Development and Validation of Assessments for a Learning Progression on Carbon Cycling in Socio-ecological Systems

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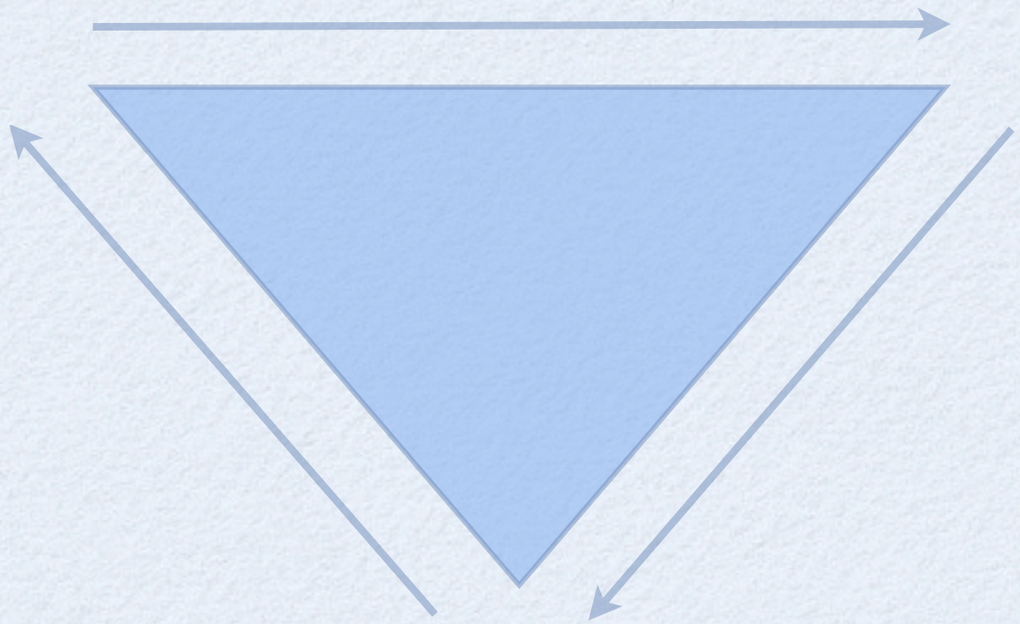
RESEARCH FRAMEWORK -- ITERATIVE TRIANGLE

- **Design-based Research**: The LP framework and assessments are constantly revised according to the findings from data analysis.
- **Assessment Triangle**: Cognition, Observation, and Interpretation

Stage 2. Observations

Revise assessment instruments

Implement assessments and collect students' responses



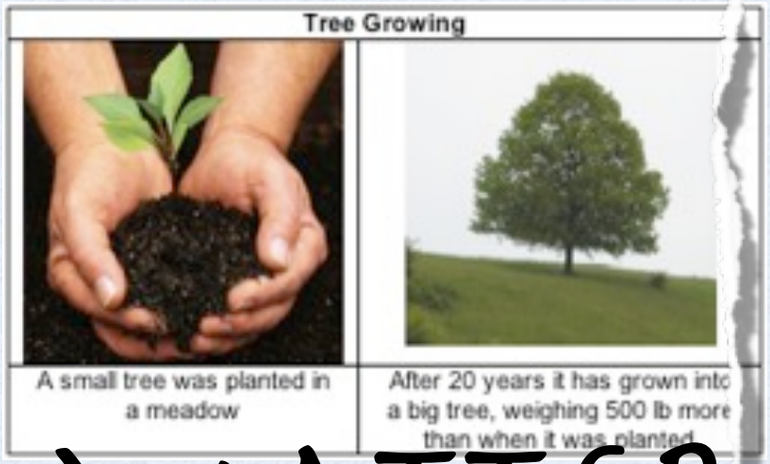
Stage 3. Interpretation (Patterns)

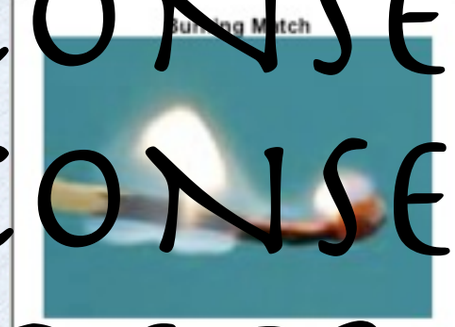
Data Analysis to identify patterns

Stage 1. Model of Cognition

Develop and revise the carbon cycling LP Framework

CARBON CYCLING PROCESSES





MATTER CONSERVATION

ENERGY CONSERVATION

ENERGY DEGRADATION

PHOTOSYNTHESIS: Organic carbon generation & harnessing energy

Cross Processes

DIGESTION & BIOSYNTHESIS: Organic carbon transformation & passing on energy

CELLULAR RESPIRATION & COMBUSTION: Organic carbon oxidation & energy dissipating

THEORETICAL FOUNDATION

Discourse, Practice, and Knowledge

- Discourse: general ways of reasoning and manner of talking about the world.
  - Primary discourse: force-dynamic causation
  - Scientific discourse: matter transformation & energy transformation
- Practice: explaining and predicting
  - Macroscopic Events → Hidden Mechanisms
  - Atomic-molecular Processes → Macroscopic Events & Large-scale Effects
- Knowledge: Knowledge is embedded within discourses and practices.
  - Scientific knowledge:
    - Processes--photosynthesis; digestion & biosynthesis; cellular respiration; combustion.
    - Principles--matter conservation, energy conservation, and energy degradation.
  - Everyday knowledge: knowledge needed for force-dynamic accounts

STEP 1. MODEL OF COGNITION: LP FRAMEWORK

Stage 2. Observations

Stage 3. Interpretation (Patterns)

Stage 1. Model of Cognition

Develop and revise the Carbon cycling LP framework:

1. *Progress variables*: **MATTER & ENERGY**
2. *Levels of achievement* that reflect student progress in discourse, practice, and knowledge

STEP 1. MODEL OF COGNITION: LP FRAMEWORK

Levels of Achievement		Progress Variables	
		Matter	Energy
Upper Anchor	4. Carbon cycling processes constrained by matter and energy principles		
Intermediate Levels	3. Unsuccessful constraints on changes of molecules and energy		
	2. Force-dynamic with Hidden Mechanisms		
Lower Anchor	1. Macroscopic Force-dynamic narratives		

- Progress Variable: Matter and Energy
- Levels of Achievement: Student progress along each progress variable
- Learning Trajectory: Student progress under different learning environment

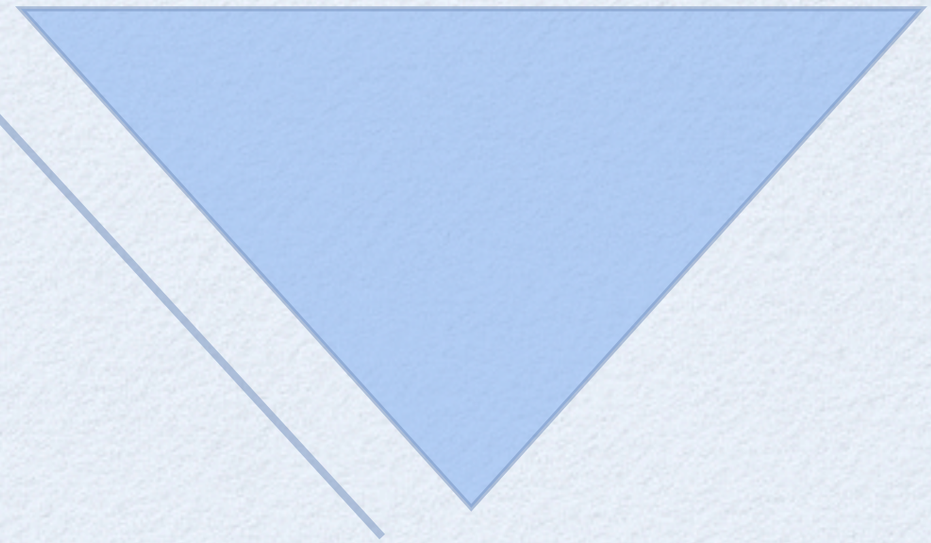
STEP 2. OBSERVATION: DATA COLLECTION

Stage 2. Observations

Revise and implement written assessment items and interview protocol

Conduct teaching experiment

Collect Pre-assessment data before the teaching intervention and Post-assessment data after the intervention



Stage 3. Interpretation (Patterns)

Stage 1. Model of Cognition

STEP 2. OBSERVATION: DATA COLLECTION

Participants

Assessments	American Participants			Chinese Participants	
	Elementary	Middle	High	Middle	High
Pre-written assessment	71	201	179	150	150
Post-written assessment	71	201	119	N/A	N/A
Pre-interview	8	8	8	9	14
Post-interview	8	8	8	N/A	N/A

STEP 2. OBSERVATION: DATA COLLECTION

Assessment Instruments -- Clinical Interview

- General Questions:
  - What does the tree need in order to grow?
  - You said that the tree needs air to grow. Then how does air help the tree to grow?
  - Do you think that the air will change into other materials inside the tree's body?
  - The tree gets heavier as it grows. How does that happen?
- Follow-up Higher-level Questions:
  - If the student mentions glucose/starch/sugar/cellulose/carbohydrates, ask: Do you think it contains carbon atoms? If yes, where does that carbon atom come from?
  - If the student associate sunlight with energy, ask: Where does the light energy go? Do you think it is used up, becomes other things, or else?

A small tree was planted in a meadow

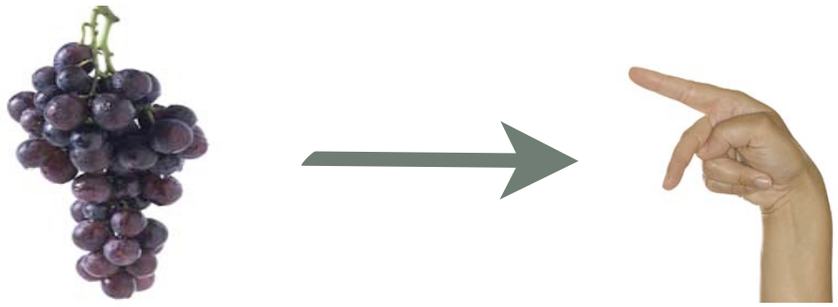
After 20 years it has grown into a big tree, weighing 500 lb more than when it was planted.

STEP 2. OBSERVATION: DATA COLLECTION

Assessment Instruments--Written Assessments

Principle	Matter	Energy	Total
Number of Items	25	20	45

Processes	Photosynthesis	Digestion & Biosynthesis	Cellular Respiration	Decomposition	Combustion	Cross Processes	Total
Number of Items	8	6	10	4	7	10	45



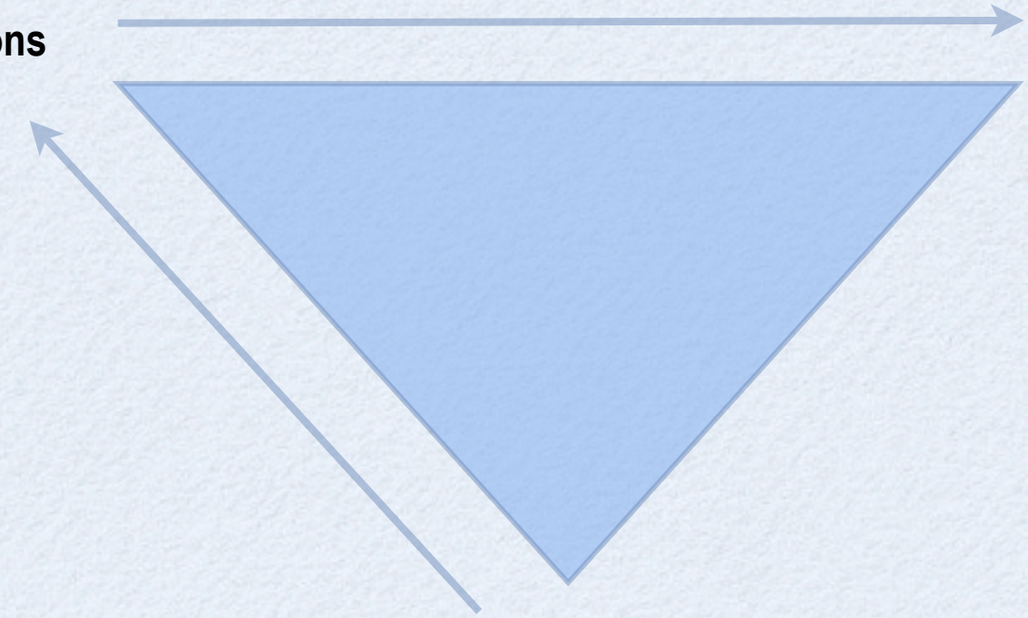
The grape you eat can help you move your little finger.

a. Please describe how a glucose molecule from the grape provide energy to move your little finger.

b. Do you think the glucose molecule of the grape can also help you to keep your body warm at the same time when they are used to move your little finger? Please explain your answer.

Stage 3. Interpretation: Data Analysis

Stage 2. Observations



Stage 1. Model of Cognition

Stage 3. Interpretation (Patterns)

1. Qualitative Data Analysis Model: Discourse, Practice, & Knowledge (Using exemplar workbooks as the coding rubric)

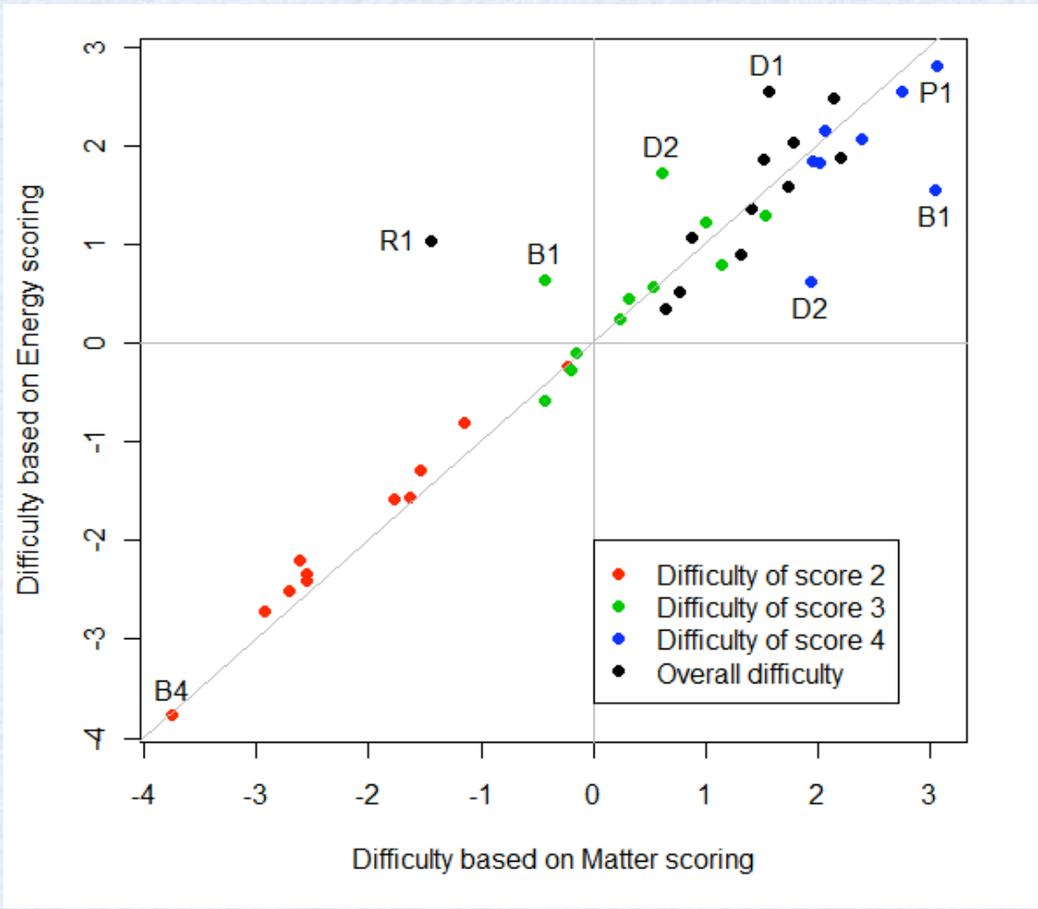
2. Quantitative Data Analysis Model: Multidimensional PCM (Partial Credit Model)

Step 3. Interpretation: Data Analysis

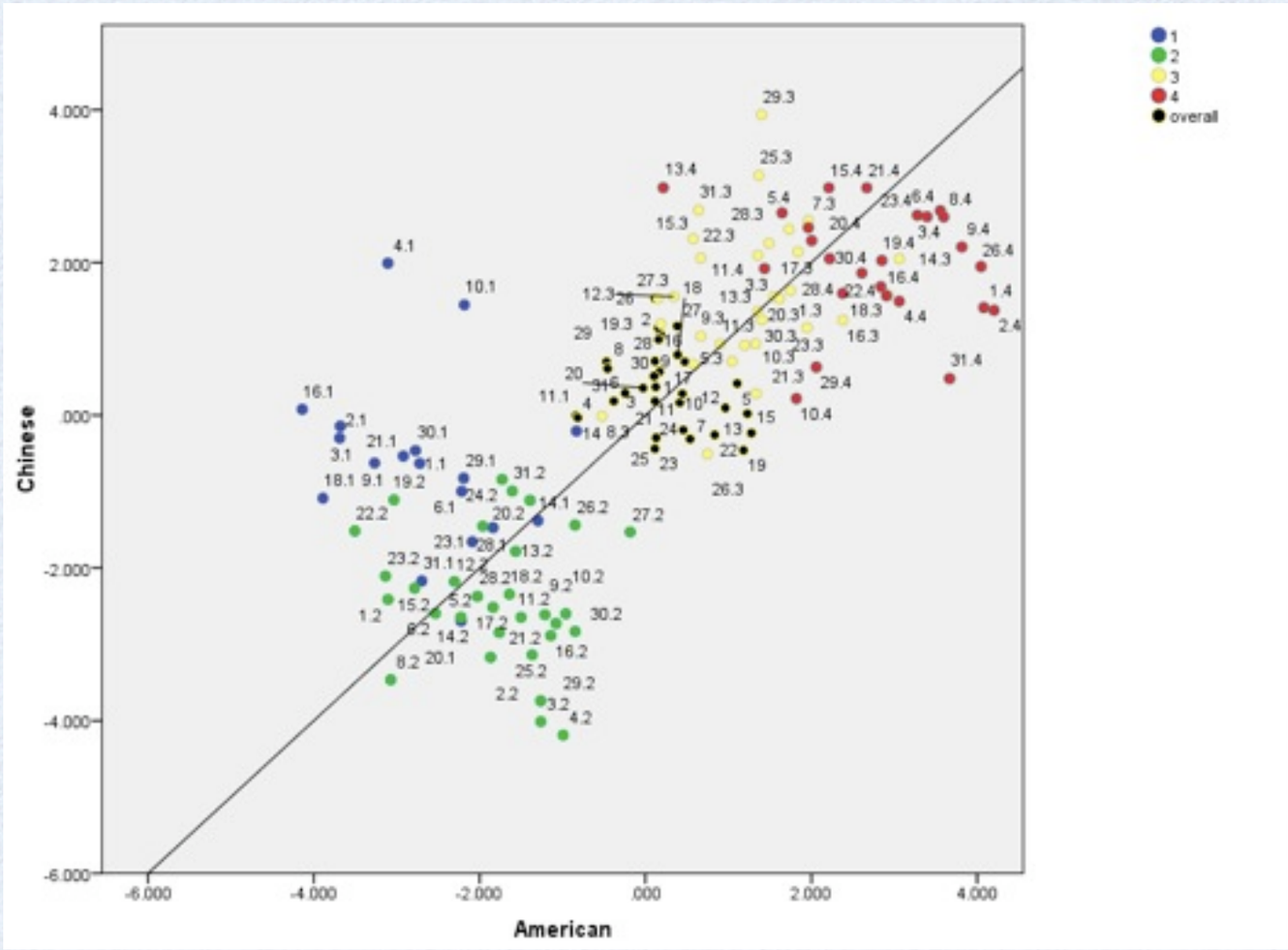
- Qualitative Data Analysis
  - LP Exemplar Workbook
  - Units of Analysis
- Quantitative Data Analysis
  - Multidimensional Partial Credit Model (BEAR)
- Validity Check
  - Qualitative comparison of interview and written assessment data
  - Rater effects
  - Correlation between different progress variables
  - Pre-post comparisons

PROGRESS VARIABLES -- MATTER AND ENERGY

Comparison of item and step difficulty for the items with both matter and energy scores (from Mohan et al., 2009)



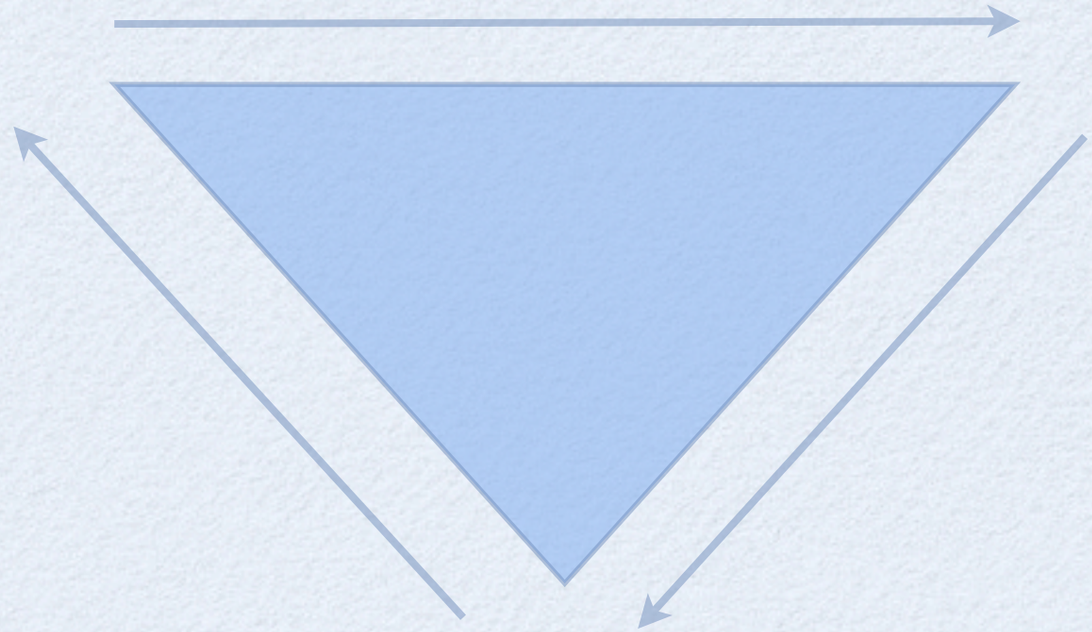
Comparison of item and step difficulty for Chinese and American students (from Chen, Charles, & Jin, 2009)



The American written assessment study found that matter and energy dimensions are not psychometrically distinguishable.

The Chinese written assessment study found that Chinese students do not consistently reach the same level across items. Some items are easier and some items are harder for Chinese students.

Stage 4. Model of Cognition: Current Learning Progression Framework



Stage 4. Model of Cognition

Develop and revise the Carbon cycling LP framework:

1. *Progress variables*: **NAMING AND EXPLAINING**
2. *Levels of achievement* that reflect student progress in discourse, practice, and knowledge

PROGRESS VARIABLES -- NAMING AND EXPLAINING

Naming and Explaining as Performance Variables

(from Jin, Li, & Anerson, 2009)

Naming Variable: students' performance of verbatim reproduction of the relevant content.

- Nouns: needs, familiar names of substances (e.g., oxygen, carbon dioxide), names of energy forms (e.g., kinetic energy, light energy), names of organs (e.g., intestine, heart), names of specific molecules (e.g., glucose, ATP), names of chemical processes (e.g., photosynthesis, cellular respiration).

- Sentences: Students' responses also contain a few sentences—verbatim recitation of science narratives which are commonly used in current science textbooks and classroom teaching. (e.g., in photosynthesis, carbon dioxide, water, and light energy make glucose; plants use sunlight, carbon dioxide, and water to make food; motion/light is energy; oxygen is required for burning.)

Explaining Variable: the performance of explaining the focus events, which reflects and implies certain reasoning patterns

- Enablers/Inputs: Is the event caused by things from outside environment? Why?

- Actor/Process: Where does the change happen (the actor)? How does the change happen? Is the macroscopic change caused by any unobservable change? How?

- Results/Outputs: What are the results or products of the change?

LEVELS OF ACHIEVEMENT (LEVEL 1)

Level 1 Explaining Performances:

- Macroscopic force dynamic accounts: macroscopic actors using their abilities to accomplish results with certain enablers.

Level 1 Naming Performances:

- Words are used to describe observations and perceptions happened to the actor and its enablers

Tree Growth: Naming 1; Explaining 1 (American Pre-interview)

I: How about the water? What happens to the water inside the tree?

A1: It sucks into the roots and then it [water] goes up, so it can make the leaves and the branches grow.

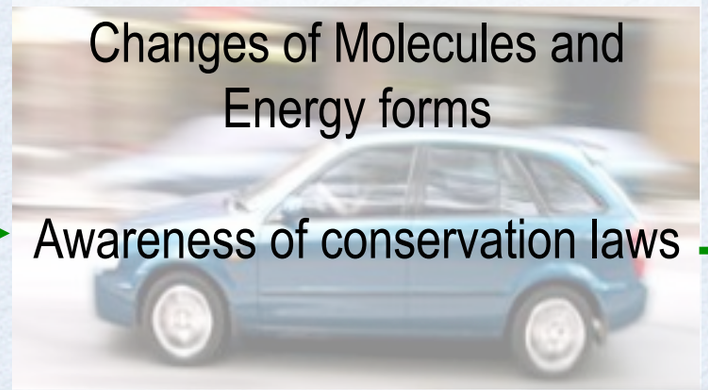
… …

I: How does the tree use sunlight for energy?

A1: I'm pretty sure with the leaves, the leaves attract the sunlight and it's like food to them, so that's how they grow. And I think it's the same with the tree.

LEVELS OF ACHIEVEMENT (LEVEL 3)

Matter/Energy Input: Atoms, Molecules, Specific energy forms



Matter/Energy output: Atoms, Molecule, and specific energy forms

Level 3 Explaining Performances: Processes with unsuccessful constraints

- Explain the macroscopic events in terms of process involving change of molecules and/or change of energy forms, but cannot successfully trace energy and matter separately from matter or trace energy with degradation.

Level 4 Naming Performances: All relevant Molecules, energy forms, & Chemical processes

- Correct reactants and products of matter transformation (chemical changes), or energy transformation
- Statements of the three principles (matter conservation, energy conservation, and energy degradation)

Car Running: Explaining Level 3; Naming Level 4 (Chinese Pre-interview)

I: What does the car need in order to run?
C10: Gasoline. Because gasoline contains chemical energy.
I: When all the gasoline runs out. Where does it go?
C10: It is converted to kinetic energy and heat energy.
I: When the car stops, where does the gasoline and kinetic energy go?
C10: Gasoline changes into gas and evaporates. Kinetic energy disappeared.

PROGRESS VARIABLES -- NAMING AND EXPLAINING

(from Jin, Li, & Anerson, 2009)

Table 1. Alignment of Naming Performances and Explaining Performances for American Students

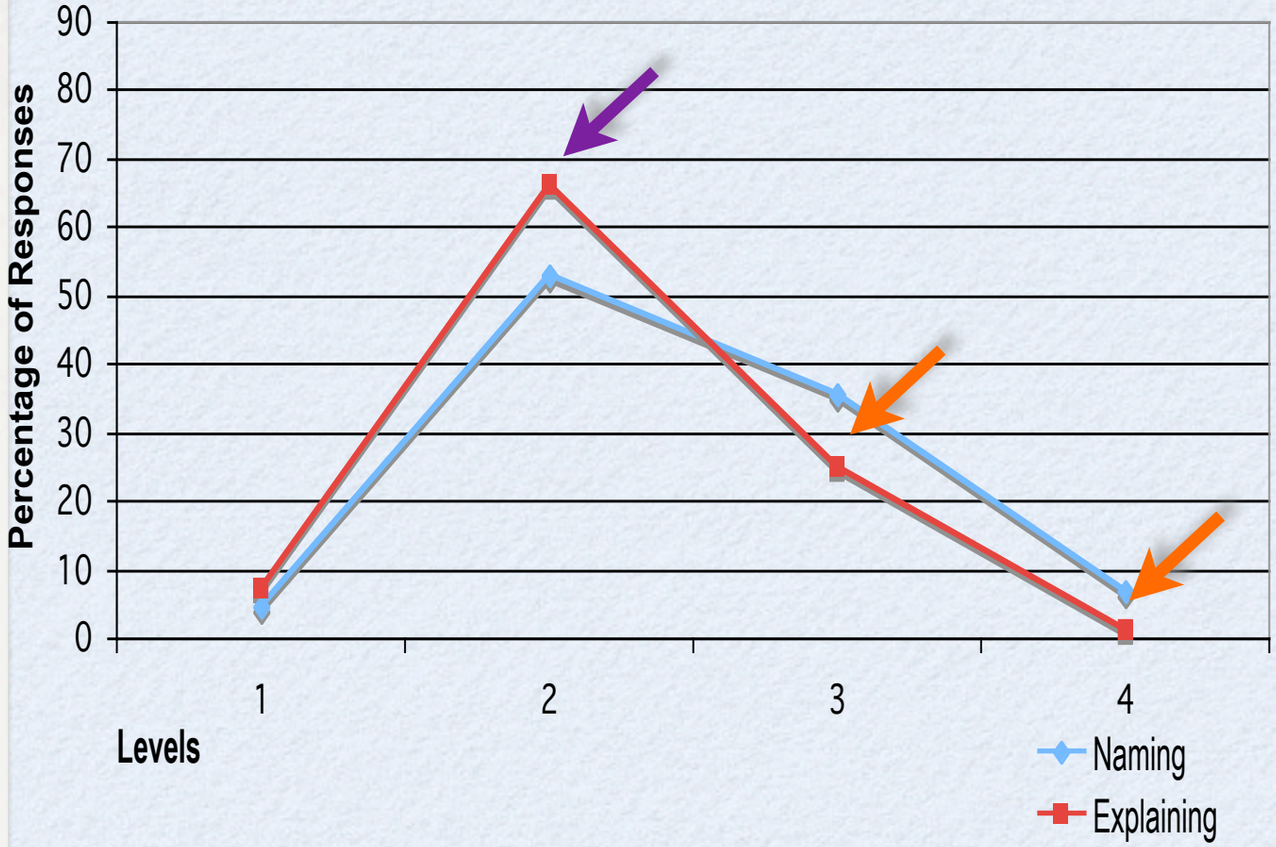
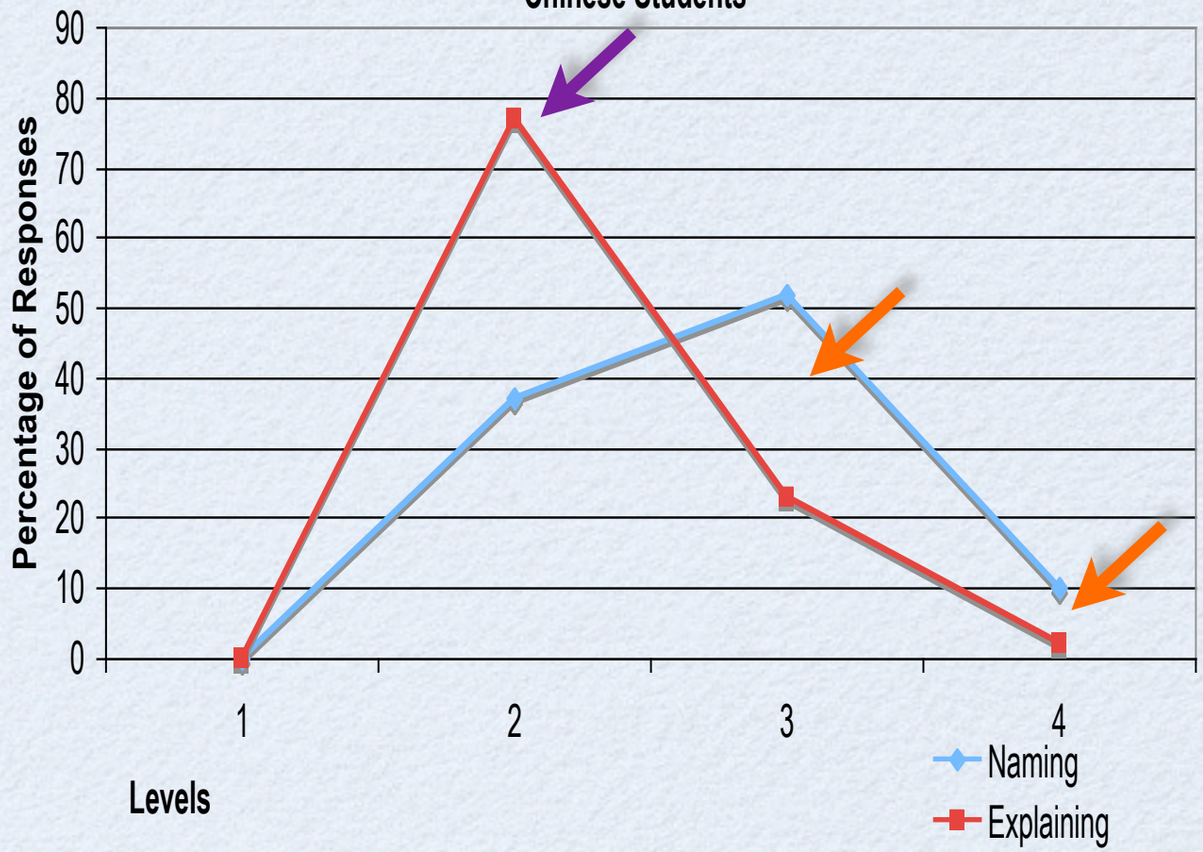


Table 2. Alignment of Naming Performances and Explaining Performances for Chinese Students



- American and Chinese students' explaining performances were very similar, with a majority of each group at level 2 -- relying primarily on force-dynamic causation with hidden mechanism.
- Naming performances and explaining performances were aligned differently for American and Chinese students. Students in both groups showed more level 3 and 4 naming performances than explaining performances, but the difference was much larger for Chinese students.

LEARNING TRAJECTORIES

Successful constraints on atomic-molecular processes with chemical details

Accounts about changes of atoms and molecules with unsuccessful constraints

Accounts about atomic-molecular processes that are constrained by matter/energy principles with limited chemical details

Force-dynamic accounts about hidden processes driven by materials and energy

Accounts about macroscopic changes of matter and energy that are constrained by conservation laws

Macroscopic force-dynamic accounts about the actor and its enablers

Details-first Accounts

Principle-first Accounts

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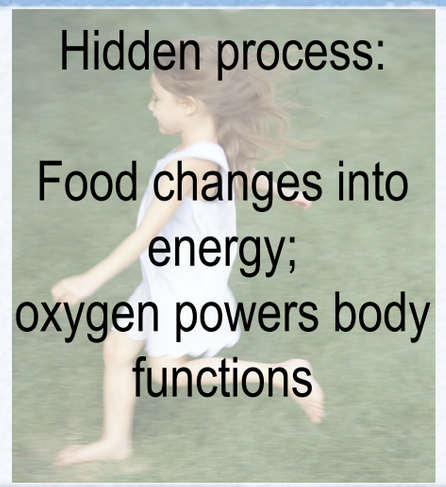
Jonathon Schramm, Michigan State University
Li Zhan, Michigan State University

LEVELS OF ACHIEVEMENT (LEVEL 2)

Matter/Energy Input:
foods, air, water



Food/Energy is used up,
or becomes waste

Level 2 Explaining Performances:

- Force-dynamic explanations with hidden mechanisms: recognition that processes involve unobservable mechanisms or hidden actors (e.g., decomposers), but focus is on enablers, actors, abilities, and results rather than transformation of matter and energy

Level 2 Naming Performances:

- Words are used to describe hidden processes involving the actor and its enablers (e.g., photosynthesis, making foods, breaking down, etc.)
- Words are used to describe familiar materials such as oxygen, carbon dioxide, nutrients, vitamin, etc.
- Name familiar evidence as energy. (e.g., light is energy.)

Girl Running: Explaining Level 2; Naming Level 2 (American Pre-interview)

I: So what does the girl need in order to run?

RKC: Water because as she's running she takes in a lot of oxygen and that [oxygen] makes the blood cells move around.

I: Okay. So do you think the food also helps the girl run? How?

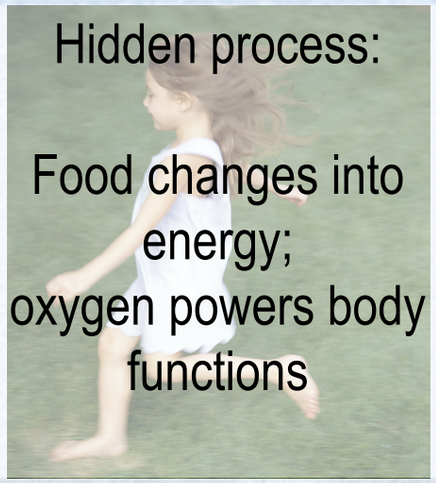
RKC: The nutrients in the food are going to the blood and that keeps the blood moving so it's all linked together, the nutrients and the blood, the water and the blood. ... ... Well, when a human runs he or she their lung moves around or it has to work extra hard to keep up because the person is moving its body very fast so and naturally it needs more energy to keep on moving fast.

I: So where does the energy come from?

RKC: Oxygen, which because the lungs move faster to keep the human breathing while its running, and the nutrients and the water.

LEVELS OF ACHIEVEMENT (LEVEL 2)

Matter/Energy Input:
foods, air, water



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- Name familiar evidence as energy. (e.g., light is energy.)

Girl Running: Explaining Level 2; Naming Level 3 (American Post-interview)

I: Okay, great. What does the girl need in order to run then?

BKD: She needs energy which comes from sugars and then she needs oxygen and muscle.

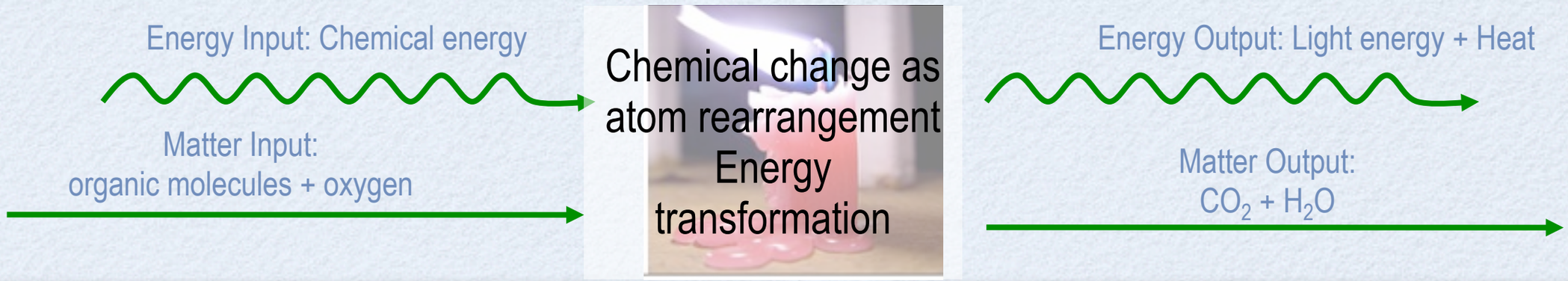
I: Okay. How do energy, muscles and oxygen that you mentioned help the girl to run?

BKD: What?

I: How does oxygen, for example, help the girl to run?

BKD: It gives oxygen to the cells through the blood. And she gets oxygen and it helps her run because it supplies the oxygen to the cells in her legs to make them move.

LEVELS OF ACHIEVEMENT (LEVEL 4)



Level 4 Explaining Performances: Scientific model-based understanding

- Separate accounting for matter and energy
- Reasoning across scales: explain focus events and their large-scale effects in terms of atomic-molecular carbon cycling processes.

Level 4 Naming Performances: All relevant Molecules, energy forms, & Chemical processes

- Correct reactants and products of matter transformation (chemical changes), or energy transformation
- Statements of the three principles (matter conservation, energy conservation, and energy degradation)

XP—Cross Processes: Naming 4; Explaining 4 (American Mid-interview)

I: Ok. Let's just think about these two groups, girl running and tree decaying with the combustion group. Do you think they could be some way similar?

EJR: Let's see. I would have to say that between two and matter changing I'd probably put the two groups together because they're taking in usually whatever type of fuel it is whether it's a candle wick, food, stored energy from when the tree was alive, or gasoline, it's all stuff that was stored and that contains stored energy. It takes that matter and converts it into carbon dioxide and water.

I: So you're also talking about stored energy in food and fuels like chemical energy right? EJR: Yeah.

I: So where does that energy go? EJR: That energy is released into materials around as either heat energy, light energy, kinetic energy, whatever the case may be.