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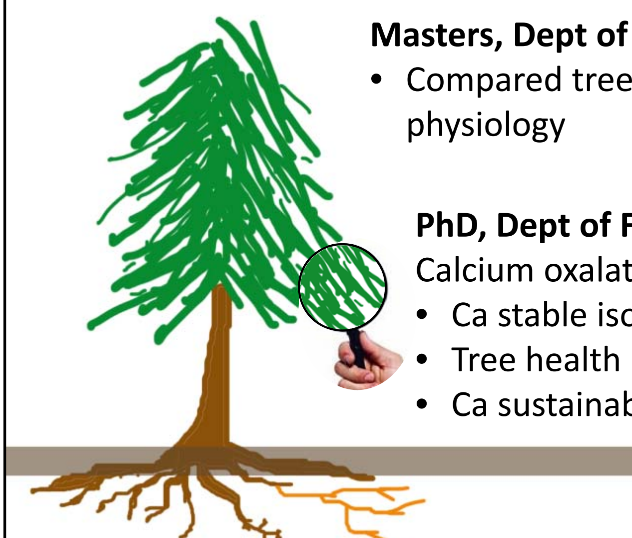
Transformations in matter and energy: student learning and inquiry to inform teaching

University of Nebraska Lincoln

Dr. Jenny Dauer

Ecosystem Ecology Research



Masters, Dept of Horticulture

- Compared tree species calcium physiology

PennState

PhD, Dept of Forest Science

Calcium oxalate influence on:

- Ca stable isotope patterns
- Tree health
- Ca sustainability

OSU Oregon State University

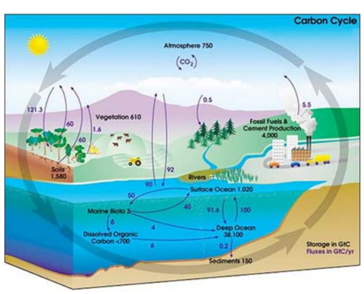
Life Science Education Research

MICHIGAN STATE
UNIVERSITY

Carbon Transforming Processes

photosynthesis * cellular respiration * combustion * biosynthesis * digestion * decomposition

Especially important for students to explain how:

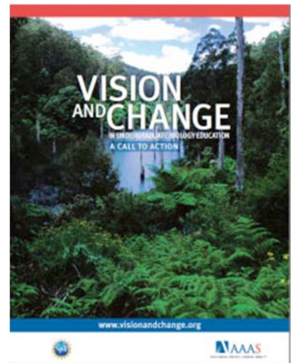


- Living organisms get their energy
- 90% of energy is obtained for human systems
- Imbalances drive climate change

Vision and Change in Undergraduate Biology Education

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

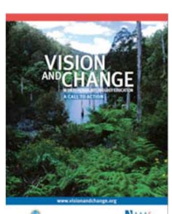
- Pathways and transformations of energy & matter
- Systems



AAAS (2011)
Support and input from NSF, HHMI, NIH

A Change to Science Instruction

Vision and Change in Undergraduate Biology Education, 2011



K-12 Next Generation Science Standards, 2013

NEXT GENERATION SCIENCE STANDARDS

NRC, AAAS, NSTA

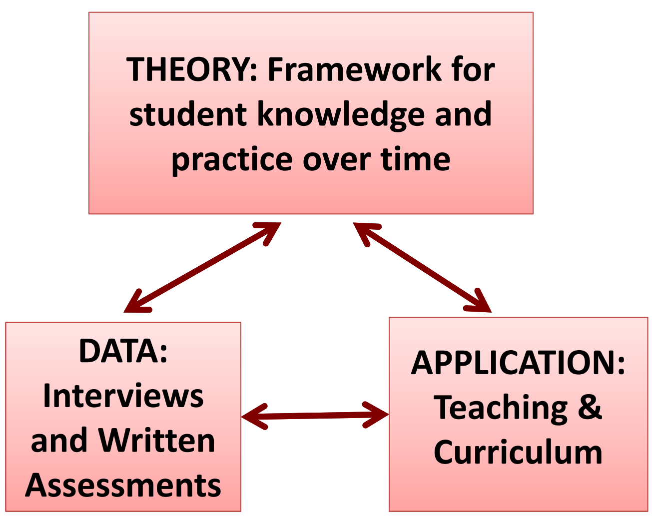
Knowledge and practice need to be integrated in instruction for student to achieve deep understanding

What are the Most Productive Stepping Stones for Students?

Picture: nwwes.deviantart.com

Duncan et al (2013) *Science*

Research Approach



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**

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Plants growing

Flame burning

Decay

Animals moving

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

Can grow!

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)

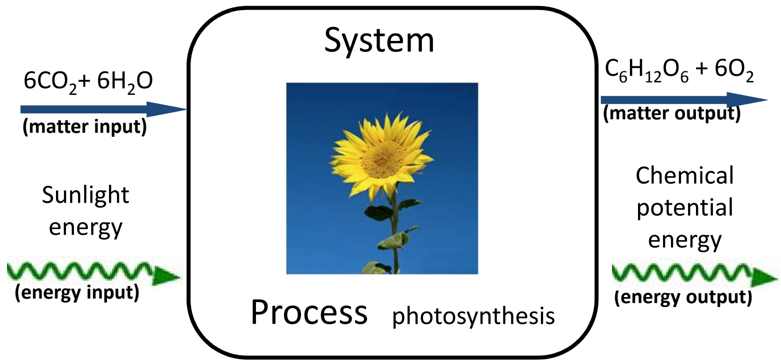
***Informal explanation**:*

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 CO_2 in the air. The carbon in that molecule is used to create glucose."



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

Scientific	**Photosynthesis:** Generating organic carbon	**Cellular Respiration:** Oxidizing organic carbon	**Decomposition:** Oxidizing organic carbon
Linking processes	Plants growing 	Animals moving 	Decay 
Informal	Plants enabled by food, water, sunlight and/or air	Animals enabled by food, water, sunlight and/or air	Natural process in dead things

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*

Hartley et al (2011) *Bioscience*

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?

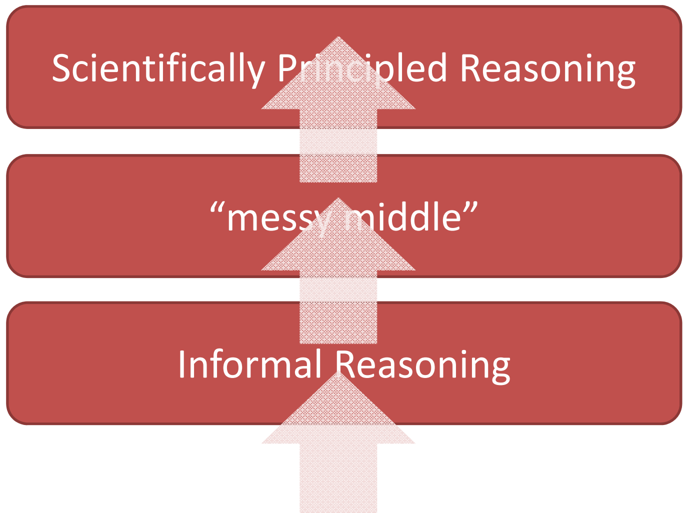
16 % Scientific

50 % Mix of Informal and Scientific

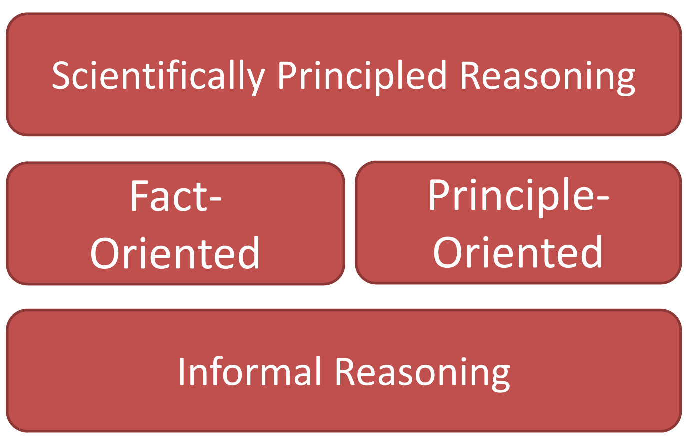
27 % Informal

Hartley et al (2011) *Bioscience*

Learning Progression



Two Types of Students in the "Messy Middle"



Miller, Webster, Dauer, Anderson (2013) NARST

Sci Principled
Fact | Princ
Informal

"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."

Sci Principled
Fact | Princ
Informal

"What happens to a man's fat when he loses weight?"

"It turned into energy and it got burnt and came out through sweat."

Sci Principled

Fact | Princ

Informal

"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."

Sci Principled

Fact | Princ

Informal

"What happens to a man's fat when he loses weight?"

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"The man loses weight through the process of cellular respiration, which **converts his fat into energy** and carbon dioxide."

Principle-oriented

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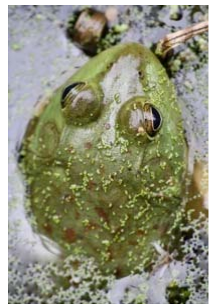
How are Principle-oriented and Fact-oriented Alike?






context-specific knowledge

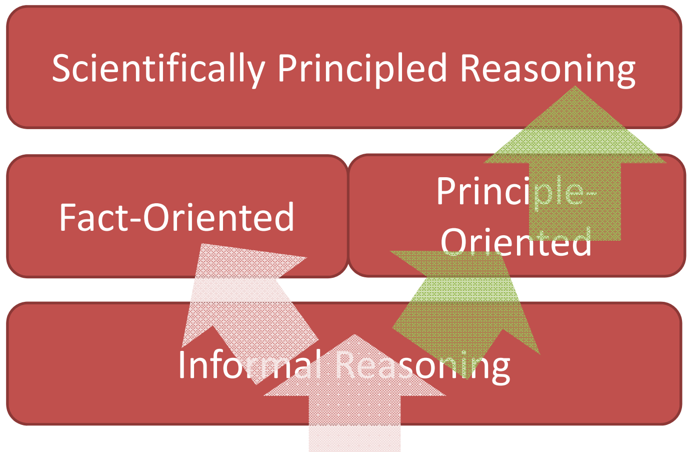
How Are They Different?

Principle-oriented

Fact-oriented

Principles of Matter and Energy

Evidence from Interviews Show that Principle-oriented Students Advance



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

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**

Does Principle-first Instruction Work?

Undergraduate non-majors science course at MSU

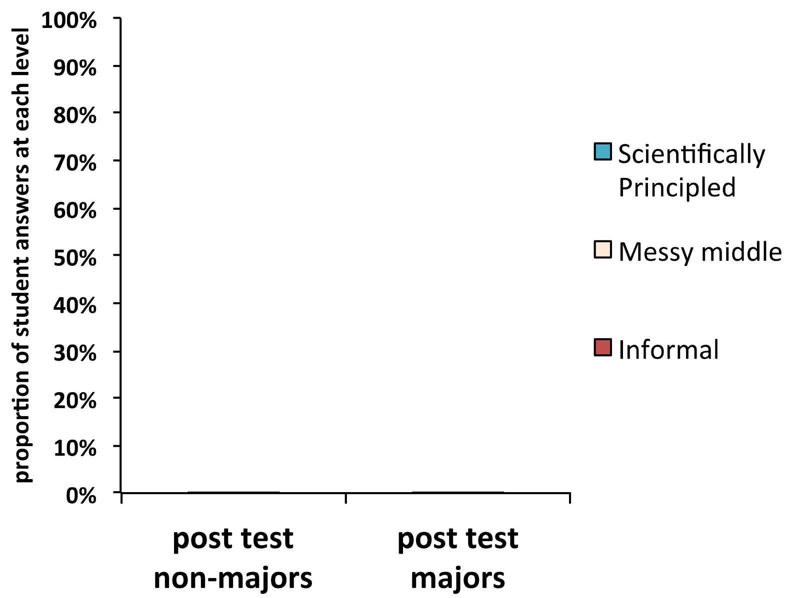
Photo credit: Dr. Jane Rice

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	Possible PRE	Possible POST
1) The girl's food provided atoms that she used to build her body.		
2) The girl used energy in food to make new atoms.		

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*

Dauer, Anderson, Miller, Webster (2012 – 2013)

For middle and high school, public in 2015

NSF DRK12 (#1020187)

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Inquiry and Argumentation about Carbon Transforming Processes

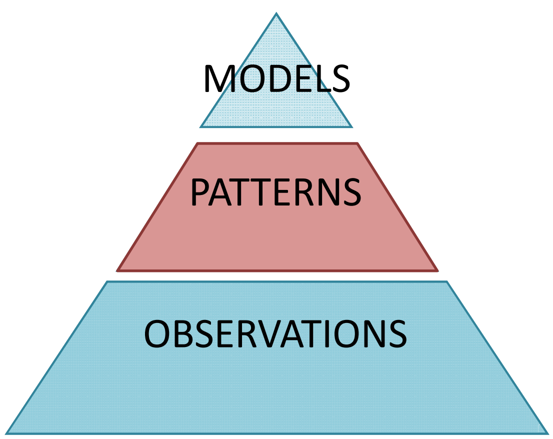
NEXT GENERATION SCIENCE STANDARDS

Photo credit: Dr. Jane Rice

Two examples of how student practices contrast with scientific practices

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

Specific “Inquiry” Practices



30 seconds think-pair-share:

Interview question about pattern finding

Do the data support the prediction? Why or why not?

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**."

College interviews, *n* = 40

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:

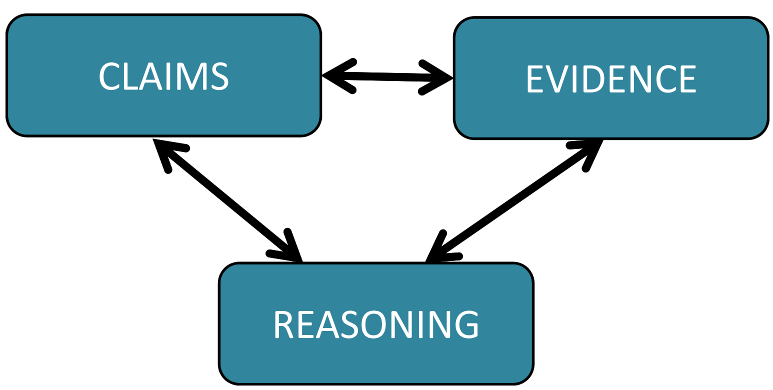
Was the data collected the right way?

Look for data that confirm the answer.

Dauer et al (2013) NARST

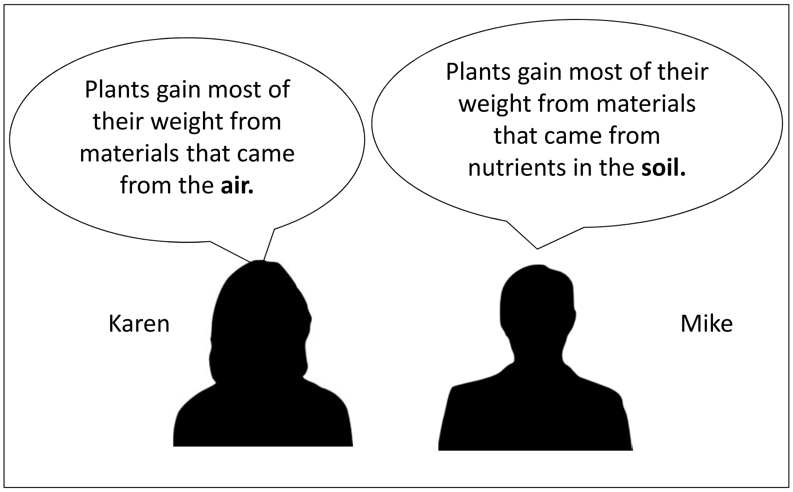
Example #2: Contrasting Approaches to Scientific Argumentation

Goal for students:



McNeill (2011) *JRST*; McNeill & Krajcik (2008) *NSTA*

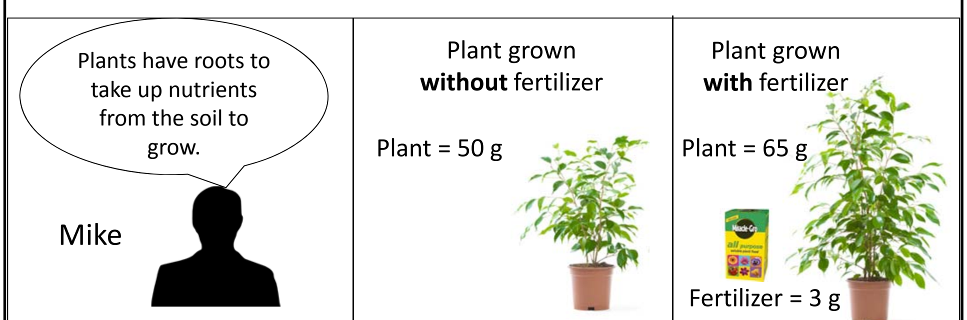
Interview Question: Claims about Tracing Matter



"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



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."

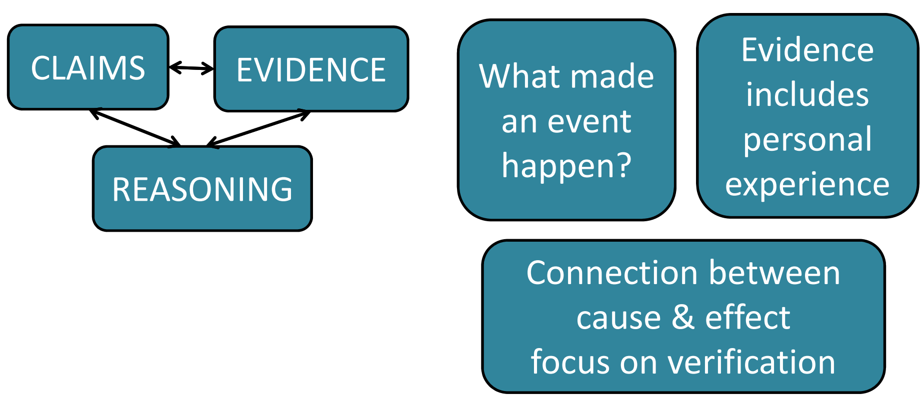
TEACHER: "How is Mike's argument supported by this evidence?"

MABEL: **"It's supported by the weight…. after the same amount of time it grew more."**

MS, HS, college interviews, *n* = 136

Example #2: Contrasting Approaches to Scientific Argumentation

SCIENTIFIC APPROACH: STUDENT APPROACH:



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

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Future Research Questions

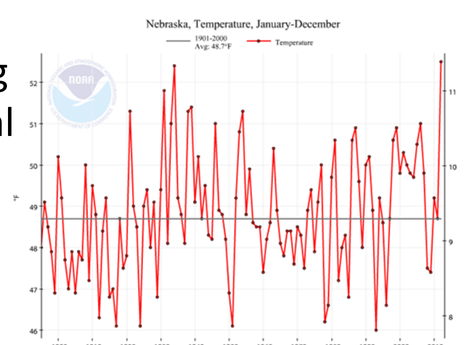
Characterize student learning and practice about
1) matter & energy
2) complex systems

- Carbon transforming processes
  - -organisms
  - -ecosystem or global level
- Relationships between atmospheric CO_2 and global temperature
- Impacts of global climate change to natural & human systems

INQUIRY & ARGUMENTATION

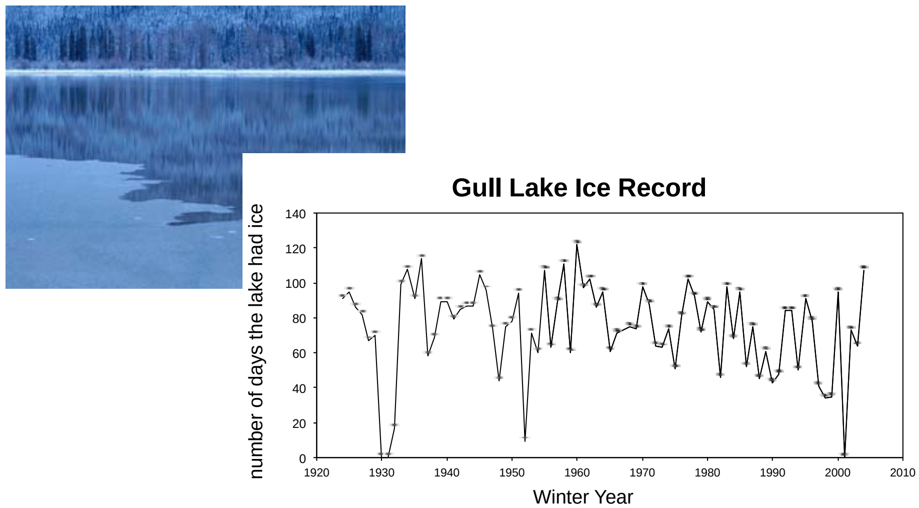
Understanding Inquiry and Arguments from Evidence in the Context of Global Change

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



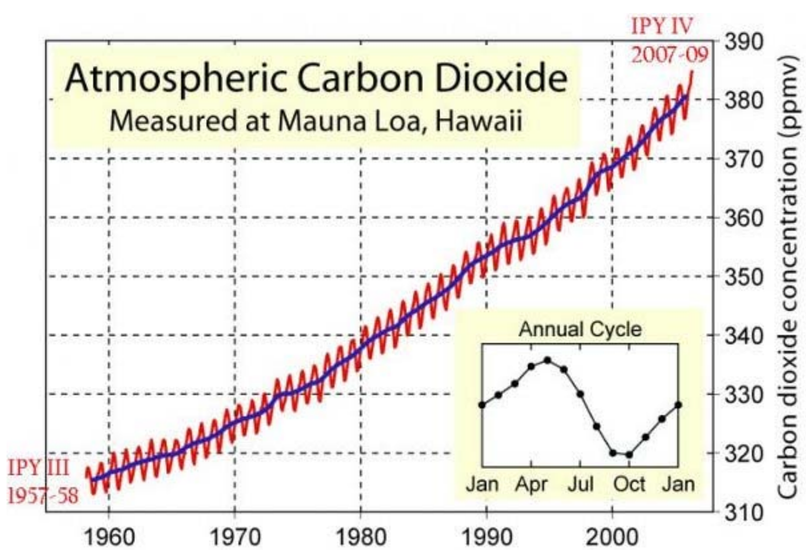
http://www.ncdc.noaa.gov/cag/

Recent Interview Instruments



Preliminary data for NSF EHR Core, July 2013 submission

Recent Interview Instruments



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MICHIGAN STATE
UNIVERSITY

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Graduate students

Hannah Miller
Alison Webster
Elizabeth de Los Santos

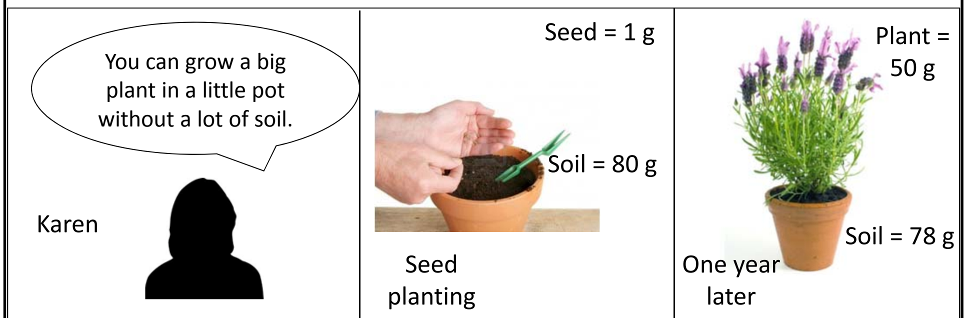
Undergraduate students

Kathryn Oleszkowicz
Courtney Lannen
Liz Tompkins

"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



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

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