Transformations in Matter and Energy: Student Learning and Inquiry to Inform Teaching

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Abstract for DBER Group Discussion on 2013-09-05

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Title:
Transformations in Matter and Energy: Student Learning and Inquiry to Inform Teaching

Abstract:
Learning progressions are descriptions of increasing levels of sophistication of student reasoning about a topic based on empirical evidence. Our learning progression framework about student explanations of carbon-transforming processes (e.g. photosynthesis, cellular respiration) describes how student’s interconnected and mutually supporting ideas and practices are deeply embedded in discourse at all levels of achievement. My research is in two areas: 1) applying the learning progression framework for student explanations of carbon-transforming processes to describe the most productive pathways for student learning, 2) extending the research to student reasoning during inquiry activities about carbon-transforming processes. One finding is that students who consistently follow the rules of conservation of matter and energy in their explanations are better positioned to advance in their understanding of carbon transforming processes. Another finding is that during inquiry investigations, students who do not apply the laws of conservation of matter or connect the macroscopic level with the atomic-molecular level in their reasoning often misinterpret the purpose of the investigation. Teaching supports that scaffold student learning about conservation of matter may be important in guiding student learning about carbon transforming processes and student inquiry practices.

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Transformations in matter and energy: student learning and inquiry to inform teaching

Dr. Jenny Dauer

Ecosystem Ecology Research

Masters, Dept of Horticulture
- Compared tree species calcium physiology

PhD, Dept of Forest Science
Calcium oxalate influence on:
- Ca stable isotope patterns
- Tree health
- Ca sustainability
Life Science Education Research

Carbon Transforming Processes

- photosynthesis
- cellular respiration
- combustion
- biosynthesis
- digestion
- decomposition

Especially important for students to explain how:

- Living organisms get their energy
- 90% of energy is obtained for human systems
- Imbalances drive climate change
Vision and Change in Undergraduate Biology Education

Carbon transforming processes and carbon cycling especially relates to 2 of 5 Core Concepts:

• Pathways and transformations of energy & matter
• Systems

A Change to Science Instruction

Vision and Change in Undergraduate Biology Education, 2011

K-12 Next Generation Science Standards, 2013

Knowledge and practice need to be integrated in instruction for student to achieve deep understanding
What are the Most Productive Stepping Stones for Students?

Duncan et al (2013) *Science*

Research Approach

**THEORY:** Framework for student knowledge and practice over time

**DATA:** Interviews and Written Assessments

**APPLICATION:** Teaching & Curriculum
Life Science Research about Matter & Energy and Systems

1) Finding the most productive path for learning about carbon transforming processes

2) Characterizing student inquiry and argumentation practices when doing investigations about carbon transforming processes

3) Characterizing student understanding of, and inquiry about, global change
Students Early in their Understanding of Carbon Transforming Processes:

Informal explanation:

Actors (e.g., plants, animals, flames) make things happen with the help of enablers (e.g., nutrients, sunlight, food/fuel) that satisfy their “needs.”

Mohan et al (2009) JRST
Informal Explanation of How Plants Grow

“The plant gains its mass as it grows by the adding of branches or leaves and that is caused by the tree getting water and nutrients.”

Enablers
Sunlight, nutrients, water, soil, air

Actors
Have abilities and purpose

Results
The plant gets bigger

Contrasting Student Ideas about Carbon Transforming Processes

Scientifically principled explanation:
Systems are composed of enduring entities (e.g., matter, energy) which change according to laws or principles (e.g., conservation laws)

Informal explanation:
Actors (e.g., plants, animals, flames) make things happen with the help of enablers (e.g., nutrients, sunlight, food/fuel) that satisfy their “needs.”

Mohan et al (2009) JRST
Scientifically Principled Explanation of Photosynthesis

“The plant’s increase in weight comes from CO₂ in the air. The carbon in that molecule is used to create glucose.”

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

1) Follows law of conservation of matter and energy
2) System at multiple scales

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Linking processes</td>
<td>Plants growing</td>
<td>Animals moving</td>
<td>Decay</td>
</tr>
<tr>
<td>Informal</td>
<td>Plants enabled by food, water, sunlight and/or air</td>
<td>Animals enabled by food, water, sunlight and/or air</td>
<td>Natural process in dead things</td>
</tr>
</tbody>
</table>

Chemical potential energy photosynthesis

System

Process photosynthesis
Informal Reasoning to Explain Real World Phenomena

General pattern across:
- different forms of questions
- different contexts
- education level of students we’ve tested and interviewed

Jin & Anderson (2012) JRST
Mohan et al (2009) JRST

What is Your Experience and Expectations About College Students?

525 science major students at 13 universities, mostly Intro Bio

30 second think-pair-share: What % of college students do you think do scientifically principled reasoning post instruction?

16 % Scientific
50 % Mix of Informal and Scientific
27 % Informal

Learning Progression

- Scientifically Principled Reasoning
- "messy middle"
- Informal Reasoning

Two Types of Students in the "Messy Middle"

- Scientifically Principled Reasoning
  - Fact-Oriented
  - Principle-Oriented
- Informal Reasoning

Miller, Webster, Dauer, Anderson (2013) NARST
“What happens to a man’s fat when he loses weight?”

“The man loses weight through the process of cellular respiration, which converts his fat molecules and oxygen into carbon dioxide and water. The chemical energy in the fat ended up as heat.”

“What happens to a man’s fat when he loses weight?”

“It turned into energy and it got burnt and came out through sweat.”
“What happens to a man’s fat when he loses weight?”

Fact-oriented
“The man loses weight through the process of cellular respiration, which converts his fat into energy and carbon dioxide.”

Principle-oriented
“The fat is being used for energy, but the atoms in the fat have to go somewhere. I guess I’m not quite sure where they go.”

“What happens to a man’s fat when he loses weight?”

Fact-oriented
“The man loses weight through the process of cellular respiration, which converts his fat into energy and carbon dioxide.”

Principle-oriented
“The fat is being used for energy, but the atoms in the fat have to go somewhere. I guess I’m not quite sure where they go.”
How are Principle-oriented and Fact-oriented Alike?

context-specific knowledge

How Are They Different?

Principle-oriented

Principles of Matter and Energy

Atoms cannot be created or destroyed

Matter cannot turn into energy

Energy cannot be created or destroyed
Evidence from Interviews Show that Principle-oriented Students Advance

- Scientifically Principled Reasoning
- Fact-Oriented
- Principle-Oriented
- Informal Reasoning

Hypothesis: students who treat conservation of matter and energy as an organizing principle are more likely to progress in their learning.

Principles of Matter and Energy
Implications for Teaching

Help students develop a *sense of necessity* to apply principles of matter and energy conservation.

**Principles-first instruction:**
In physical and chemical changes....

1. **Atoms last forever**
   - Atoms can be rearranged to make new molecules

2. **Energy lasts forever**

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Does Principle-first Instruction Work?

Undergraduate non-majors science course at MSU

Photo credit: Dr. Jane Rice
Example Assessment

When a baby was five months old, she weighed 8 kg. After 7 years, the baby has grown into a big girl, weighing 25 kg. Where did her increase in mass come from? \( (n = 135) \)

Select POSSIBLE or IMPOSSIBLE

<table>
<thead>
<tr>
<th></th>
<th>Possible PRE</th>
<th>Possible POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) The girl’s food provided atoms that she used to build her body.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) The girl used energy in food to make new atoms.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Undergraduate non-majors science course at MSU

Rice et al (in revision) *J of Col Sci Teaching*
Testing Principles-first Research-based Curriculum, n=995

- Systems & Scale
- Animals
- Plants
- Decomposers
- Ecosystems
- Human Energy Systems

For middle and high school, public in 2015
NSF DRK12 (#1020187)

Life Science Research about Matter & Energy and Systems

1) Finding the most productive path for learning about carbon transforming processes

2) Characterizing student inquiry and argumentation practices when doing investigations about carbon transforming processes

3) Characterizing student understanding of and inquiry about global change
Inquiry and Argumentation about Carbon Transforming Processes

Two examples of how student practices contrast with scientific practices

1) Pattern-finding
2) Arguments from evidence about tracing matter

Specific “Inquiry” Practices

- Models
- Patterns
- Observations

Photo credit: Dr. Jane Rice
Student prediction: the weight of the plants in the pot would increase while the plants were growing.

Weight of the container with the plant (g) | Change in weight of the container with the plant (g)
--- | ---
Before | After | 
5.23 | 5.45 | +0.22
5.03 | 4.82 | -0.21
4.77 | 5.96 | +1.19
5.16 | 5.29 | +0.13
4.87 | 4.77 | -0.10
5.12 | 5.08 | -0.04
Average: 5.03 g | Average: 5.23 g | Average: + 0.20 g

Typical Student Response

MAGGIE: “I think that it does support the predictions, because on average they did gain more weight ... and there’s probably other contributing factors as to why the other ones lost weight.”

INTERVIEWER: “Do you have any comments about the quality of the data from this experiment?”

MAGGIE: “It doesn't say how long she weighed it.”
**Example #1: Contrasting Approaches to Pattern Finding**

**SCIENTIFIC APPROACH:**
Can I trust the data?  
How accurate and precise are the measurements?  
Is there a signal in the noise? What is the central tendency and variability of the data?

**STUDENT’S APPROACH:**
Was the data collected the right way?  
Look for data that confirm the answer.

Dauer et al (2013) NARST

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**Example #2: Contrasting Approaches to Scientific Argumentation**

Goal for students:

CLAIMS \[\rightarrow\] EVIDENCE

REASONING

Interview Question: Claims about Tracing Matter

Plants gain most of their weight from materials that came from the **air.**

Plants gain most of their weight from materials that came from nutrients in the **soil.**

Karen Mike

“How does Mike’s argument support his idea that plant gains weight from materials that came from the soil?”

CLAIM: is about *tracing matter*  
EVIDENCE: weight data

Plants have roots to take up nutrients from the soil to grow.

Mike

<table>
<thead>
<tr>
<th>Plant grown <strong>without</strong> fertilizer</th>
<th>Plant grown <strong>with</strong> fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant = 50 g</td>
<td>Plant = 65 g</td>
</tr>
<tr>
<td>Fertilizer = 3 g</td>
<td></td>
</tr>
</tbody>
</table>

STUDENT’S REASONING: Atomic-molecular models, conservation of matter
Typical Student Response to Mike’s Experiment

TEACHER: “Can you explain what Mike’s argument was?”
MABEL: “His argument was that the plant was growing better with the fertilizer because it has nutrients in it and it helps the roots grow.”

TEACHER: “How is Mike’s argument supported by this evidence?”
MABEL: “It’s supported by the weight…. after the same amount of time it grew more.”

Example #2: Contrasting Approaches to Scientific Argumentation

<table>
<thead>
<tr>
<th>SCIENTIFIC APPROACH:</th>
<th>STUDENT APPROACH:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLAIMS</td>
<td>EVIDENCE</td>
</tr>
</tbody>
</table>

Dauer et al (2013) NARST
Implications for Teaching

- More practice pattern finding
- Explicit about the nature of the claim
- Experiments that are meaningfully tied to core concepts

Life Science Research about Matter & Energy and Systems

1) Finding the **most productive path** for learning about carbon transforming processes

2) Characterizing student **inquiry and argumentation practices** when doing investigations about carbon transforming processes

3) Characterizing student understanding of and inquiry about **global change**
Future Research Questions

Characterize student learning and practice about
1) matter & energy
2) complex systems

- Carbon transforming processes
  - organisms
  - ecosystem or global level
- Relationships between atmospheric CO₂ and global temperature
- Impacts of global climate change to natural & human systems

INQUIRY & ARGUMENTATION

Understanding Inquiry and Arguments from Evidence in the Context of Global Change

- Observations: what are valid data
- Pattern-finding: variability in data
- Model of a complex system: understanding if phenomena are local versus generalizable

http://www.ncdc.noaa.gov/cag/
Recent Interview Instruments

Gull Lake Ice Record

Number of days the lake had ice

Winter Year

Preliminary data for NSF EHR Core, July 2013 submission

Recent Interview Instruments

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Carbon dioxide concentration (ppm)

Annual Cycle

January, April, July, October, January

IPY III 1955-58

IPY IV 2007-08
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MICHIGAN STATE UNIVERSITY

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“How does Karen’s argument support her idea that plant gains weight from materials that came from the air?”

CLAIM: is about *tracing matter*  
EVIDENCE: weight data

You can grow a big plant in a little pot without a lot of soil.

Karen

Seed = 1 g  
Soil = 80 g  
Plant = 50 g

Soil = 78 g  
Seed planting  
One year later

**STUDENT’S REASONING:** Atomic-molecular models, conservation of matter

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**Student response to Karen’s experiment**

INTERVIEWER: Well, what's the evidence that proves to you that she's right that plants gain their weight from air?  
JESS: *The plant needs air to grow.*

...

INTERVIEWER: So, how many grams did the soil lose?  
JESS: *Like 2.*

INTERVIEWER: And how many grams did the plant gain?  
JESS: *Like a lot.*

INTERVIEWER: So, do you think the weight came from the dirt?  
JESS: Yes, I do. I do because ... I mean if *the soil weighs like less now then I think the plant ate it all.*

MS, HS, college interviews, \( n = 136 \)