Scientific Thinking and Conceptual Change:

Revealing Student Thinking as a Foundation for Improving Learning Outcomes in STEM

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Automated Analysis of Constructed Response Research Group

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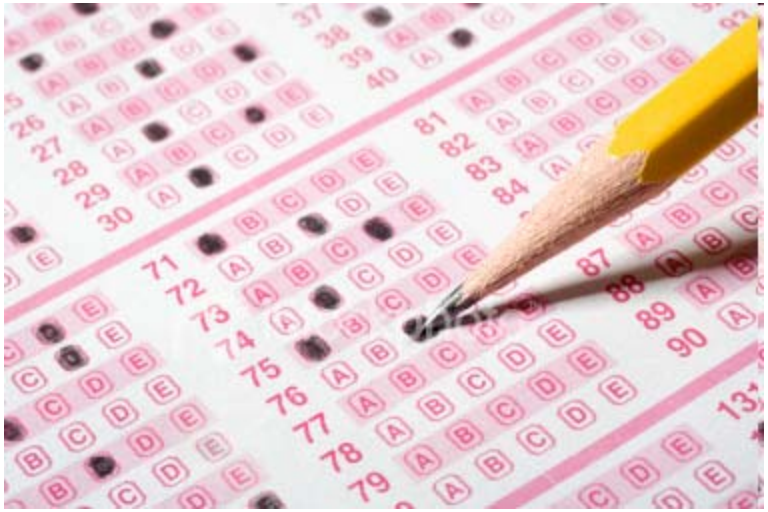
STEM Education Reform

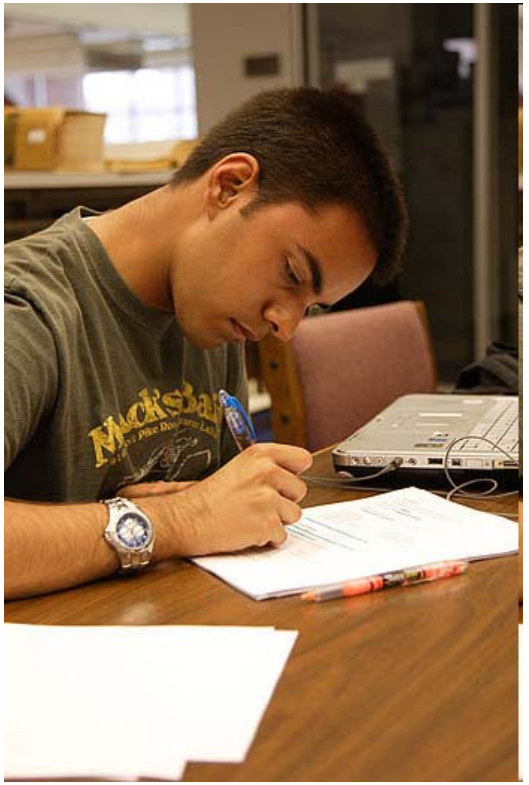
At all levels, science education needs to be redefined, with much less emphasis on the memorization of science facts and terms.

Closely related changes in the introductory science courses in college, emphasizing "science as a way of knowing," are the key to driving these reforms.

Science and the World's Future, Bruce Alberts, MSU STEM Education Symosium

Backwards Design: Assessment to Reveal Student Thinking





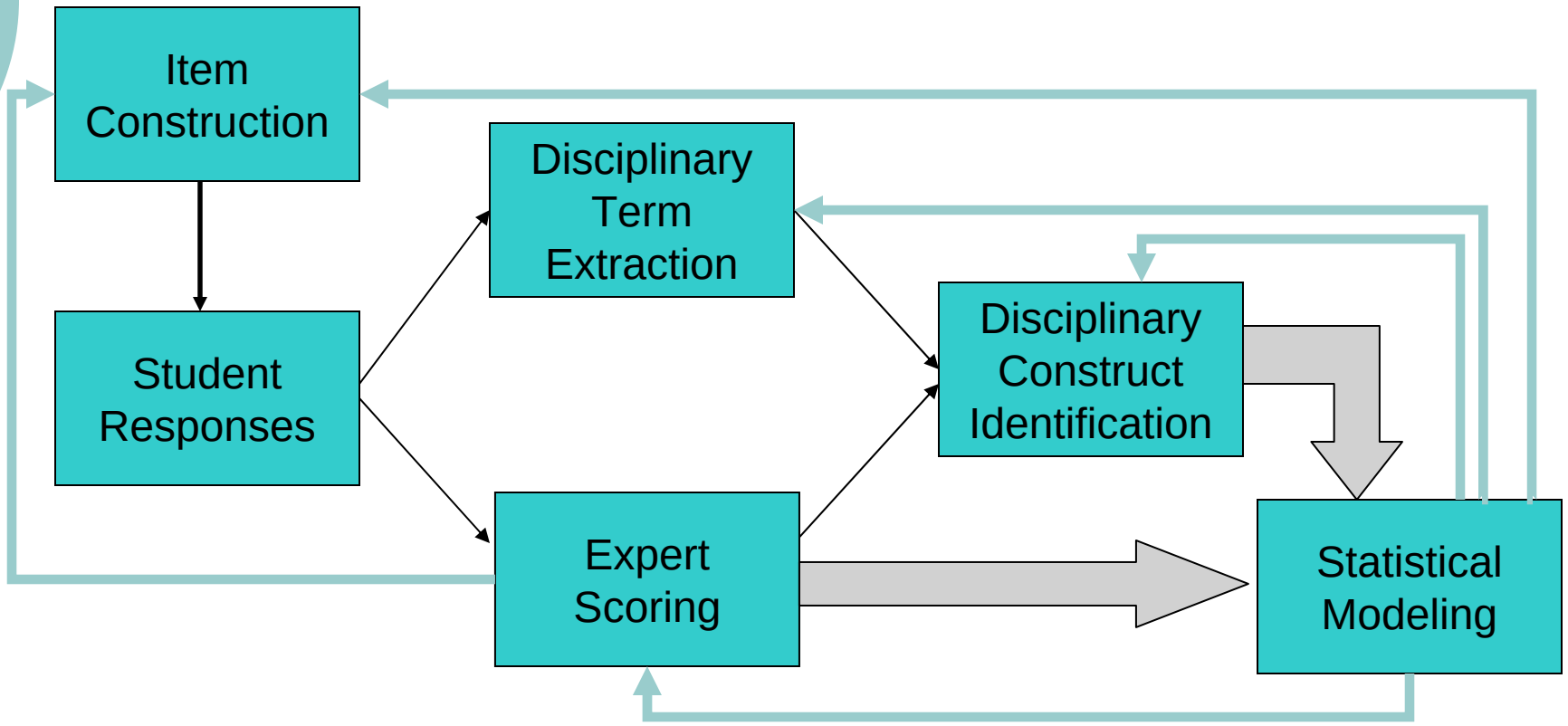
Theoretic Framework: Conceptual Change

- Conceptual barriers impair students' understanding complex processes in science
- Conceptual Change
  - Role of prior knowledge in learning
- Student ideas
  - May be identified by students' use of language
  - *Constructed Response* questions can provide insight into student ideas

AACR Objectives

- Evaluate students' understanding of scientific concepts
  - Create models of student thinking
- Use linguistic and statistical analysis to analyze students' writing
  - Develop necessary libraries and resources
  - Validate by predicting expert ratings

Our Approach: Linguistic Feature-Based



Validating by Predicting Expert Ratings Example: Chemistry of Biology

- Evaluate students' understanding of basic chemistry related to cellular and molecular biology
  - Free energy and acid/base chemistry
- Introductory Biology Cells and Molecules (BS111)
  - Large enrollment (400-500 / section)
  - General chemistry prerequisite

Functional Groups: Multiple Choice

Consider two small organic molecules in the cytoplasm of a cell, one with a hydroxyl group (-OH) and the other with an amino group ($-NH_2$).

Which of these small molecules (either or both) is most likely to have an impact on the cytoplasmic pH?

35%	A. Compound with amino group
45%	B. Compound with hydroxyl group
7%	C. Both
13%	D. Neither

Explain your answer

Sample Student Answers

The amino group can break down compounds faster and can therefore change the pH of the cytoplasm

Has a carboxyl group, is more acidic

The amino group is more basic and can change the pH better than the hydroxyl group.

The hydroxyl group doesn't affect the pH as much as an amino, which has a NH2.

The level of Hydrogen concentration defines the pH.

The amino group is an acid. It will cause the pH in the compound to rise.

Hydroxyl is a base.

Expert Ratings of Explanations

- Two experts rated explanations from correct answers using 3-level rubric
  - 36% Level 1: Correct explanations of functional group chemistry (may include correct supporting reasoning)
  - 12% Level 2: Partly correct explanations with errors in facts or reasoning
  - 51% Level 3: Totally incorrect/irrelevant response

    - Cronbach Alpha > .92

Predicting Expert Ratings

	Computer Predicted Rating		
Expert Rating	1	2	3
1	**82.9**	12.2	4.9
2	21.4	**42.9**	35.7
3	6.9	12.1	**81.0**

- 77% of the cases scored correctly, $p < .001$
- Expert/computer inter-rater reliability
  Intraclass correlation = 0.835

Weight Loss: Multiple Choice

You have a friend who lost 15 pounds of fat on a diet. Where did the mass go?

44% A) The mass was released as CO_2 and H_2O.

23% B) The mass was converted to energy which was used up.

21% C) The mass was converted to ATP molecules.

9% D) The mass was broken down to amino acids and eliminated from the body.

3% E) The mass was converted to urine and feces and eliminated from the body.

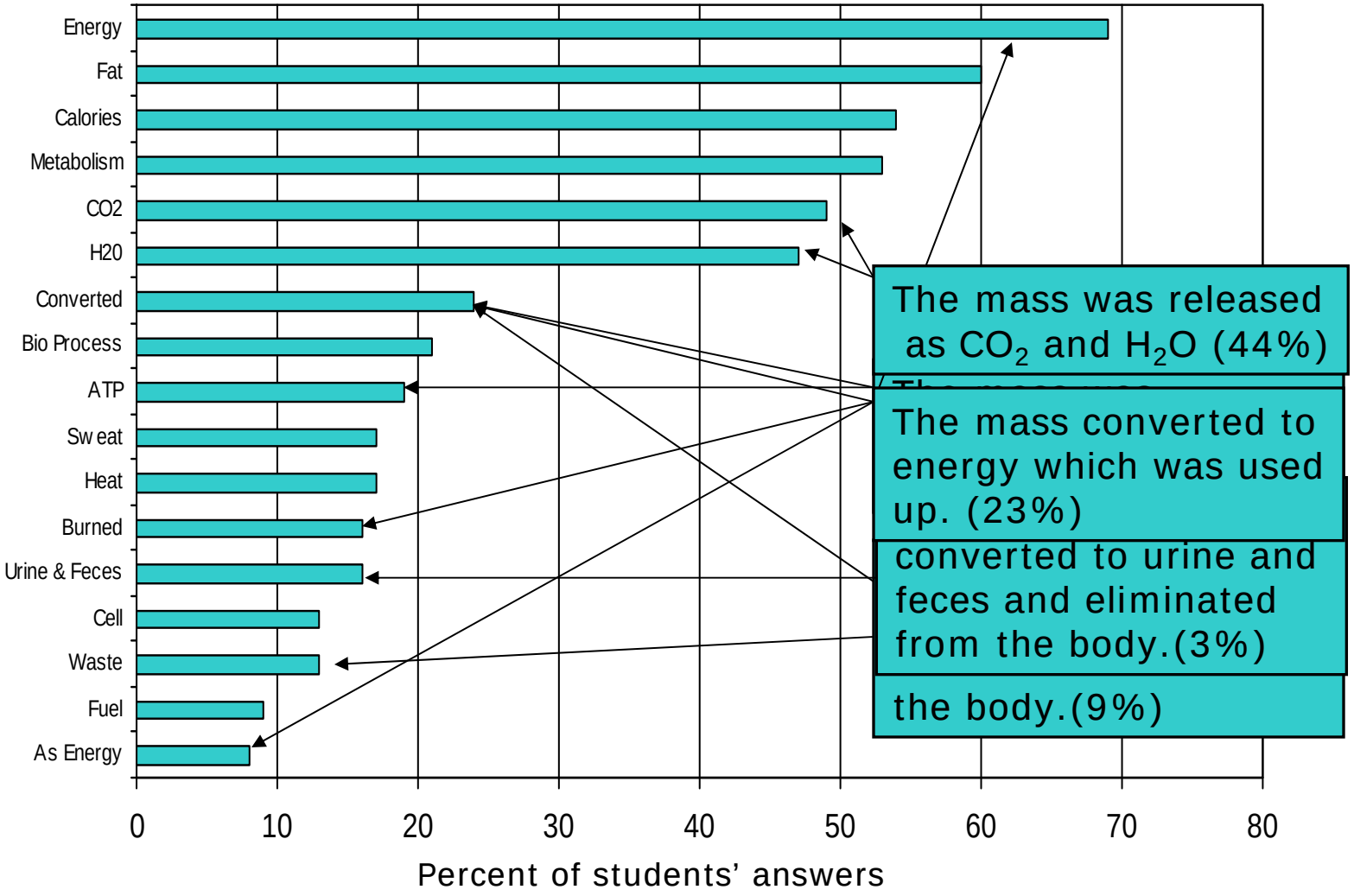
DQC question, BS 111, Fall, 2006 (N = 459)

Weight Loss: Constructed Response

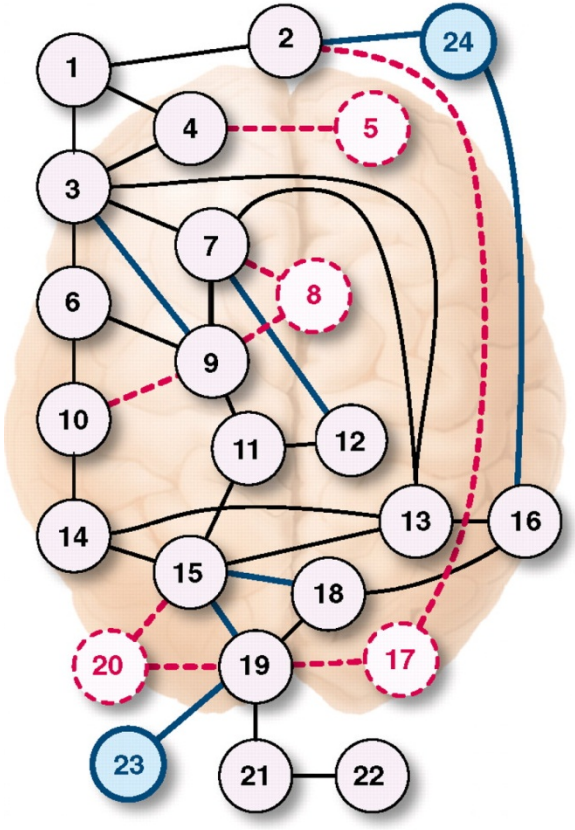
You have a friend who lost 15 pounds of fat on a diet. Where did the mass go?

BS 111, Fall, 2009, (N = 316)

Concepts in Students' Answers



Conceptual Change:
Role of Prior Knowledge in Learning

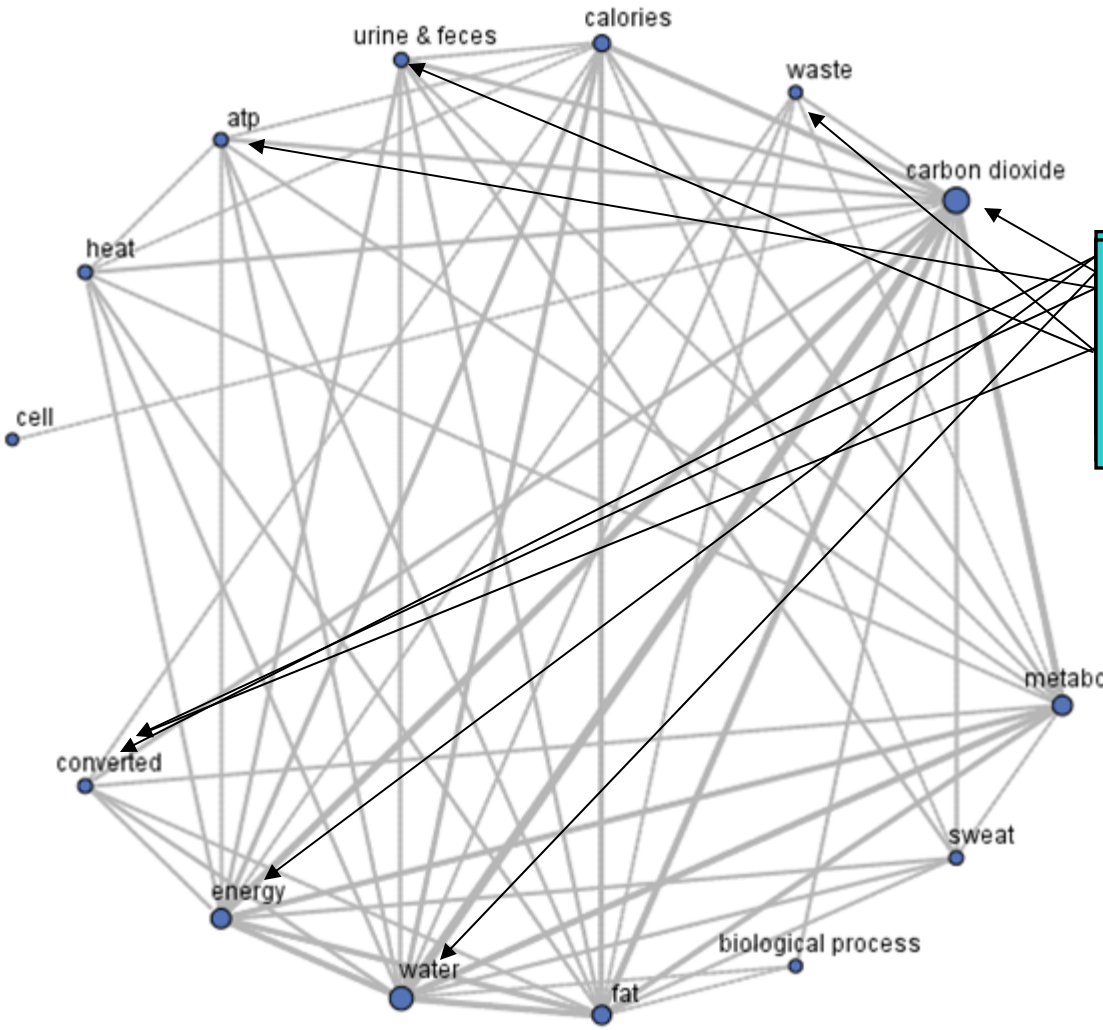


Expansion and modification of a hypothetical reader's knowledge structure.

Correct prior knowledge (black)
Newly acquired knowledge (blue)
Corrected misconceptions (red)

Figure 3 from: van den Broek, P. (2010). Using texts in science education: Cognitive processes and knowledge representation. *Science, 328*(5977), 453-456.

Relationships Among Concepts in Students' Writing



The mass was broken down to amino acids and eliminated from the body.(9%)

Conceptual Change: Instructional Implications

- Student ideas are heterogeneous
- Instruction should start with student ideas
- Cannot simply “replace” misconceptions

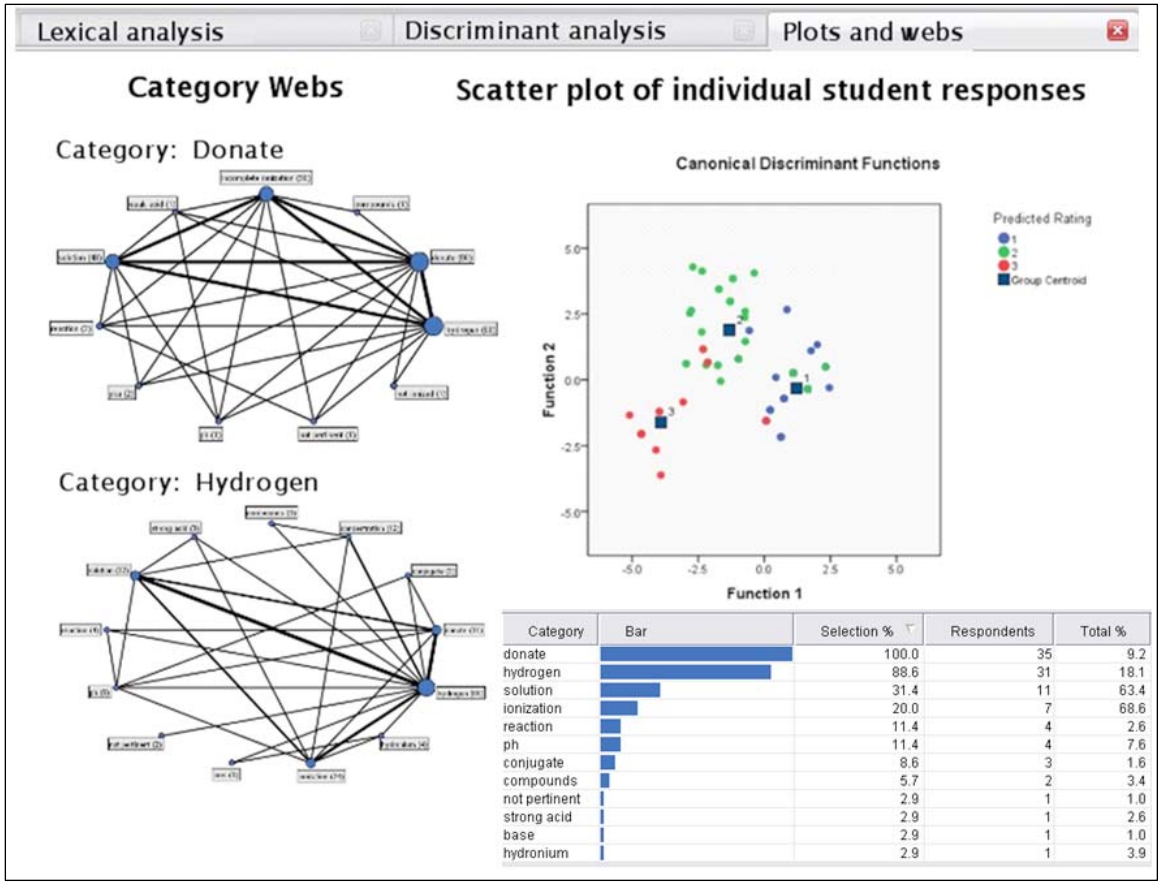
Chi, M. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 61-82). New York: Routledge.

Current Work

Automated Analysis of Constructed Response Concept Inventories to Reveal Student Thinking: Forging a National Network for Innovative Assessment Methods

- CCLI - II
- MSU, OSU, CU-B, U-W, WMU
- Constructed response versions of concept inventory questions
  - Cellular metabolism
  - Genetics
  - Evolution
  - Geoscience
- Questions, libraries, text analysis packages

Future Work
Web Portal



Category	Bar	Selection %	Respondents	Total %
donate		100.0	35	9.2
hydrogen		88.6	31	18.1
solution		31.4	11	63.4
ionization		20.0	7	68.6
reaction		11.4	4	2.6
ph		11.4	4	7.6
conjugate		8.6	3	1.6
compounds		5.7	2	3.4
not pertinent		2.9	1	1.0
strong acid		2.9	1	2.6
base		2.9	1	1.0
hydronium		2.9	1	3.9

Questions

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