TEACHER 6: Okay. How about the nutrients?

STUDENT: The nutrients is also its food.

TEACHER 6: Also its food? All right. Okay these are the right cards. All right, so we have six cards here... (moving on to next task)
To do: Investigating students’ reasoning about large-scale data, climate change, and sustainability
Thanks to Contributors to this Research

• Jennifer Doherty, Hannah Miller, Staci Sharp, Allison Freed, Wendy Johnson, Elizabeth Xeng de los Santos, Sarah Stapleton, Joyce Parker, Jane Rice, Kathryn Oleszkowicz, Liz Thompkins, Melissa Janos, Caitlin Mack, Carly Atkinson, Cara Morrison, Anthony Machniak, Emily Scott Michigan State University
• Kathleen Schwille, Elizabeth Wolzak, Melissa McPhee, Alison Michel, National Geographic Society
• Dan Gallagher, Mary Margaret Welch, Seattle Public Schools
• Jenny Dauer, University of Nebraska, Lincoln
• RET’s: Marcia Angle, Lawton Schools, Rebecca Drayton, Gobles Schools, Cheryl Hach, Kalamazoo Math & Science Center, Liz Ratashak, Vicksburg Schools, Debi Kilmartin, Gull Lake Schools
• Mark Wilson, Karen Draney, Jinnie Choi, HyoJeong Shin, and Jinho Kim at the Berkeley Evaluation and Assessment Research Center
• Greg Newman, Kirstin Holfelder, Neely Clapp, Colorado State University
Thanks to Funders

This research is supported in part by grants from the National Science Foundation: Learning Progression on Carbon-Transforming Processes in Socio-Ecological Systems (NSF 0815993), and Targeted Partnership: Culturally relevant ecology, learning progressions and environmental literacy (NSF-0832173), CCE: A Learning Progression-based System for Promoting Understanding of Carbon-transforming Processes (DRL 1020187), and Tools for Reasoning about Water in Socio-ecological Systems (DRL-1020176). Additional support comes from the Great Lakes Bioenergy Research Center. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the United States Department of Energy.