What are they thinking and why?

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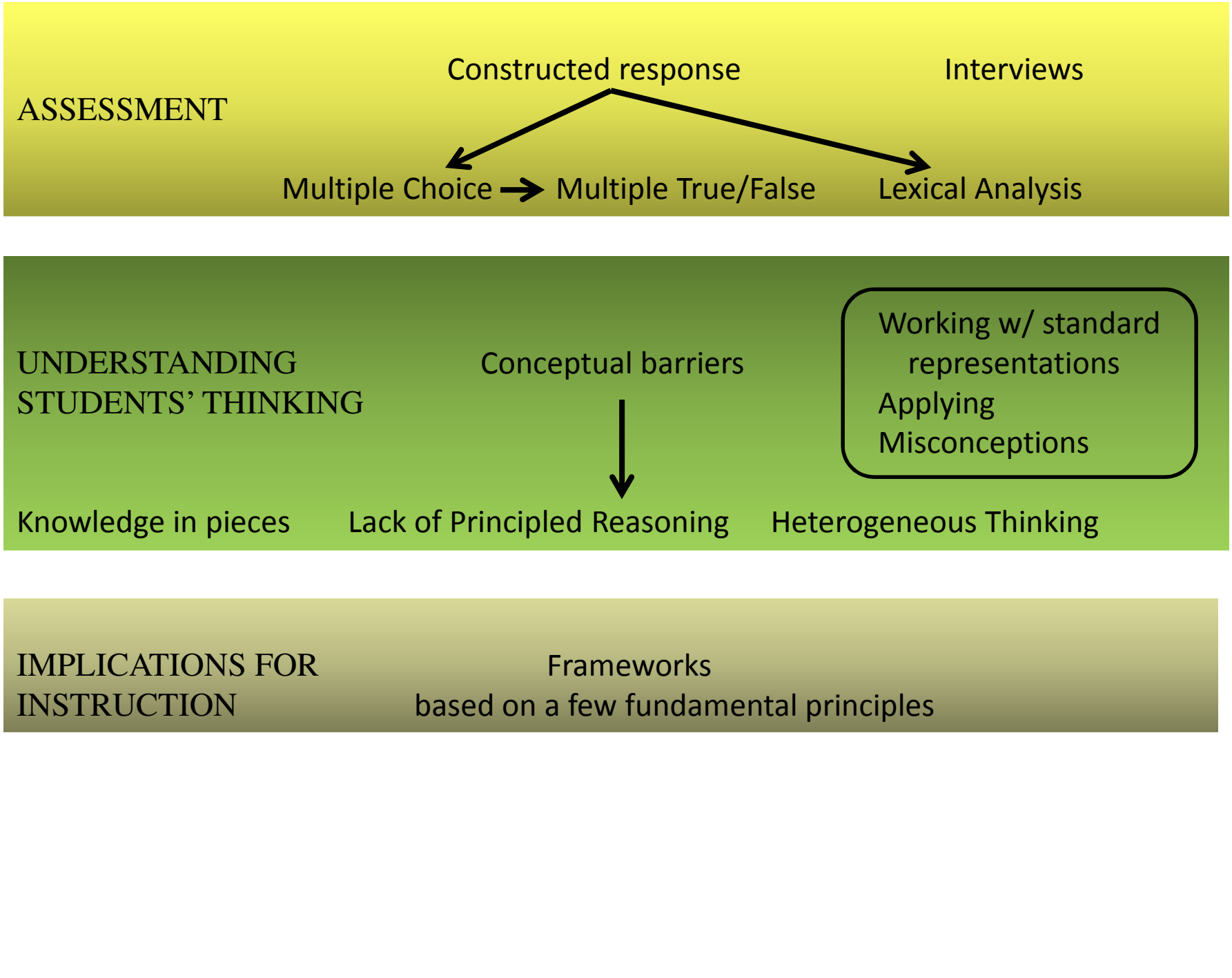

ASSESSMENT
Constructed response
Interviews
Multiple Choice
Multiple True/False
Lexical Analysis
UNDERSTANDING STUDENTS' THINKING
Conceptual barriers
Working w/ standard representations
Applying Misconceptions
Knowledge in pieces
Lack of Principled Reasoning
Heterogeneous Thinking
IMPLICATIONS FOR INSTRUCTION
Frameworks
based on a few fundamental principles

Diagnostic Question Clusters
Assessment in the service of instruction*

- Diagnose conceptual barriers
- Guide instructional changes
- Evaluate results

- Model of the type of reasoning that we want students to develop

*Champagne and Lovitts, 1990

Conceptual Barriers

- Misconceptions
- Conceptual barriers
  - Difficulty
    - With definitions and identifying examples
    - Working with standard representations
    - Explaining - Applying or transferring to different contexts

Methodology

- Identify patterns in students' answers to constructed response, simple application questions
- Common wrong responses become the basis for foils/distractors in multiple choice Qs
- Interviews give us more detailed pictures of students' thinking.

Interpreting the patterns

- List of misconceptions
- Looking across a cluster of questions – broader pattern
- Lack of **principled reasoning**

Principled Reasoning

- Tracing matter - Inputs and outputs
- Tracing energy - When things change, energy is involved
- Tracing information – guides and regulates processes
- Keeping track of scale - Does the cause arise from what is going on at a different scale?
- Structure/function - What structures facilitate the functions?

- Systems
- Evolution

Lack of Principled Reasoning

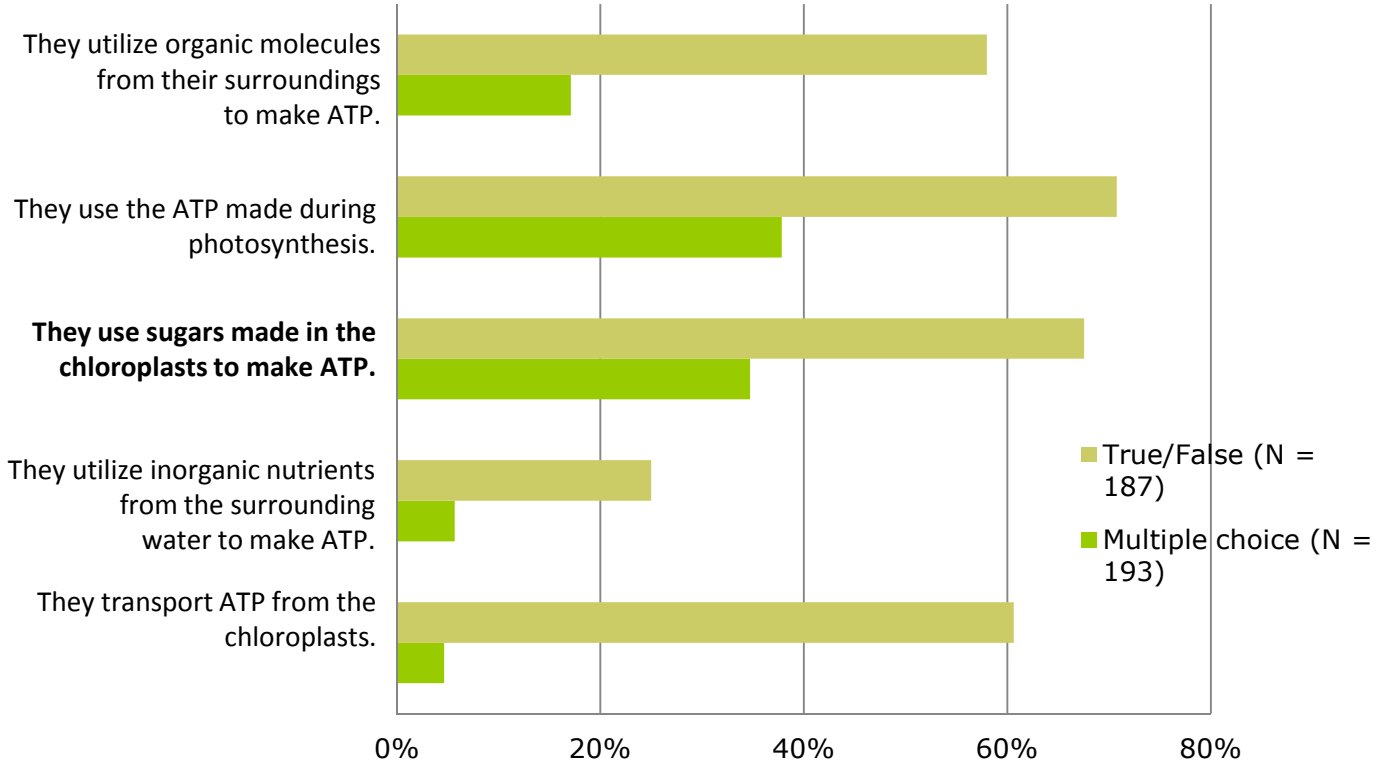
"*In photosynthesis, [coming in are] CO_2, starch or glucose. Coming out is oxygen, water, and energy*."

Susan, introductory biology student after instruction

- Photosynthesis produces ATP that is used throughout the plant.
- The weight a dieter loses is burned up.
- The weight a dieter loses is excreted as sweat, urine, or feces.

Heterogeneous Thinking

Euglena is a single-celled, photosynthetic eukaryote.
How does a Euglena obtain energy to do such cellular work such as active transport across its membrane?



Conceptual Change Framework Theory

- Students' knowledge "theory-like,"
  - Coherent, but not scientific

Vosniadou, S., Vamvakoussi, X., & Skiopeliti, I. (2008). The framework theory approach to the problem of conceptual change. In S. Vosniadou (Ed.), International handbook of research on conceptual change (pp. 3-34). New York: Routledge.

Conceptual Change Knowledge-in-Pieces

- Collection of knowledge fragments
  - Students select and combine depending on the particular circumstances
  - They may combine accurate and inaccurate pieces (heterogeneous thinking)
  - We would like them to combine and edit them using a few principles.

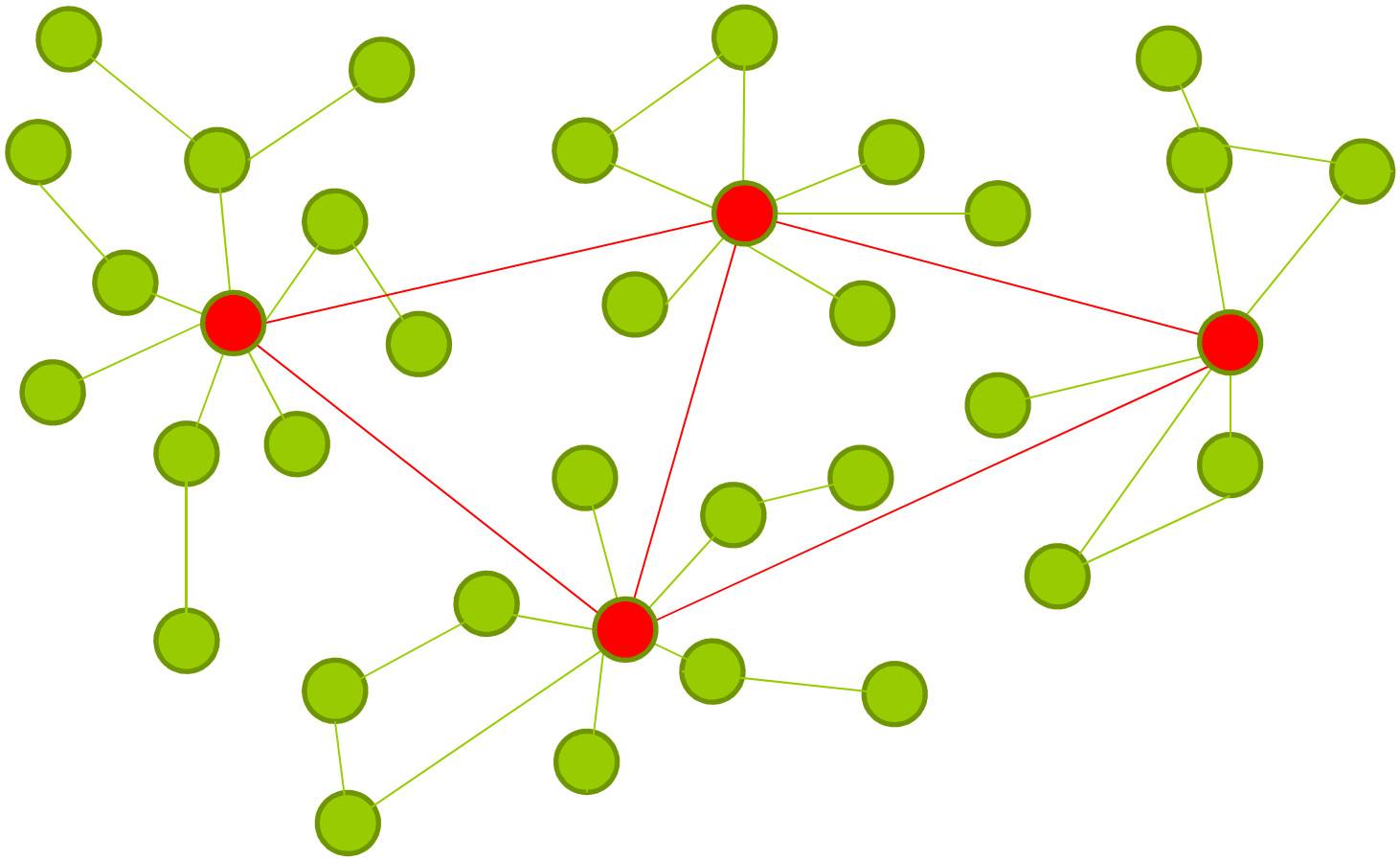
diSessa, A. A. (2008). A bird's-eye view of the "pieces" vs. "Coherence" controversy (from the "Pieces" side of the fence). In S. Vosniadou (Ed.), International handbook of research on conceptual change. New York: Routledge.

Language as Thought

- Semantic Categories
  - Substances (Nouns)
  - Space (Location and Shape)
  - Time/Events (Verbs)
  - Causes
- Framing
  - Word choice reflects conceptual frameworks
  - Simple objects
    - Cause and effect visible
  - Complex objects (actors)
    - Cause and effect not apparent
    - Motives (needs) and intention (adapt)

Pinker, S. (2007) The stuff of thought: Language as a window into human nature. Viking, New York, NY.

Scale-Free, Small World Graph



Introduction: Use of constructed responses

- Students have complex ideas
- One limitation of multiple choice questions is the forced selection of a single idea
- Having students create their own explanations may better reveal their complex ideas

Research Question

- How can we better reveal and understand students' complex ideas?
  - When students construct own answer, more likely to reveal mix of ideas
  - Impossible to analyze all students' submissions in very large courses
  - Can computer help?
    - **Lexical analysis** allows the processing of large numbers of student responses to reveal ***common patterns of ideas***

Why Research Photosynthesis?

- Photosynthesis a complex biological process
  - energy transformations
  - molecular rearrangements
  - structure/function relationships
- Existing diagnostic questions and research into student difficulties

Multiple Choice Questions

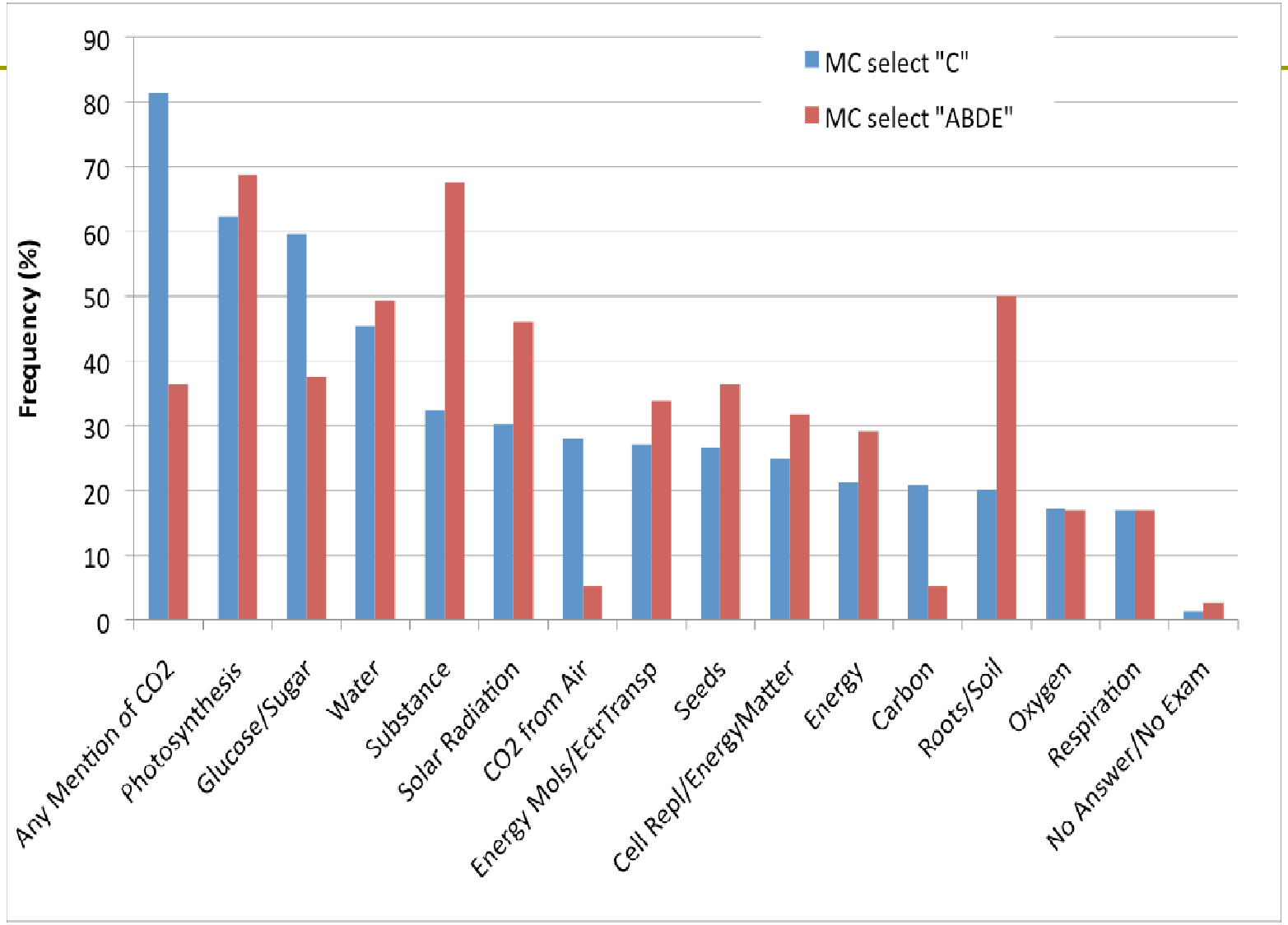
- Q. A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing water), yet it starts from a seed that weighs less than 1 gram. Which of the following contributes most to this huge increase in biomass?
  A. Absorption of mineral substances from root (7.7%)
  B. Absorption of organic substances from soil via roots (12.7%)
  C. Incorporation of CO2 gas from atmosphere into molecules by green leaves (59.4%)
  D. Incorporation of H2O from soil into molecules by green leaves (7.7%)
  E. Absorption of solar radiation into the leaf (12.7%)

- A similar question stem using corn and same distractors was also used

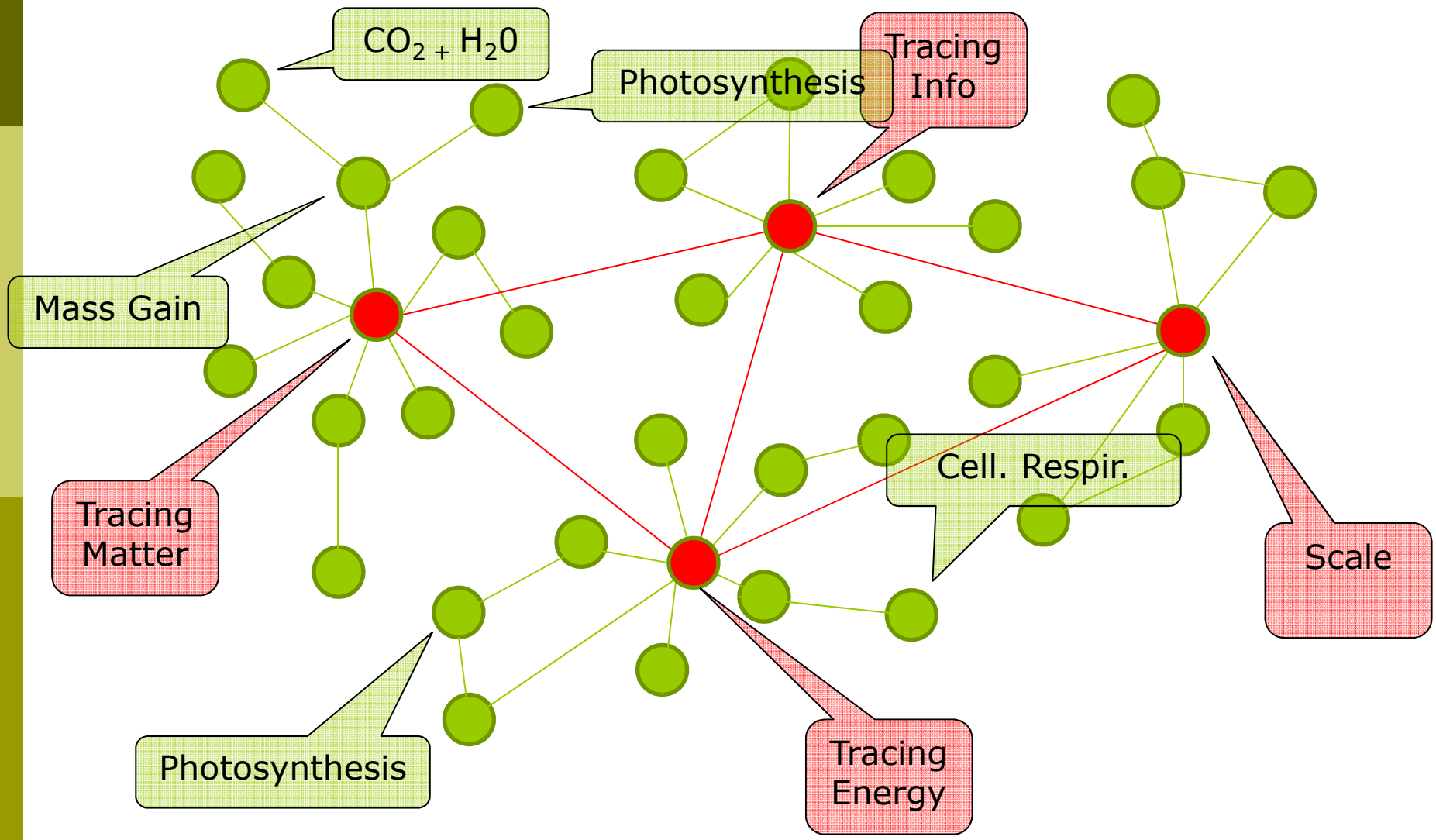
Constructed Response Prompt

Q: *A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram.* ***Explain this huge increase in biomass****.*

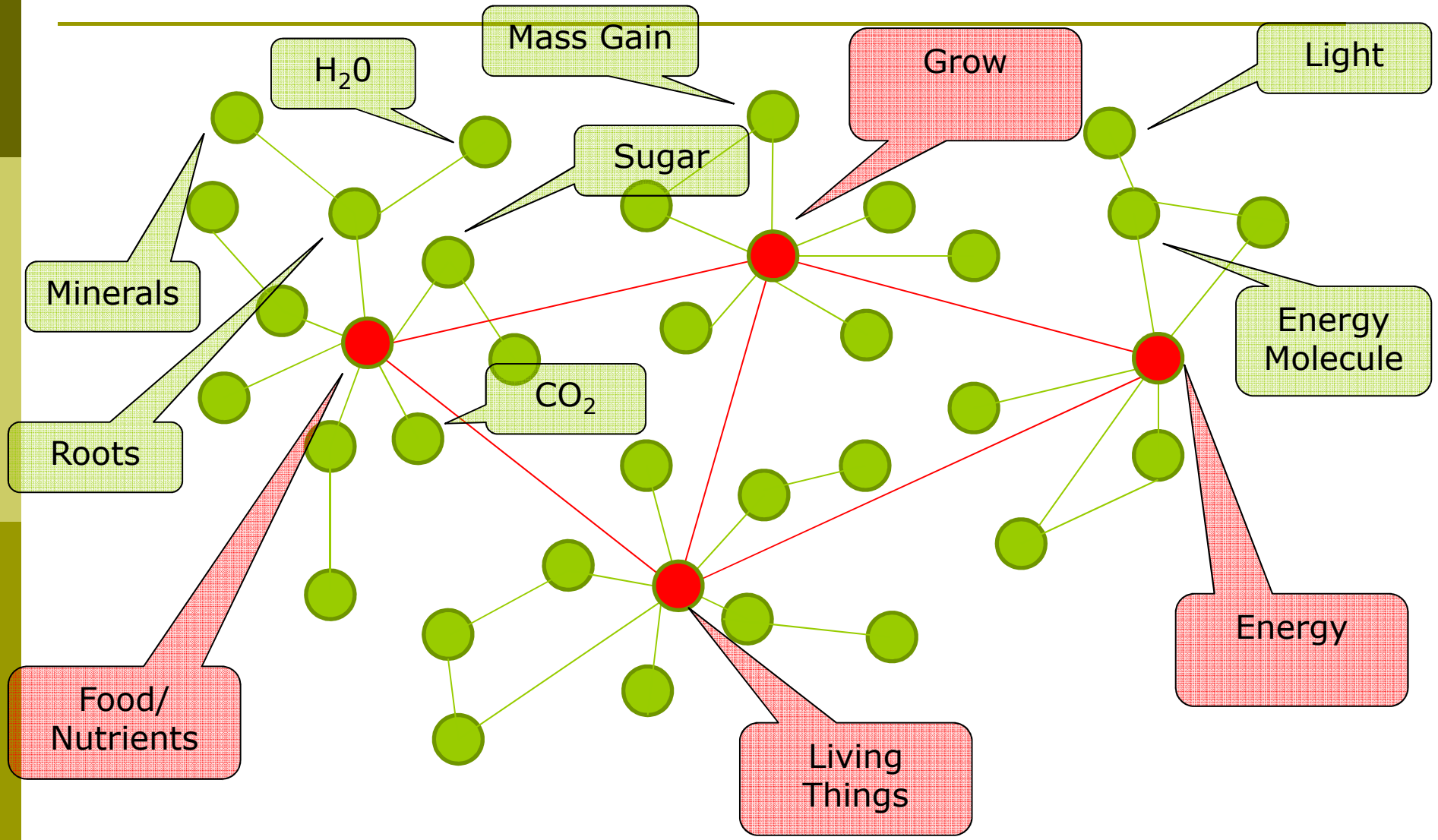
MC Selection vs. CR Categories



Expert: Mass Gain



Novice: Mass Gain



Growing Semantic Networks Learning Implications

- Lexical development in individuals
- New nodes added
  - Differentiation: new concept as variation of existing concept
  - Probability of differentiation proportional to number of connections
- Bias to access concepts with high connectivity
- Recently learned concepts are less connected

Your students

- What are some conceptual barriers that your students have?
- Are these symptomatic of
  - poor principled reasoning,
  - knowledge in pieces,
  - heterogeneous thinking,
  - Other?
- How do you know?

Group Discussion

Implications for instruction

- Because our students are poor principled reasoners, we are piling details onto a weak foundation.
- We need to explicitly teach and assess how to use basic principles.
- Frameworks based on a few principles

Principles for instruction

- Should not attempt to “replace” students’ conceptual frameworks
- Attempt to adapt, rather than simply replace
- Structure instruction to build on “hubs” of existing knowledge structures
- Discussion rather than confronting and trying to replace their concepts (Smith, diSessa, & Roschelle, 1993).

diSessa, A. A. (2008). A bird's-eye view of the "pieces" vs. "Coherence" controversy (from the "Pieces" side of the fence). In S. Vosniadou (Ed.), International handbook of research on conceptual change. New York: Routledge.

	Tracing Matter	Tracing Energy	Structure/Function
ORGANISMAL LEVEL			
Using Food for Energy			
CELLULAR LEVEL			
Cellular Respiration		**Some chemical energy in the C-C and C-H bonds in glucose → chemical energy in ATP**	
SUB-CELLULAR LEVEL			
Glycolysis			
Pyruvate oxidation (Acetyl CoA production)			
Kreb's Cycle			
Electron Transport Chain & Oxidative Phosphorylation			

	Tracing Matter	Tracing Energy	Context/Structure
ORGANISMAL LEVEL			
Using Food for Energy	**Food provides molecules that serve as fuel and building material for all organisms. Some of the matter in food leaves aerobic organisms in the form of carbon dioxide and water.**		
CELLULAR LEVEL			
Cellular Respiration	**$C_6H_{12}O_6 + 6H_2O + 6O_2 \rightarrow 6CO_2 + 12H_2O$**		
SUB-CELLULAR LEVEL			
Glycolysis	**(1)6-carbon glucose → (2)3-carbon pyruvate + (2)H_2O**		
Pyruvate oxidation (Acetyl CoA production)	**(2)3-carbon pyruvate → (2)2-carbon acetyl CoA + (2)CO_2**		
Kreb's Cycle	**(2)2-carbon acetyl CoA → (2)$2CO_2$**		
Electron Transport Chain & Oxidative Phosphorylation	**Electrons from NADH & $FADH_2$ + O_2 → H_2O + NAD & FAD (No carbon skeleton)**		

How can we use frameworks to organize concepts for students?

1. Pick a topic/process that you teach
2. Build a framework
    1. What principles apply?
    2. What are relationships among principles? (columns and row headings)
    3. Organize the content into the cells
    4. What is left out?

Frameworks guiding assessment

1. Build an application Q
    1. Pick a specific example.
    2. Frame the Q and correct answer.
    3. How would this Q reveal problems with principled reasoning?

Group Discussion

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