Insight into Student Thinking in STEM: Lessons Learned from Lexical Analysis of Student Writing

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Automated Analysis of Constructed Response (AACR) Research Group

http://aacr.crcstl.msu.edu

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Forging a National Network for Innovative Assessment Methods

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Overview

- Background
- Example
- Collaborators' work
- Project goals and directions
- Invitation to participate

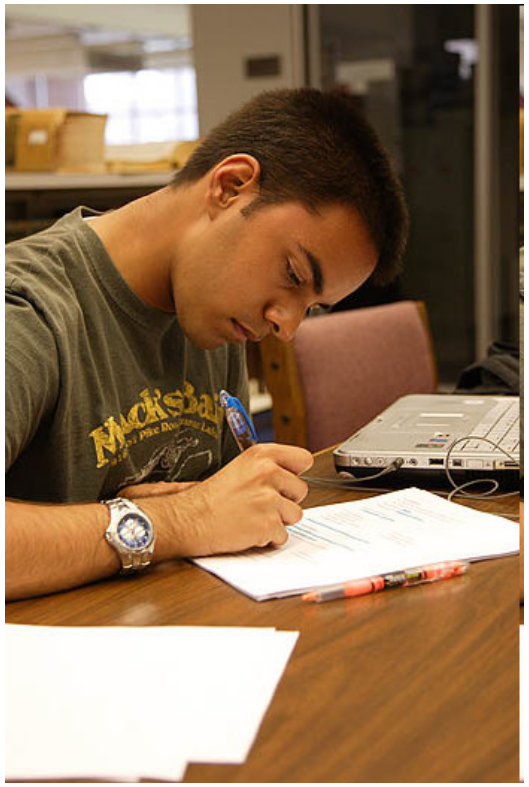
STEM Education Reform

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**

Assessment to Reveal Student Thinking



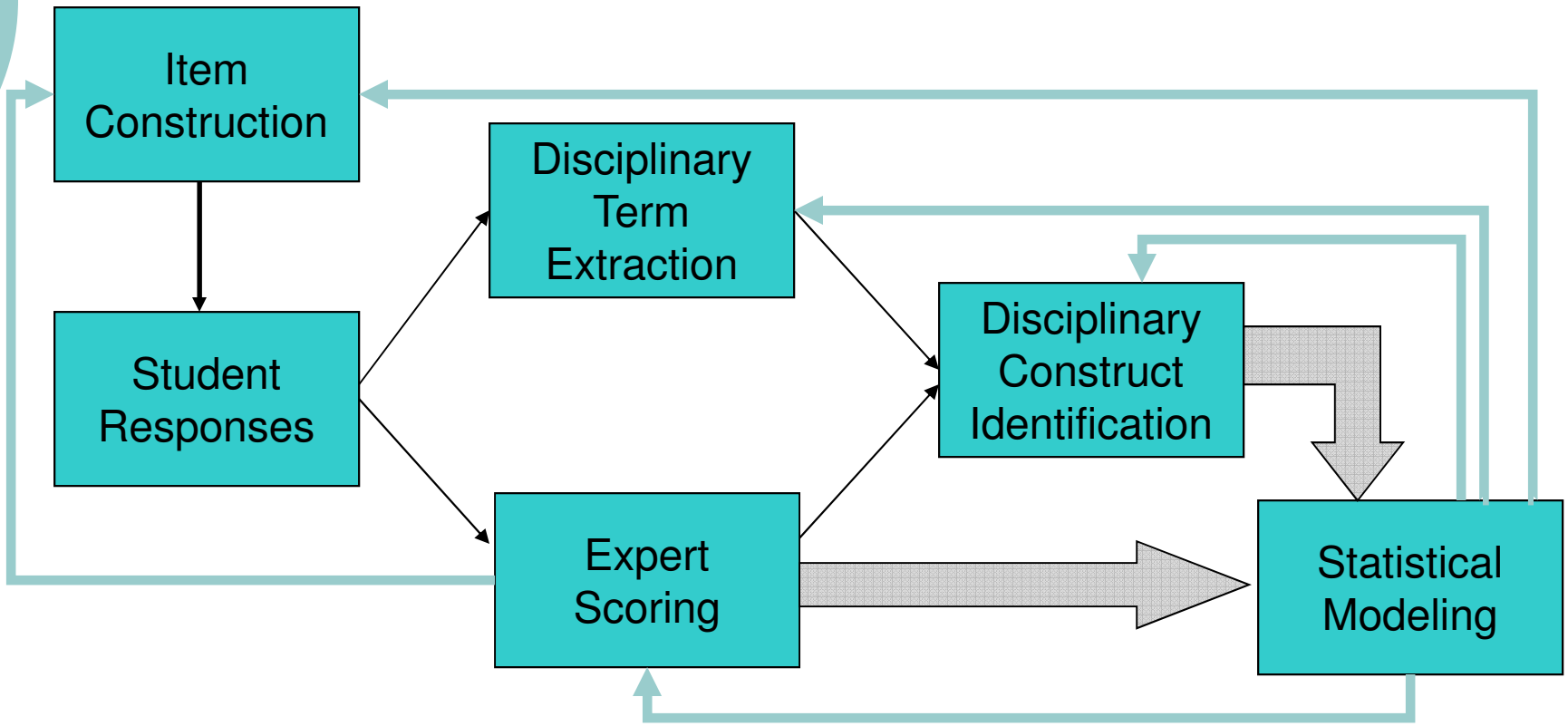
Theoretic Framework

- Conceptual barriers impair students' understanding complex processes in science
  - Pellegrino, J.W., Chudowsky, N., and Glaser, R. (2001); Tanner, K., and Allen, D. (2005)
- Conceptual Change
  - Role of prior knowledge in learning
    - Vosniadou, S., (2008)
- Student ideas
  - May be identified by students' use of language
    - Pinker (2007)
  - *Constructed Response* questions can provide insight into student ideas
    - Bennett and Ward (1993); Birenbaum and Tatsouka (1987); Bridgeman (1992); Kuechler and Simkin (2010)

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



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

Haudek, K., Moscarella, R. A., Merrill, J. E., & Urban-Lurain, M. (In Review). What are they thinking? Automated analysis of student writing about acid/base chemistry in introductory biology. *CBE - Life Sciences Education.*

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?

33%	A. Compound with amino group
49%	B. Compound with hydroxyl group
12%	C. Both
6%	D. Neither

Explain your answer

Sample Student Answers

[illegible] 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

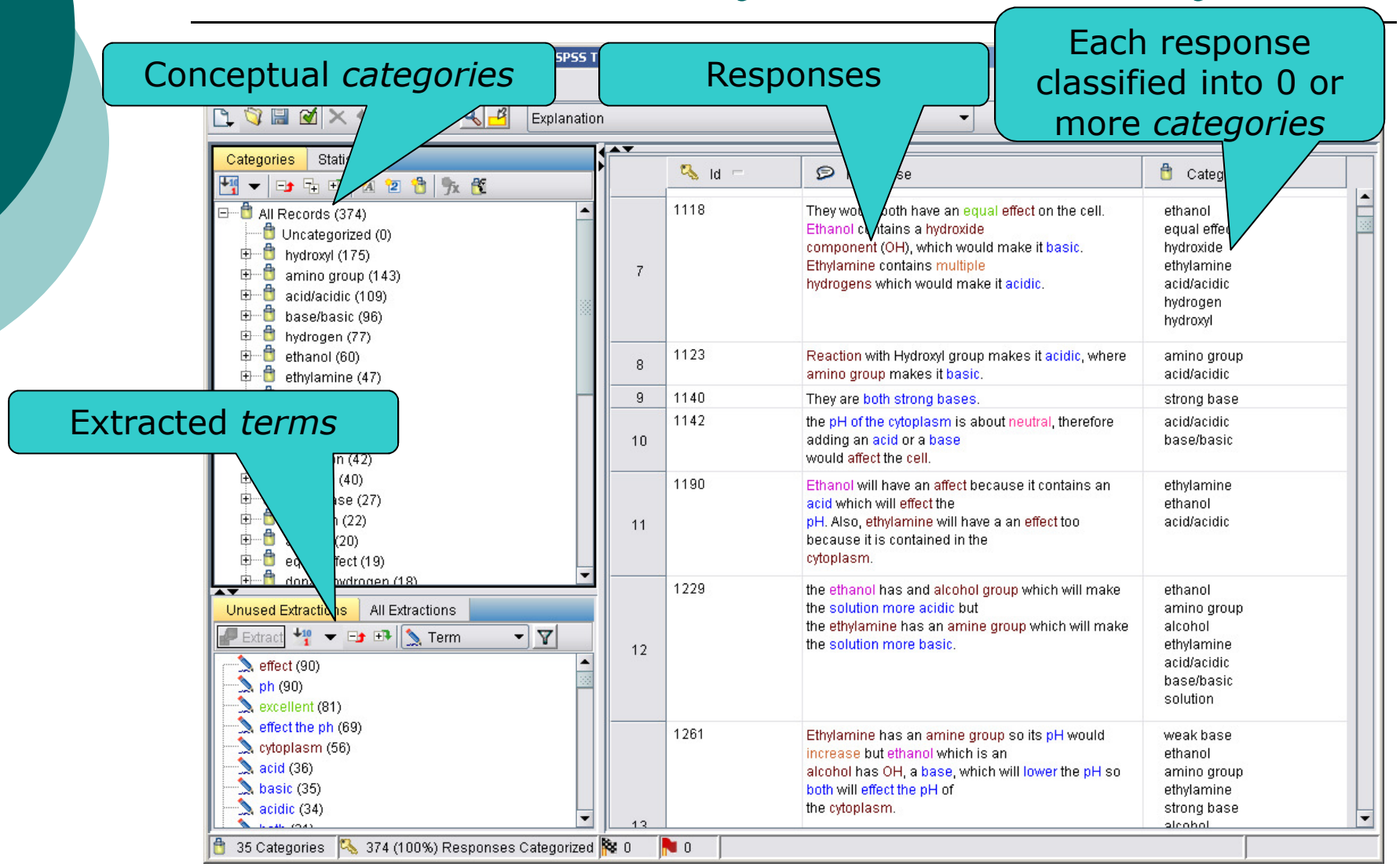
37% - Level 1: Correct explanations of functional group chemistry (may include correct supporting reasoning)

10% - Level 2: Partly correct explanations with errors in facts or reasoning

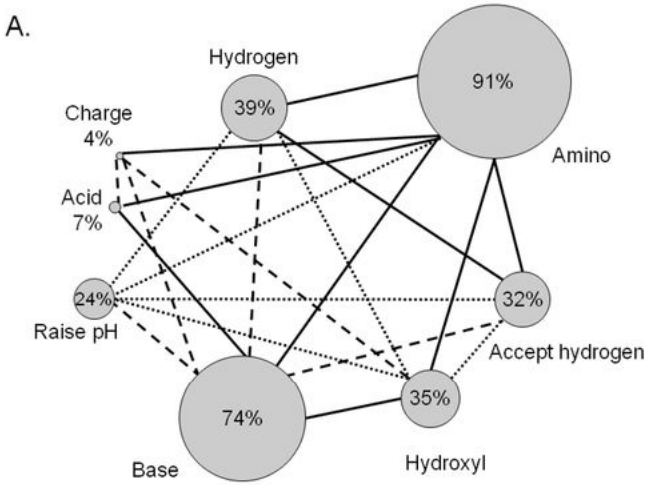
53% - Level 3: Totally incorrect/irrelevant response

Inter-rater reliability = .90

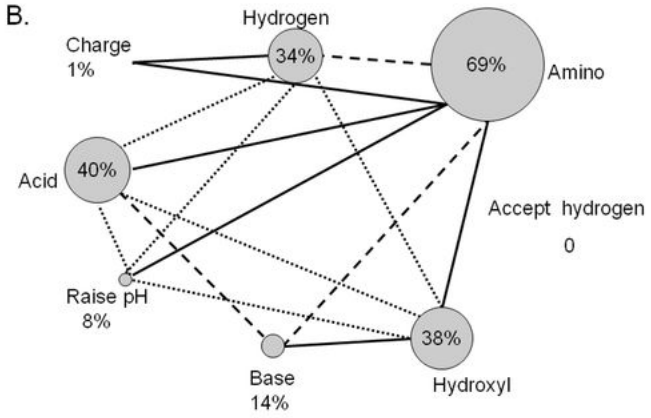
SPSS Text Analysis for Surveys



Complexity of Student Ideas: Expert Rated 1 & 3



- Expert Rating 1



- Expert Rating 3

Predicting Expert Scoring

Category name	Coefficient
base	0.758
charge	0.192
raise pH	0.254
accept hydrogen	0.662
acid	-0.509
hydroxyl	-0.217
amino group	0.287
hydrogen	-0.328

- Expert-Expert IRR = .90
- Expert-Computer IRR = .75

Photosynthesis

- Photosynthesis a complex biological process
  - Energy transformations
  - Molecular rearrangements
  - Structure/function relationships
- Existing diagnostic questions and research into student difficulties

Lyons C, Jones S, Merrill J, Urban-Lurain M, Haudek KC. *Moving Across Scales: Using Lexical Analysis to Reveal Student Reasoning about Photosynthesis*. In: National Association of Research on Science Teaching. Orlando, FL; 2011.

Methods

- Exam data from introductory cell biology course (n=391)
- Each student received one MC DQC and one constructed response
- Used 2 versions of the DQC questions that allowed a cross-over design
- Lexical analysis by SPSS Text Analytics for Surveys

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?

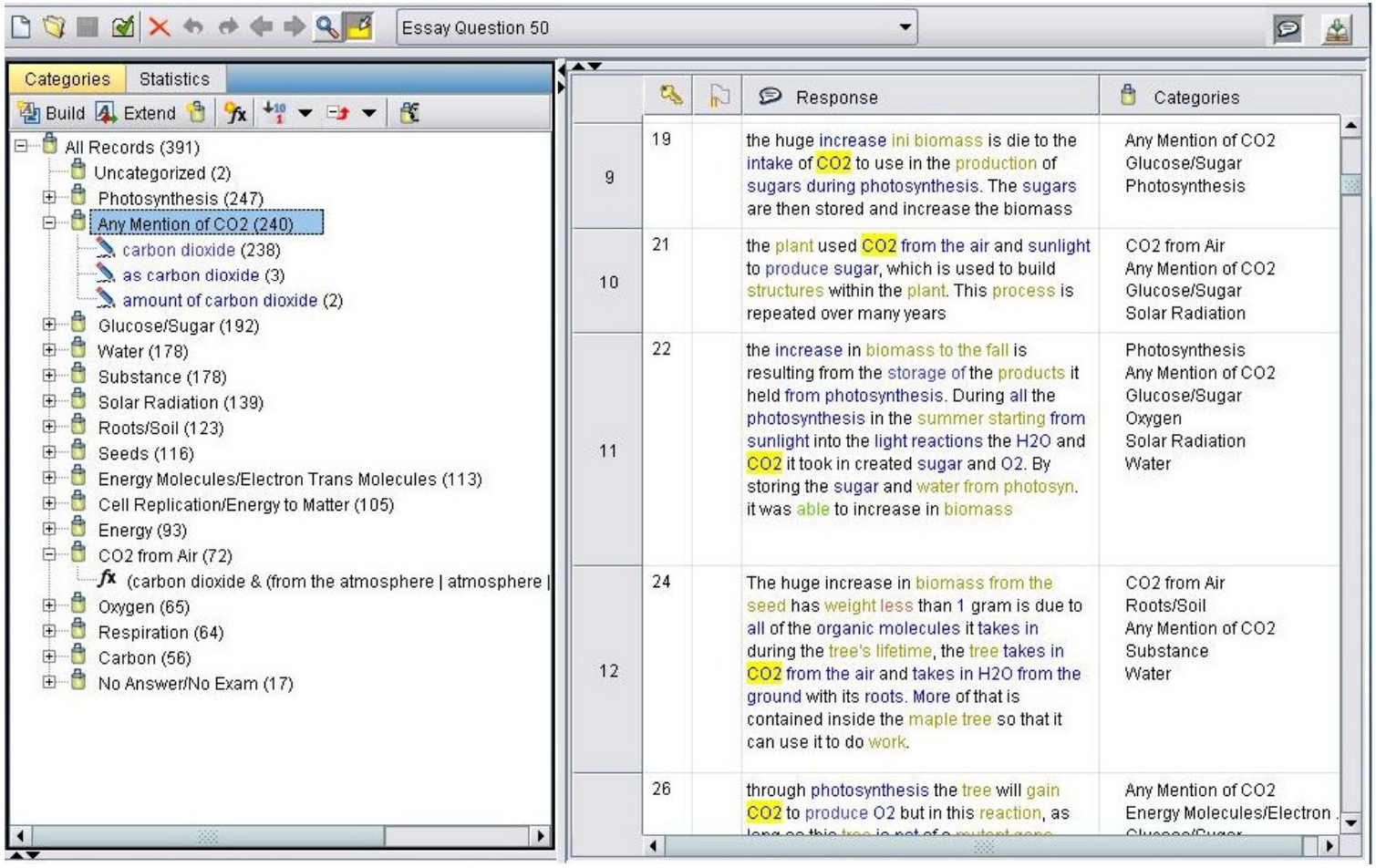
8%	A.	Absorption of mineral substances from root
13%	B.	Absorption of organic substances from soil via roots
59%	**C.**	**Incorporation of CO2 gas from atmosphere into molecules by green leaves**
8%	D.	Incorporation of H2O from soil into molecules by green leaves
13%	E.	Absorption of solar radiation into the leaf

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

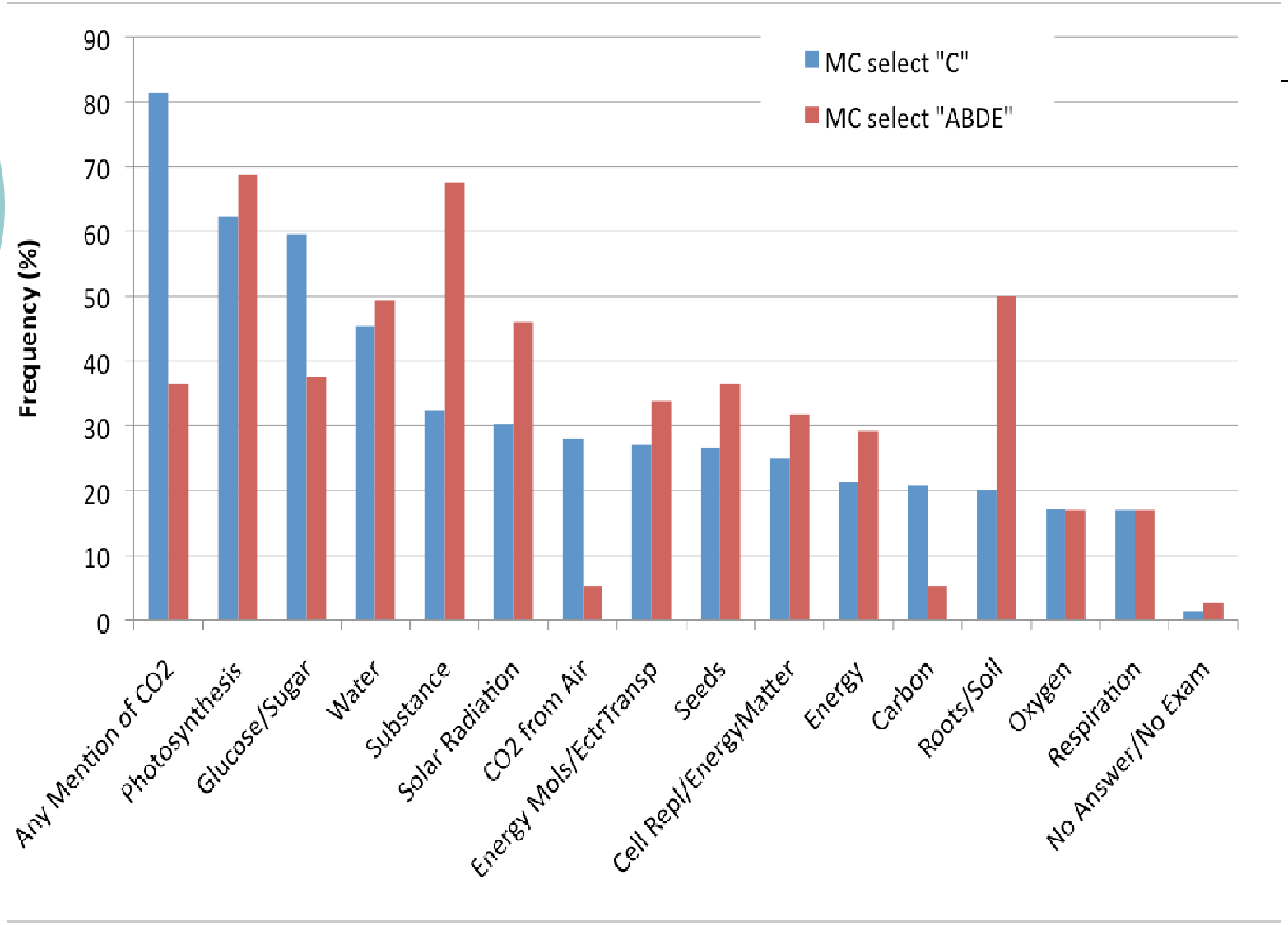
Constructed Response Prompt

- 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**.

Lexical Analysis

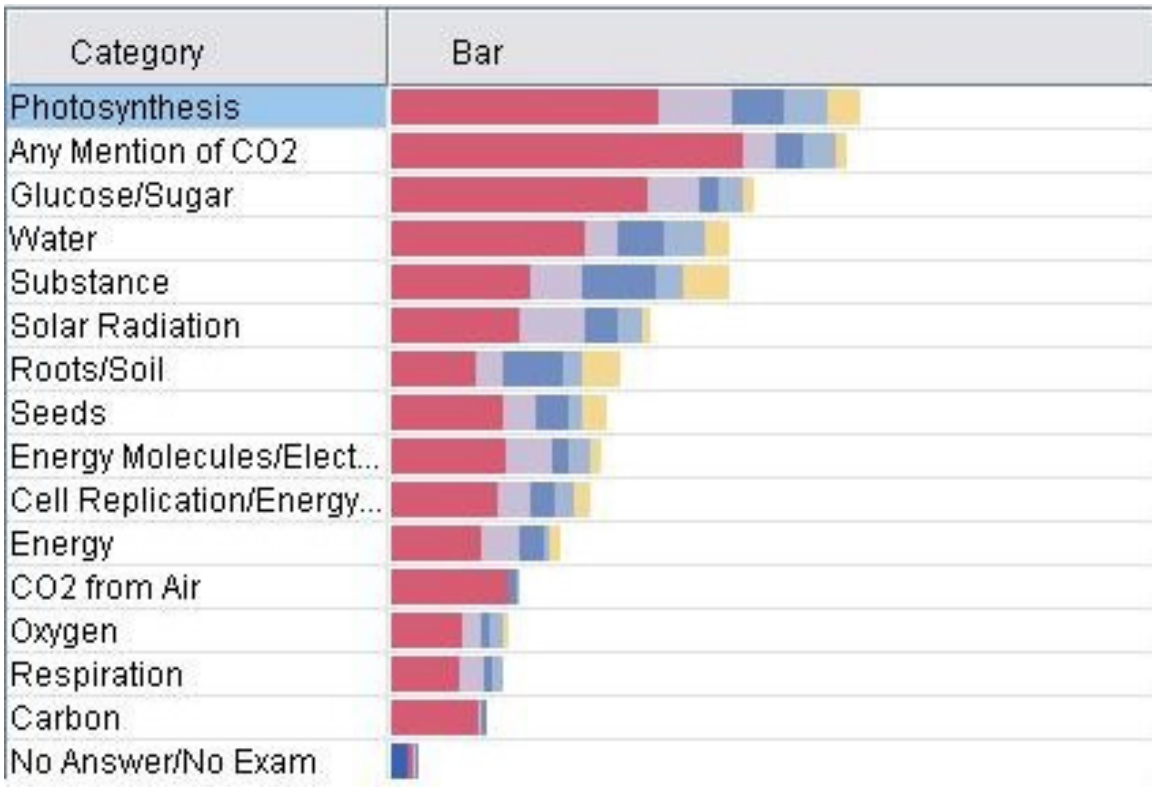


MC Selection vs. CR Categories



CR Reveals More Complexity of Student Thinking Than MC

JM1

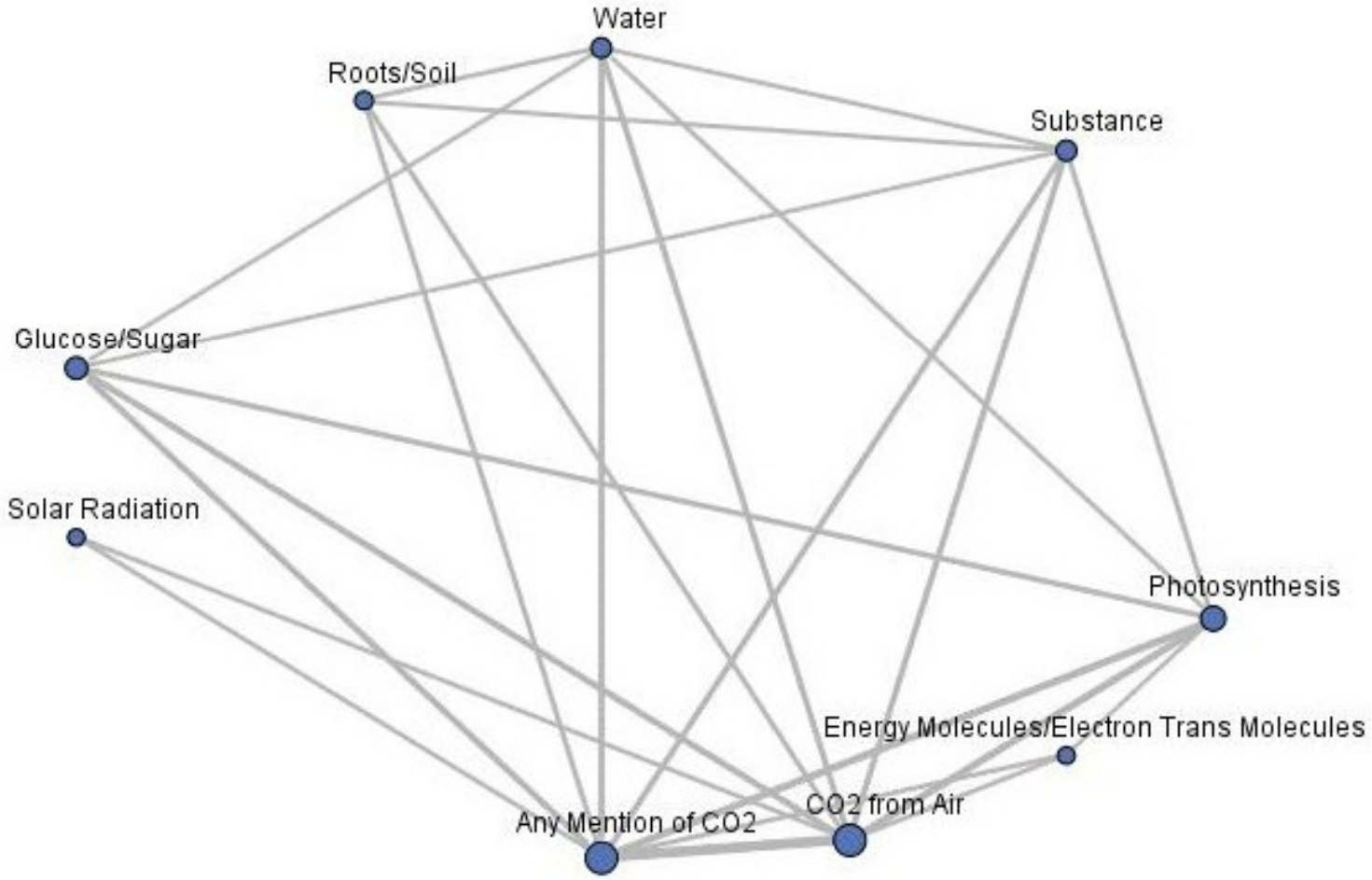


Concepts in constructed response coded by MC choice

Slide 23

JM1 Add mc %s
John Merrill, 4/1/2011

Concept Heterogeneity Revealed Through Written Explanations



Evolution and Natural Selection

- Open Response Instrument (ORI) and Evolutionary Gain and Loss Test (EGALT)
- Construct-grounded approach
  - 3 "Core Concepts"
    - Variation
    - Heritability of variation
    - Differential survival/reproduction
  - 4 "Key Concepts" used by experts
    - Biotic potential
    - Natural resources
    - Differential survival
    - Change in population

Ha, M., Nehm, R., Urban-Lurain, M., & Merrill, J. E. (In Press). Applying computerized scoring models of written biological explanations across courses and colleges: Prospects and limitations. *CBE - Life Sciences Education.*

Evolution and Natural Selection
Compare Lexical Analysis Approaches

SPSS Text Analytics for Surveys

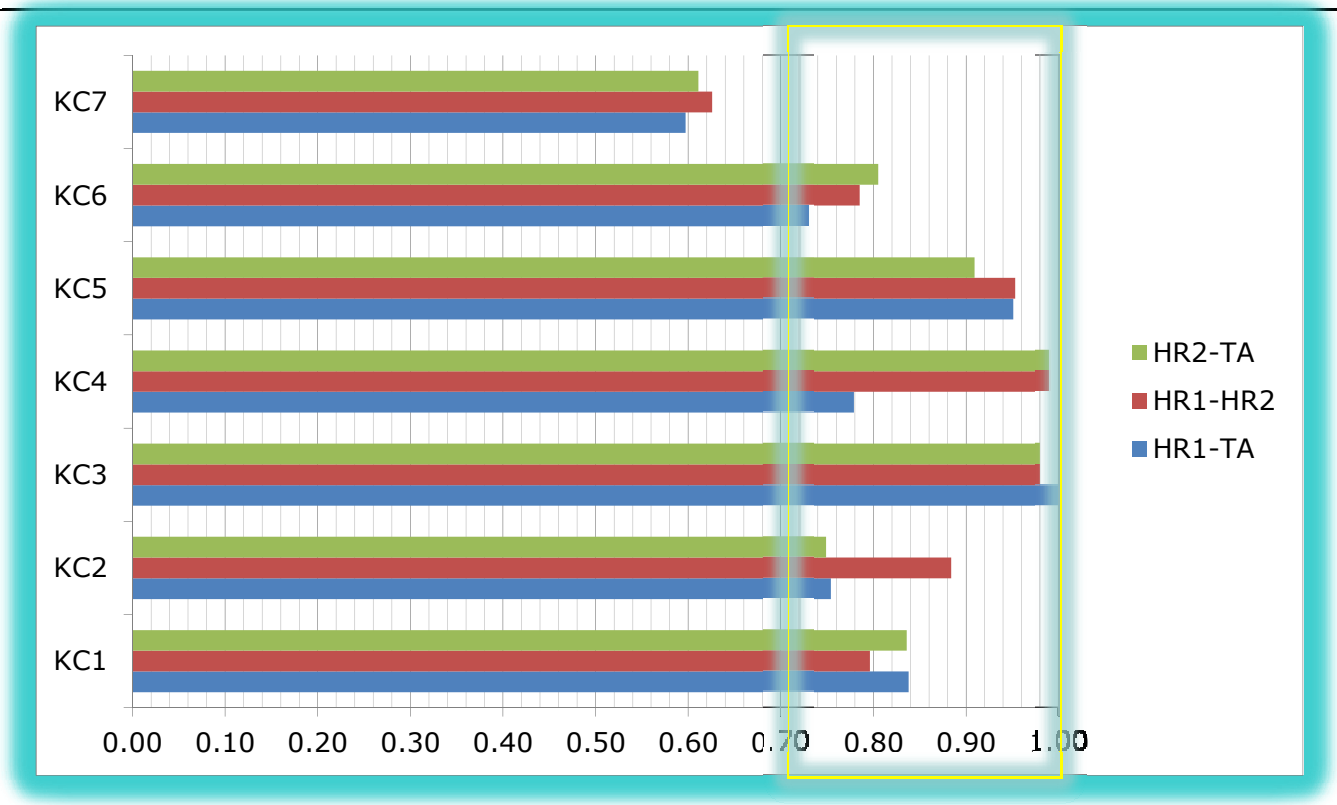
- Developed for open-ended web-based market research
- Supports exploratory, iterative development of lexical resources
- Manual creation of disciplinary libraries

Summarization Integrated Development Environment (SIDE)

- Developed for discourse analysis online discussions
- Machine-learning classification techniques
- "Black box"

Evolution and Natural Selection
Human Raters (HR1, HR2) vs. Computer (TA)

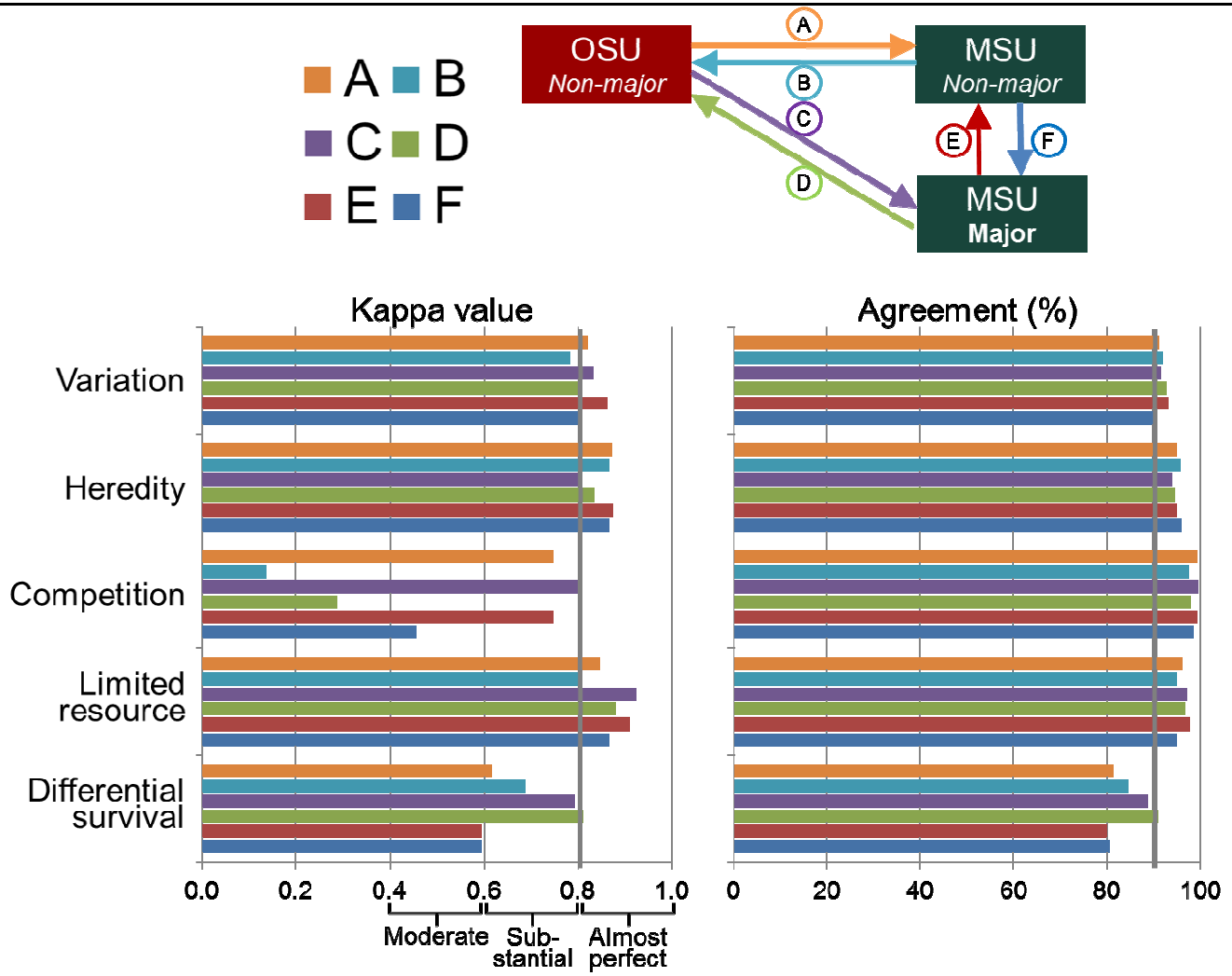
Core and key concepts of natural selection



Kappa values

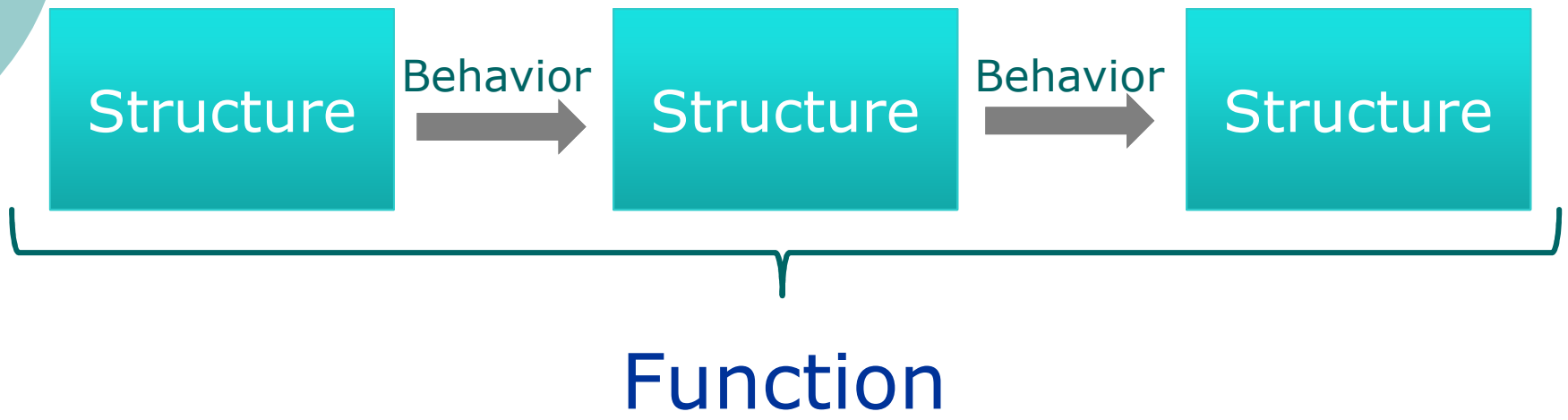
Target

Comparing Scoring Models Across Three Student Populations



Models in Introductory Biology

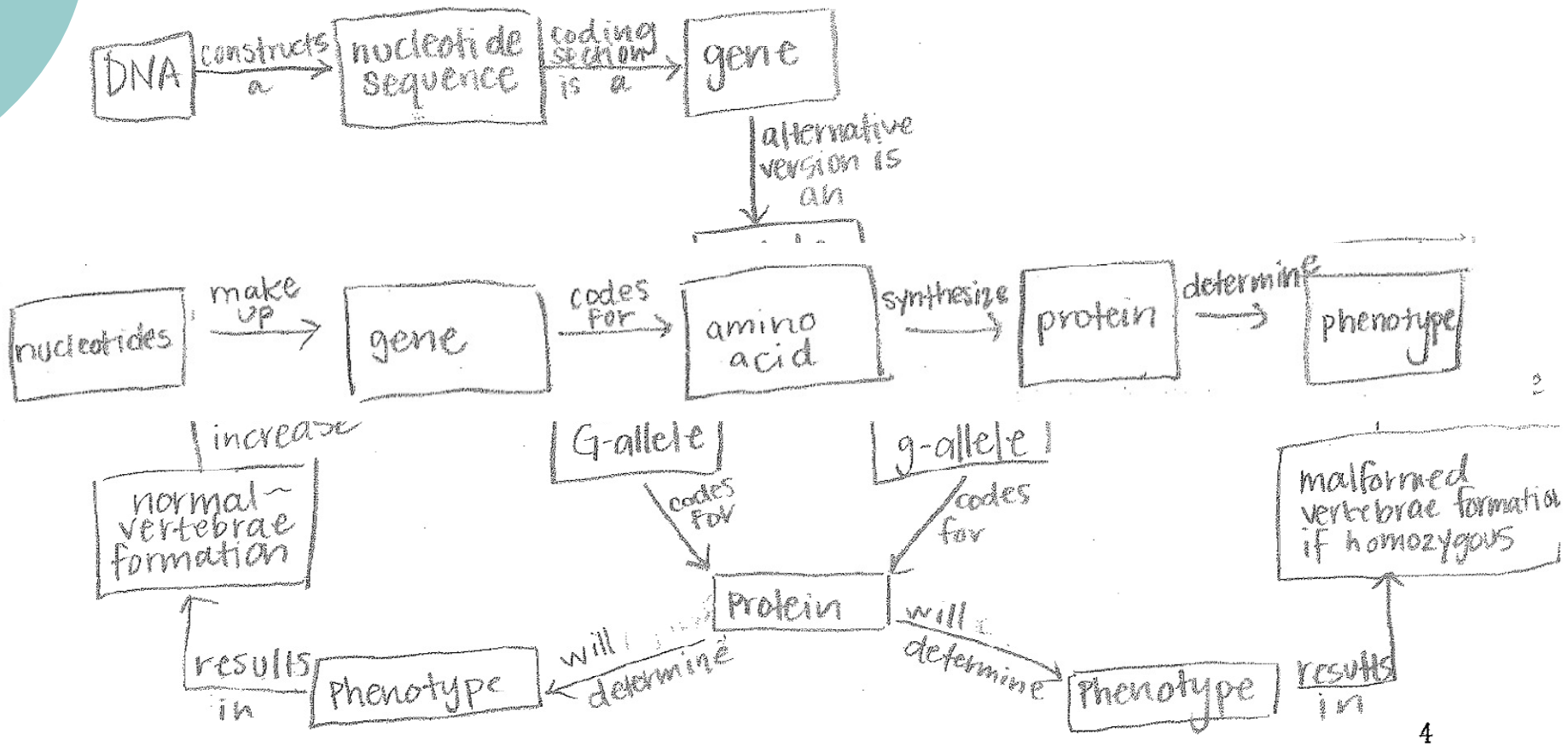
- Structure-Behavior-Function (SBF)



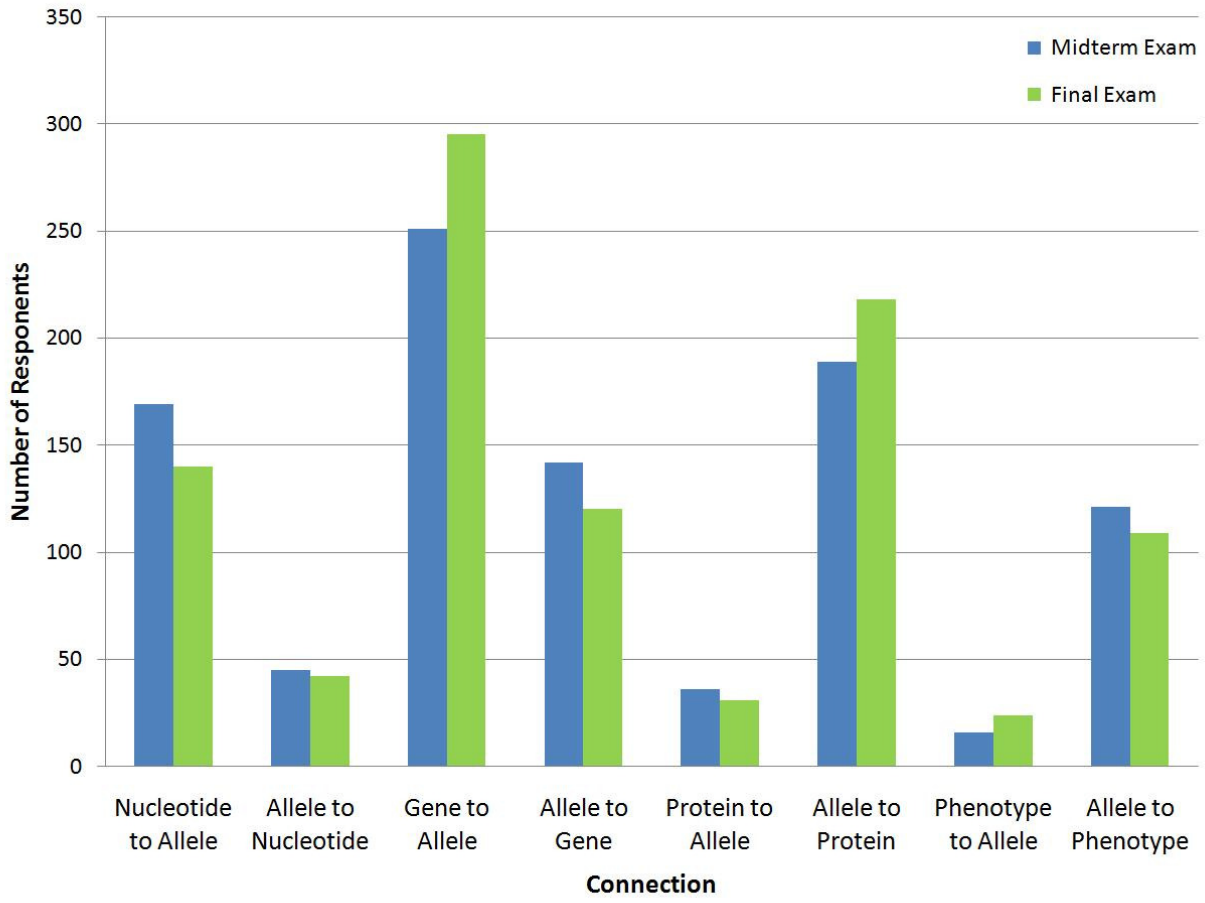
Jones S, Long T, Kostelnik K, Urban-Lurain M. *Making connections: Can lexical analysis reveal students' thinking about key genetics concepts?*. In: University Undergraduate Research and Arts Forum (UURAF). Michigan State University; 2011.

Models in Introductory Biology
Analyze Changes in Student Models

Relationship Between Genotype and Phenotype



Numbers of Students Connecting Pairs of Concepts



Genetics Concept Assessment (GCA) (Smith & Knight)

- Iterative development process
  - Review literature
  - Interview genetics faculty and students to explore misunderstandings.
  - Develop and administer a pilot assessment.
  - Eliminate jargon, write distracters with student-supplied incorrect answers, revise easy questions.
  - Validate and revise through student interviews and input from faculty experts at several institutions.

Genetics Concept Assessment (GCA) Constructed Response Research

- Create constructed response items for persistently difficult topics
  - Nature and consequences of mutations
  - DNA content of cells
  - Allele representation on chromosomes undergoing meiosis and mitosis
- Collecting data
  - University of Washington
  - University of Colorado – Boulder
  - Michigan State University

Genetics Concept Assessment (GCA) Research Questions

- Can lexical analysis be used to accurately score genetics concept assessment questions?
- Will student responses reveal the same persistent misunderstandings if the questions are asked in a short answer format?
- Are there some genetics concepts where multiple-choice and short answer response questions are similarly effective?

Geoscience Concept Inventory (GCI) (Libarkin)

- GCI WebCenter database of 813 student alternative conceptions about Earth Systems
- GCI
  - Evaluate learning in entry-level geoscience courses
  - Correlates strongly with individual expertise in geosciences
  - Rasch analysis to compare large number of items for equivalence

Geoscience Concept Inventory Lexical Analysis Research

- Exploring lexical analysis across diverse items to identify student misconceptions
- Role of lexical analysis in construction, revision, and validation of MC items

Statistics / Lexical Ambiguity (Kaplan)

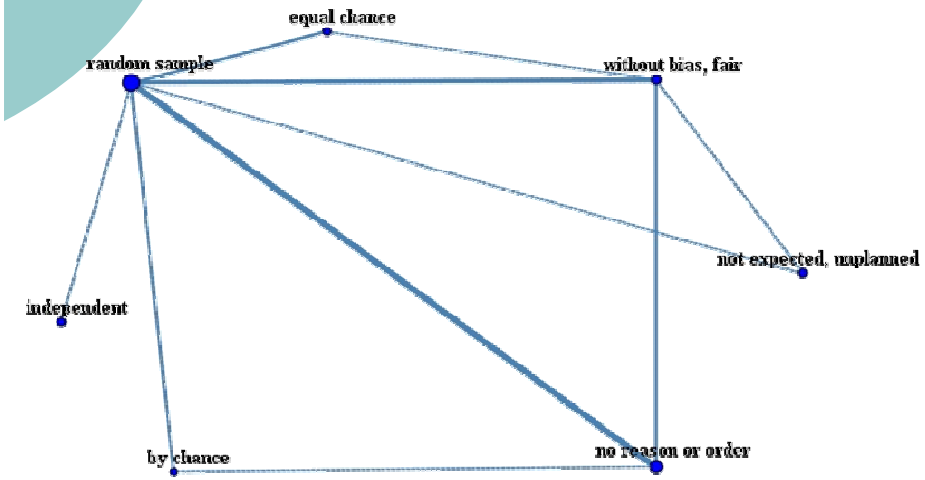
- Lexical Ambiguity
  - Domain-specific words similar to common English words
- Statistics
  - Random
  - Association
  - Correlation
  - Bias
  - Skew
- Barrier to learning, particularly in introductory courses

Lexical Ambiguity
Random

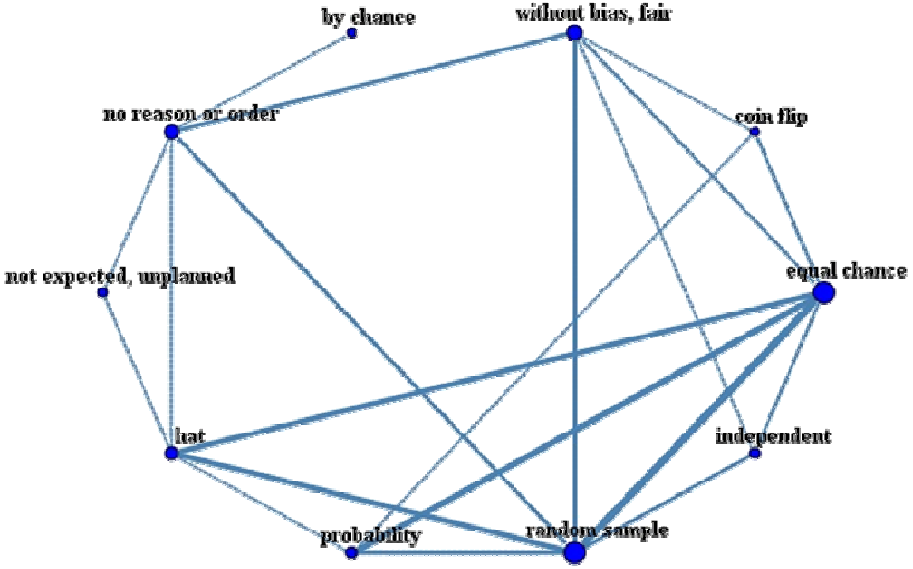
- 49%: An occurrence that is unplanned, unexpected or haphazard
- 17% Without criteria, plan or prior knowledge
- 8% Without pattern
- 4% Without bias

Lexical Ambiguity
Random

Pre-Instruction



Post-Instruction



Project Goals and Direction

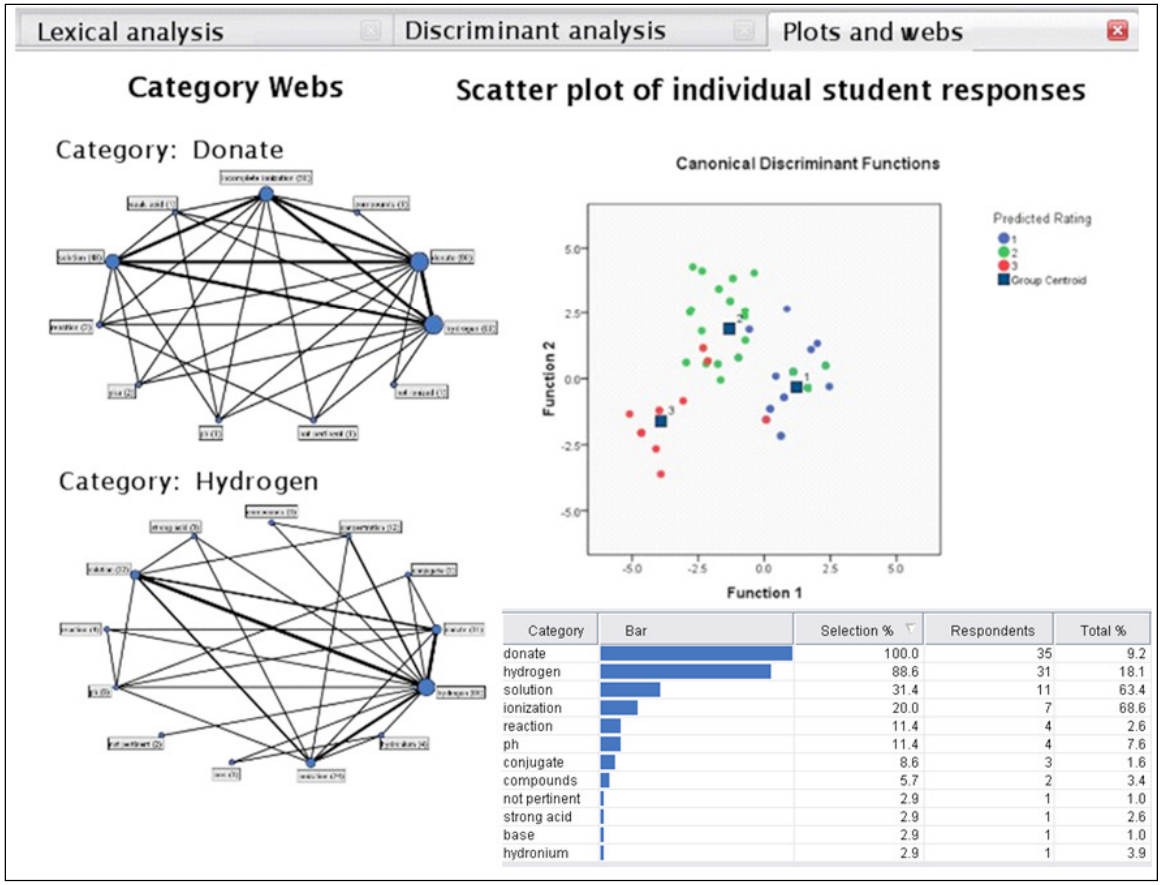
AACR
Building on Community Goals

- Create constructed-response concept inventory questions in each topic
- Create lexical resources for each topic
- Evaluate student responses using expert scoring rubrics
- Develop statistical classification functions to predict expert ratings
- Validate automated analyses
- Disseminate questions and resources
- Build community of researchers and teachers exploring these techniques

AACR
Research Questions

- Are constructed-response items always needed to uncover student thinking?
- Are lexical analysis protocols generalizable?
- What are the relative strengths and weakness of different automated analysis techniques?
- How well do these techniques predict expert scoring?
- How can text analysis inform rubric creation?
- How can linguistics enhance lexical analysis research in STEM fields?

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

AACR
Forging a National Network

- Seeking collaborators
  - Pilot items and collect data
  - Develop, evaluate and/or apply scoring rubrics
  - Suggest other concepts, inventories or questions
  - Join online discussions

Questions

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