Chemistry Misconceptions, Concept Inventories, and Measuring Student Learning

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Miami University

- Oxford, OH
- 14,500 undergrads & 1500 grad students
- 11 Ph.D. programs of selective excellence
- Ph.D. in chemistry education
- Top 25 Initiative

What's in a name?

Nomothetic terms

- Errors
- Naïve conceptions
- Erroneous conceptions
- Misunderstandings
- Persistent pitfalls
- Classroom mismatches
- Student difficulties
- Incorrect generalizations
- Prescientific conceptions
- Conflicting schemas
- Mistakes
- Misconceptions

Ideographic terms

- Personal model of reality
- Pupil's ideas
- Alternative conceptions
- Alternative frameworks
- Developing conceptions
- Children's science
- Children's views
- Commonsense theories
- Children's understanding
- Children's knowledge
- Personal constructs
- Intuitive beliefs

- Wandersee, J.H.; Mintzes, J.J.; Novak, J.D. (1994). "Research on Alternative Conceptions in Science" Edited by Dorothy Gabel. *Handbook of Research on Science Teaching and Learning*. Macmillan Publishing Co: New York.

Two Methodologies

Nomothetic

- Knowledge is compared to accepted scientific knowledge

- Literal meaning:
  - "founded upon or derived from custom or law"

- More likely experimental

Ideographic

- Explanations constructed by a learner to make sense of an experience

- Literal meaning:
  - "Self written"

- More likely fewer students in greater depth and using student self-report data

- Wandersee, J.H.; Mintzes, J.J.; Novak, J.D. (1994). "Research on Alternative Conceptions in Science" Edited by Dorothy Gabel. *Handbook of Research on Science Teaching and Learning*. Macmillan Publishing Co: New York.

DISCIPLINE-BASED EDUCATION RESEARCH

Understanding and Improving Learning in Undergraduate Science and Engineering

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Chemistry Research

- Elucidating mechanisms
- Characterize products
- Identify intermediates
- Synthesize new materials

•Bunce, D.M.; Gabel, D.; Herron, J.D.; Jones, L.L. "Chemical Education Research," *J. Chem. Educ.*, 71, **1994**, 184.

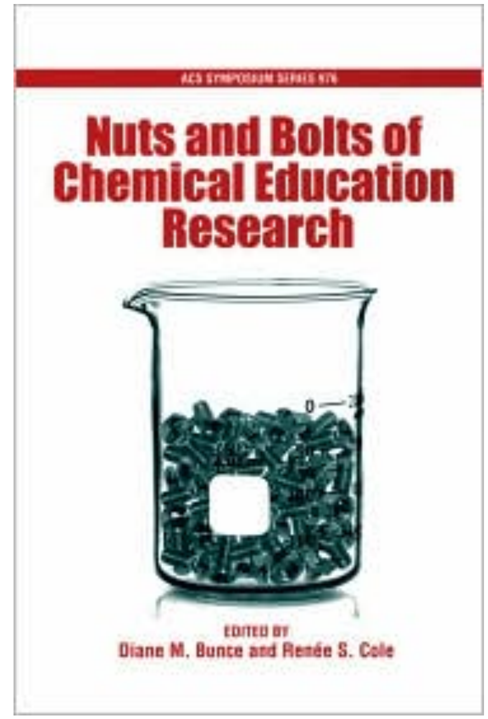
Chemistry Education Research

- Elucidating mechanisms *for teaching & learning*
- Characterize products *of learning*
- Identify intermediates *along the pathway to learning*
- Synthesize new materials *to increase learning*

•Bunce, D.M.; Gabel, D.; Herron, J.D.; Jones, L.L. "Chemical Education Research," *J. Chem. Educ.*, 71, **1994**, 184.

Chemistry Education Research

- Chemistry has 118 elements
- CER has 5 elements
  - students
  - teachers
  - curriculum
  - context
  - assessment



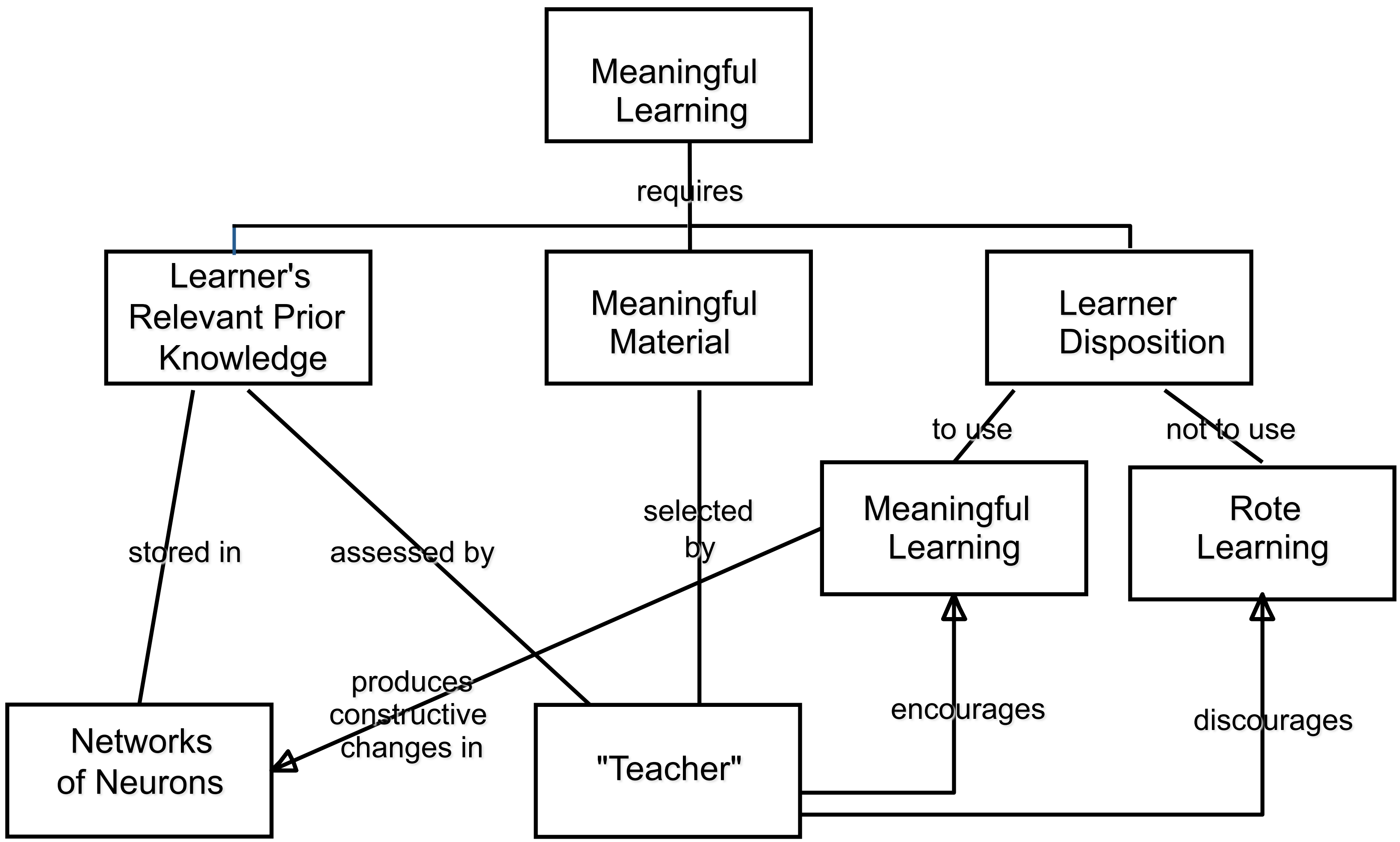
•Bunce, D.M.; Gabel, D.; Herron, J.D.; Jones, L.L. "Chemical Education Research," *J. Chem. Educ.*, 71, **1994**, 184.
•Bunce, D.M. and Cole, R. (Eds.) *Nuts and Bolts of Chemical Education Research*, Oxford Press, 2008

CER & Limitations

- Data collection
  - Limitations to manipulating human beings
  - Not serendipitous → reconstruct conditions
  - Identification of variables
    - Dynamics of classrooms
    - Rates of learning
    - Mechanisms for change
- Theory development
  - Verify existing, apply to new systems
  - Computational, mathematical description
  - BUT, students are not O_2 molecules!

Bunce, D.M.; Gabel, D.; Herron, J.D.; Jones, L.L. "Chemical Education Research," *J. Chem. Educ.*, 71, **1994**, 184.

Ausubel & Novak's Theory of Learning



•Bretz, S.L. "Human Constructivism and Meaningful Learning," *J. Chem. Educ.* 2001, 78(8), 1107.

Inquiry Pedagogy Research

- Lecture Setting
  - At-risk general chemistry students
  - POGIL Symmetry operations
  - Spiral organic chemistry curriculum
- Laboratory experiments
  - Microwave liquid crystal synthesis/characterization
  - Monolithic HPLC column synthesis/characterization
  - Ligand binding, optical and paramagnetic spectroscopy of met-myoglobin

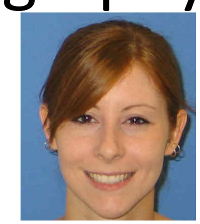
Grove, Hershberger, & Bretz, *Chem. Educ. Res. Pract.*, 2008, 9, 157-162
Linenberger, Bretz, Crowder, Lorigan, & Tierney, *J. Chem. Educ.*, 2011, 88(2), 223-225
Bindis, Bretz, & Danielson, *J. Chem. Educ.*, 2011, 88(5), 675-678.
Jensen, Grundy, Bretz, & Hartley, *J. Chem. Educ.*, 2011, 88(8), 1133-1136.
Emenike, Danielson, & Bretz, *J. Coll. Sci. Tchg.*, 2011, 41(2), 84-92.
Luxford, Crowder, & Bretz, *J. Chem. Educ.*, 2012, 89(2), 211-214.
Grove & Bretz, *Chem. Educ. Res. Pract.*, 2012, DOI: 10.1039/clrp90069b

Concept Inventories & Assessment







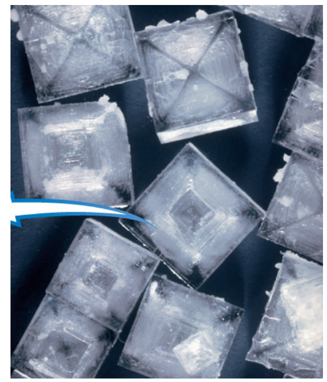


- Acid-base reactions
- Acidity
- Atomic emission, flame tests & energy level diagrams
- Covalent & ionic bonding
- Enzyme-substrate interactions
- Intermolecular forces & chromatography
- Oxidation-reduction reactions

- Sanabria-Rios and Bretz, "Investigating the Relationship between Faculty Cognitive Expectations about Learning Chemistry and the Construction of Exam Questions," *Chem. Educ. Res. Pract.*, 2010, 11, 212-217
- Holme, Bretz, Cooper, Lewis, Pienta, Stacy, Stevens, Towns. "Enhancing the Role of Assessment in Curriculum Reform in Chemistry," *Chem. Educ. Res. Pract.*, 2010, 11, 92-97
- Grove and Bretz, "CHEMX: Assessing Students' Cognitive Expectations in Learning Chemistry," *J. Chem. Educ.*, 2007, 84(9), 1524-1529
- McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433
- Bretz and Linenberger, "Development of the Enzyme-Substrate Interactions Concept Inventory," *Biochemistry and Molecular Biology Education*, EarlyView, DOI: 10.1002/bmb.20622

Johnstone's Chemistry Domains

macroscopic



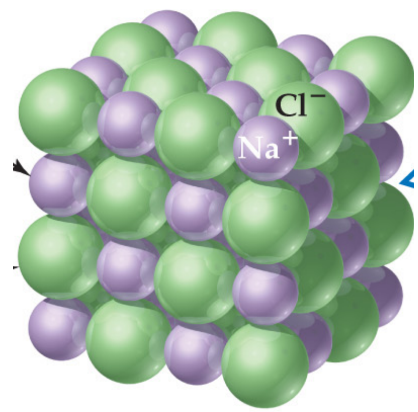
demo

followed by

Na --> $Na^+ + e^-$

$Cl + e^-$ --> Cl^-

$Na^+ + Cl^-$ -->NaCl

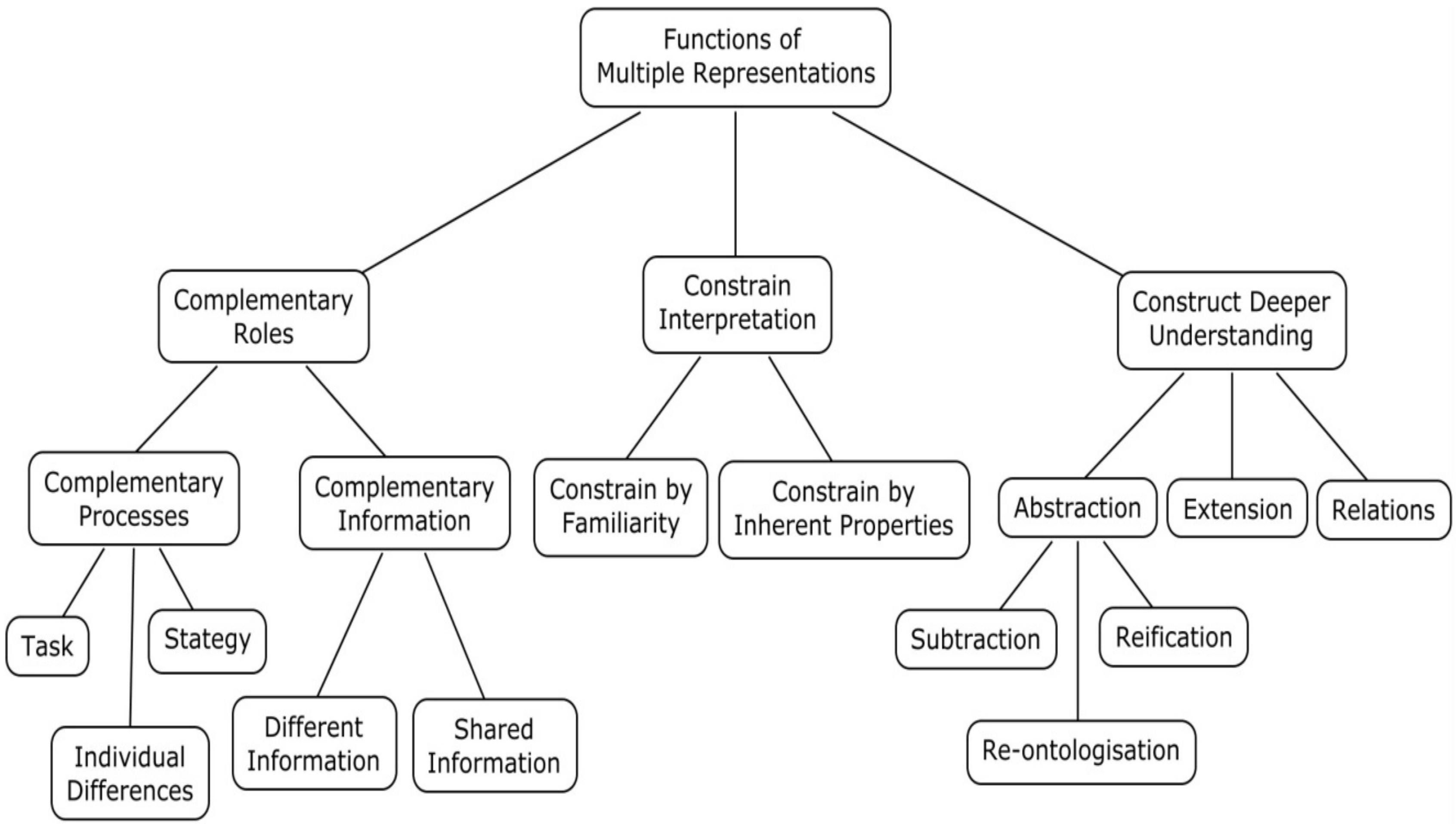


symbolic

particulate

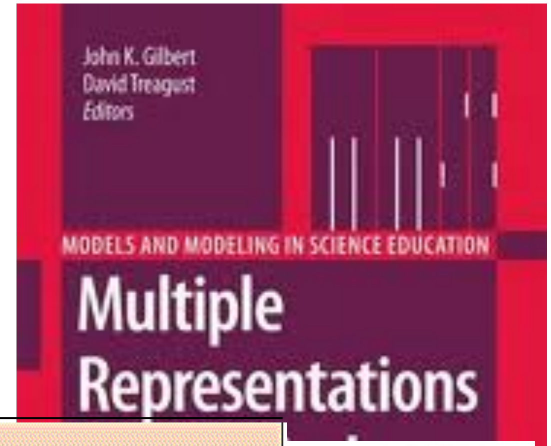
•Johnstone, A.H. "Why is Science so Hard to Learn?" *J. Computer Assisted Learning*, 1991, 7(2), 75-83

Multiple Representations & Coherence Formation

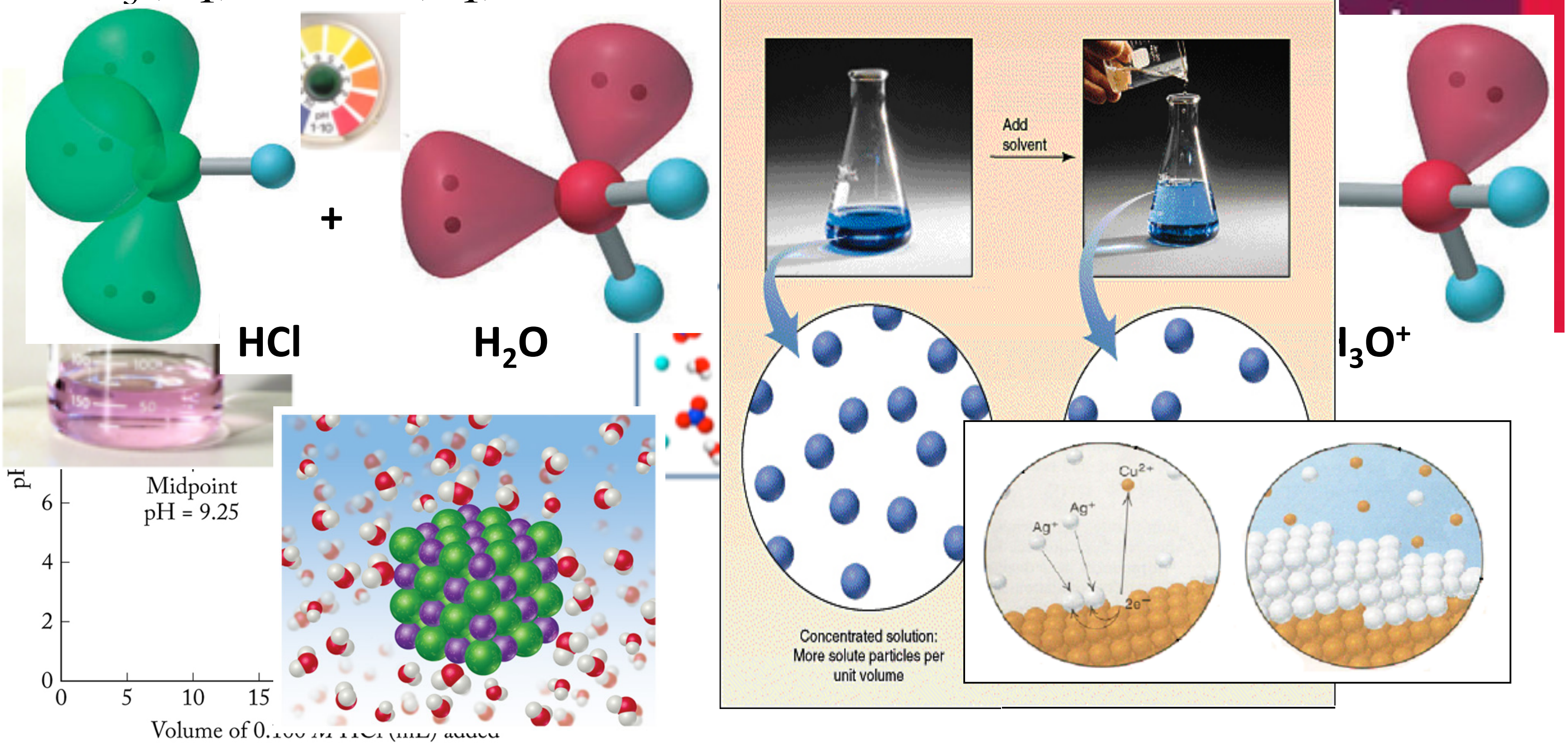


•Ainsworth, S. *Comput. Educ.,* 1999 *33*, p. 132.
•Seufert**,** *Learning and Instruction*, 2003, 13(2), 227-237.

Multiple Representations in Chemistry

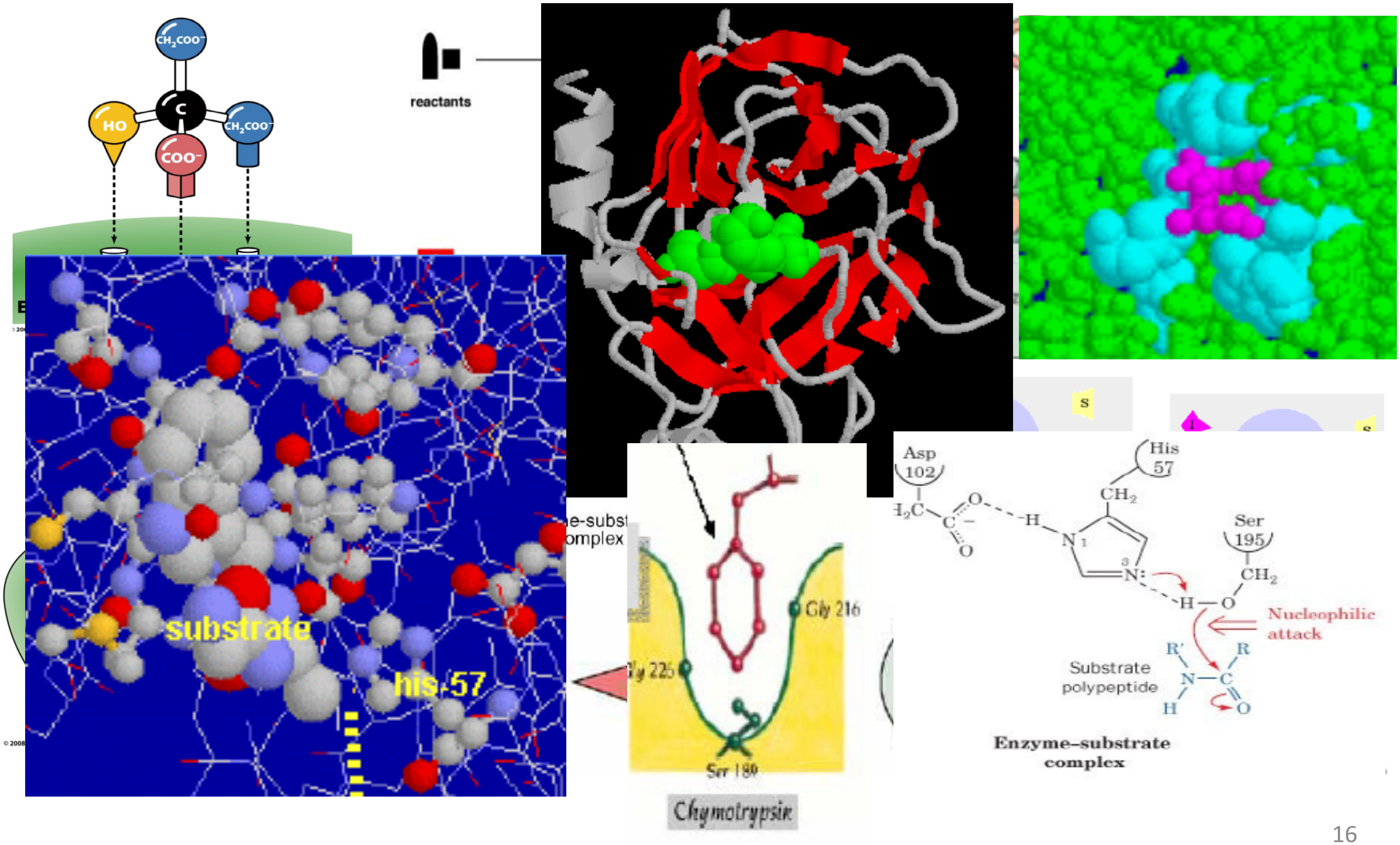


$$HNO_3(aq) + KOH(aq) \longrightarrow KNO_3(aq) + H_2O(l)$$



- Johnstone, A.H. “Why is Science so Hard to Learn?” *J. Computer Assisted Learning*, 1991, 7(2), 75-83
- Linenberger, K.J. & Bretz, S.L. “Generating Cognitive Dissonance in Student Interviews through Multiple Representations,” *Chem. Educ. Res. Pract.,* 2012; Advance Article, DOI: 10.1039/C1RP90000064A

Representations of Enzyme-Substrate Interactions



Voet, D. and Voet, J.G. (2004). *Biochemistry* (3rd ed.), D. Harris & P. Fitzgerald (Eds.), Hoboken, NJ: John Wiley & Sons, Inc.

Research Questions

- Analytical Questions
  - What do multiple representations reveal about students' understandings of important chemistry concepts?
  - What misconceptions exist and how prevalent are they?
- Methodological Questions
  - How can multiple representations be used to surface cognitive dissonance?
  - How can Johnstone's domains be used to identify misconceptions?
  - How are reliability and validity best established when student knowledge is often incomplete, incorrect, and fragmented?

Research Design

- Sequential, mixed-methods protocol
- Multi-Phase Interview to Elicit Misconceptions
    - Prior knowledge
    - Domain 1 (or Representation 1)
    - Domain 2 (or Representation 2), etc.
    - Reflection & reconciliation of cognitive dissonance
- Videotaped & Livescribe capture

Towns, M. "Mixed Methods Designs in Chemical Education Research," *Nuts and Bolts of CER*, 2008, ACS Symposium Series.
Linenberger, K.; Bretz, S.L. "Generating Cognitive Dissonance in Student Interviews through Multiple Representations," *Chem. Educ. Res. Pract.*, 2012**,** Advance Article, DOI: 10.1039/C1RP90000064A
Linenberger, K.; Bretz, S.L. "A Novel Technology to Investigate Students' Understandings of Enzyme Representations," *J. Coll. Sci. Tchg.*, Sept. 2012

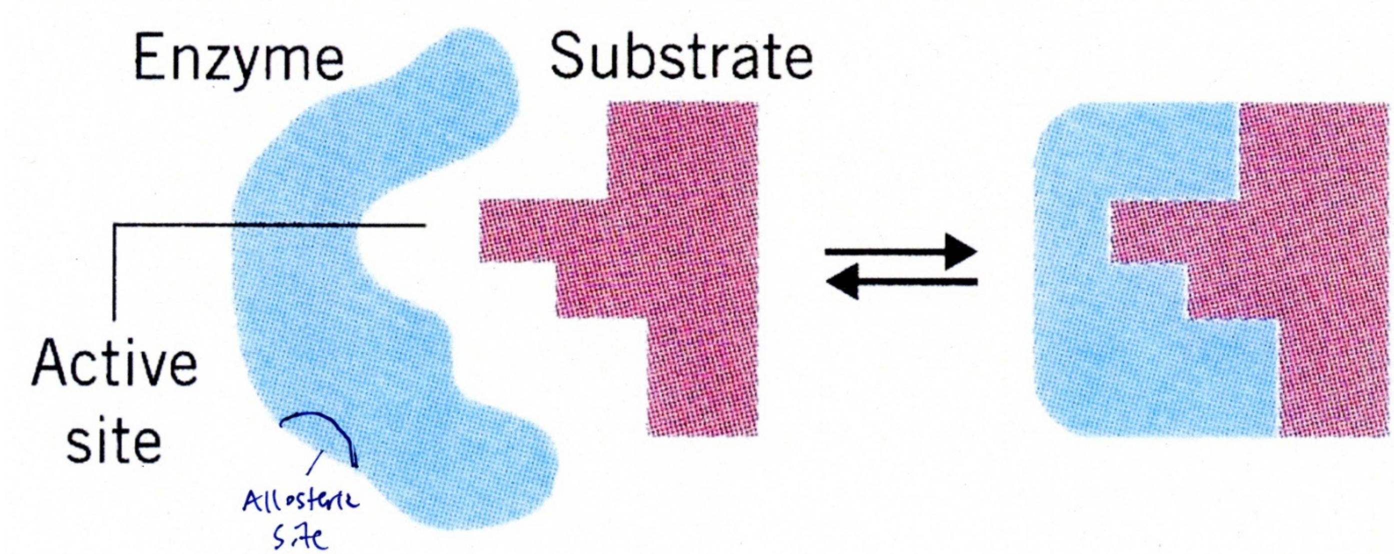
Research Design

- Concept Inventory Development
    - Single, two-tier, and four-tier items
    - Student misconceptions as distracters
    - Faculty experts review
- Data Analysis
    - Classical Test Theory & Item Response Curves
    - Significant & Common Alternative Conceptions
    - Confidence-Levels of Respondents

Ding, L. & Beichner, R. *Physical Review Special Topics – Physics Education Research*, 2009, *5*, 1-17.
Morris, Branum-Martin, Harshman, Baker, et. al. *Am. J. Physics*, 2006, *74*, 449-453. **10.** Gilbert, J.K. *Res. Sci. Educ*. 1977, *7*, 165-171.
Caleon, I.S.and Subramaniam, R. *Int J. Sci. Educ*. 2010, *32*, 939-961. Caleon, I.S.and Subramaniam, R. *Res. Sci. Educ.* 2010, *40*, 313-337.

Enzyme-Substrate Interactions Concept Inventory

I feel like there should be an **allosteric site over here** though [*draws in an allosteric site on the enzyme*] that would like **change it**. Possibly. That would change like um, like this right here [*the original reactant enzyme in Image 2*] **looks like an inactive enzyme**. Like it doesn't look like it's [*the substrate*] gonna fit. But then if a **particle comes in here** [*the allosteric site*] and **changes the um, the conformation of the enzyme** it [*the substrate*] should end up fitting.



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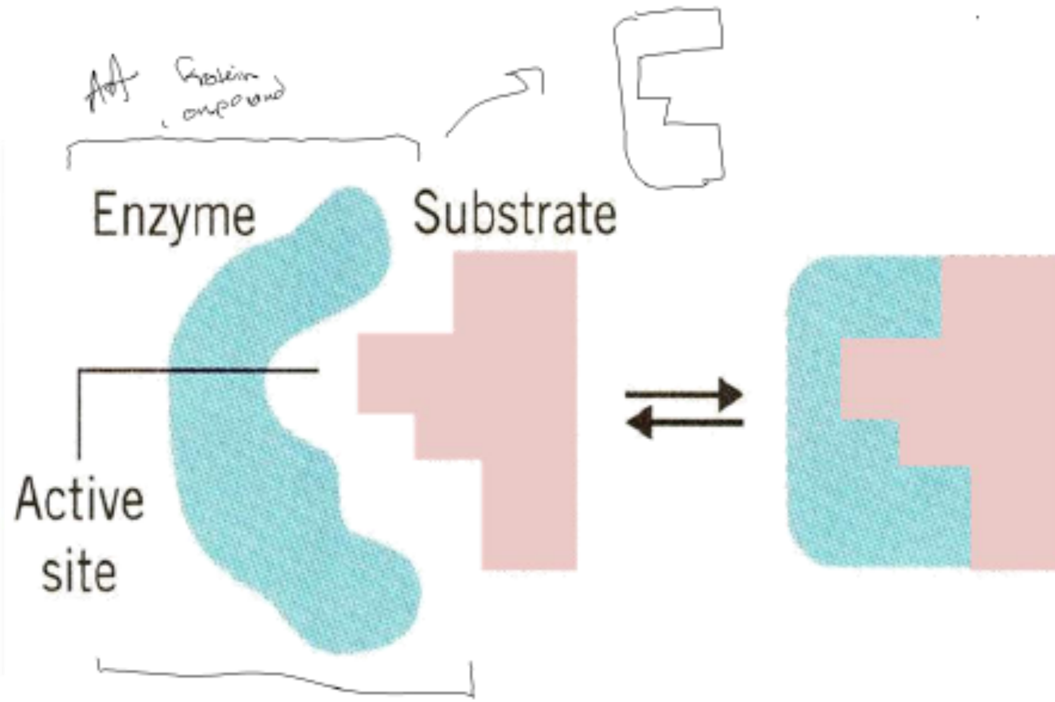
•Bretz and Linenberger, "Development of the Enzyme-Substrate Interactions Concept Inventory," *Biochemistry and Molecular Biology Education*, EarlyView, DOI: 10.1002/bmb.20622

Enzyme-Substrate Interactions Concept Inventory

[*draws brackets around enzyme]* I guess these brackets represent the area around the enzyme and if you have another **amino acid** or **protein** or **some other compound** [*writes "AA protein compound"*] that can **surround the enzyme** and for this it would need to **push this in and push this top in** [*the top and bottom of the enzyme*] and where I boxed it then these little **grooves should fall into place** to form or to match up with the substrate.



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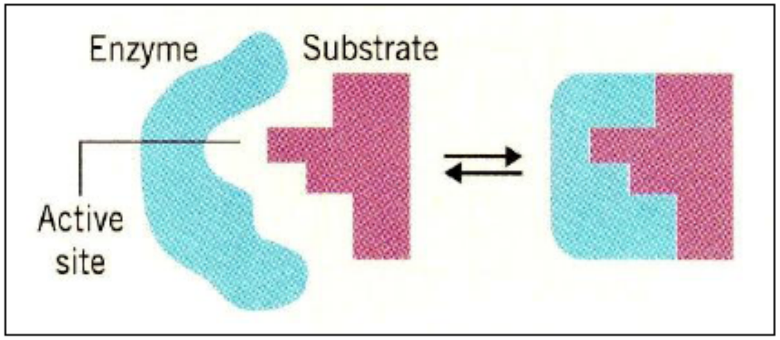

14. Select the answer that best describes the binding in the image.

A. The enzyme changes shape before the substrate binds to the enzyme.
B. An activator always binds the enzyme to change its shape, after which the substrate can bind.
C. The enzyme changes shape as the substrate binds to the enzyme.
D. The reaction will not proceed because the enzyme does not match the substrate.

15. Which statement best explains how the enzyme in the image changes conformation?

A. Two additional molecules push on both the top and bottom of the enzyme.
B. Interactions with the substrate align the enzyme with the substrate.
C. A molecule binds to an allosteric site on the enzyme.
D. A molecule binds to a second active site on the enzyme.

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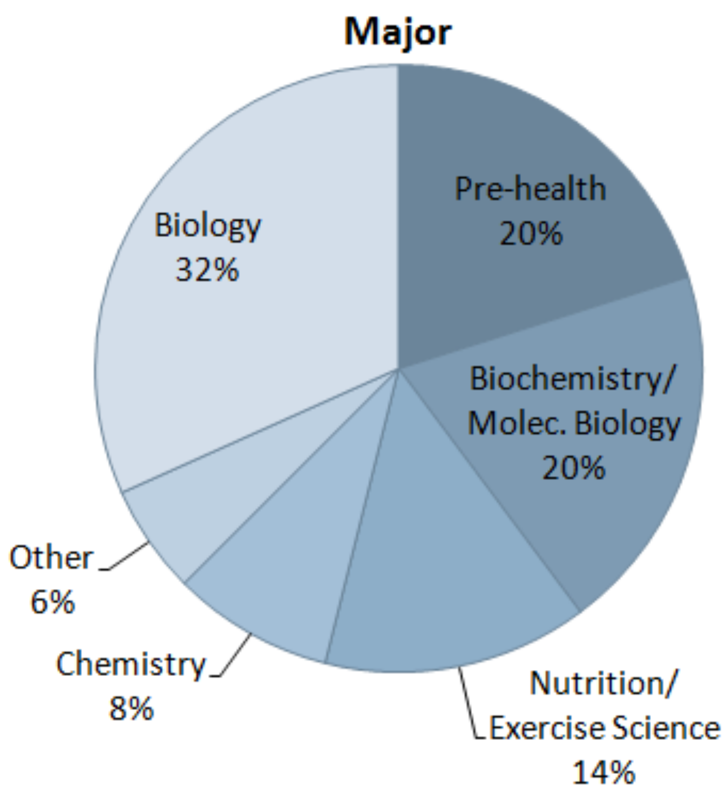
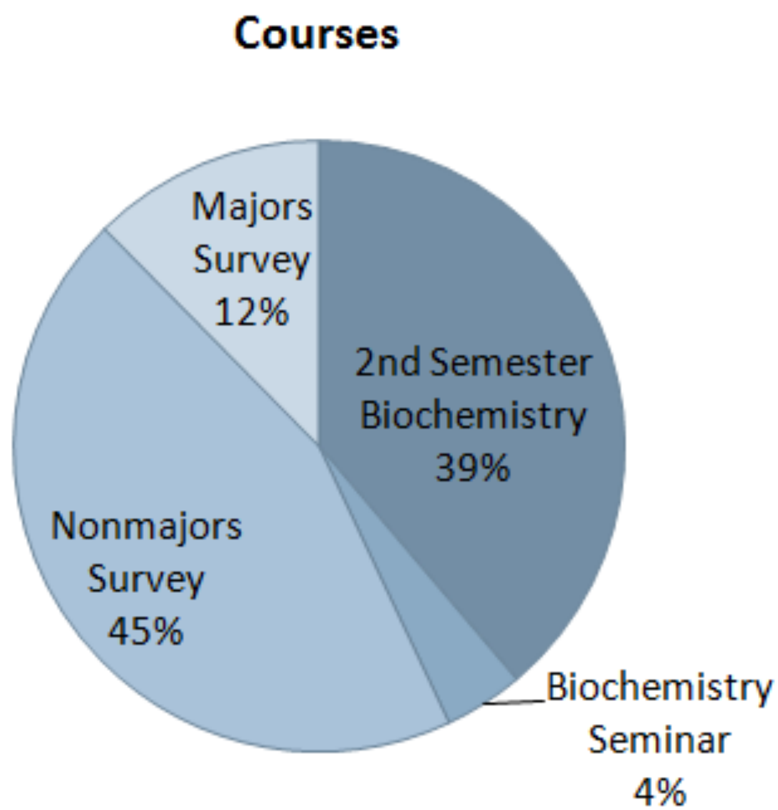
Full Study Sample

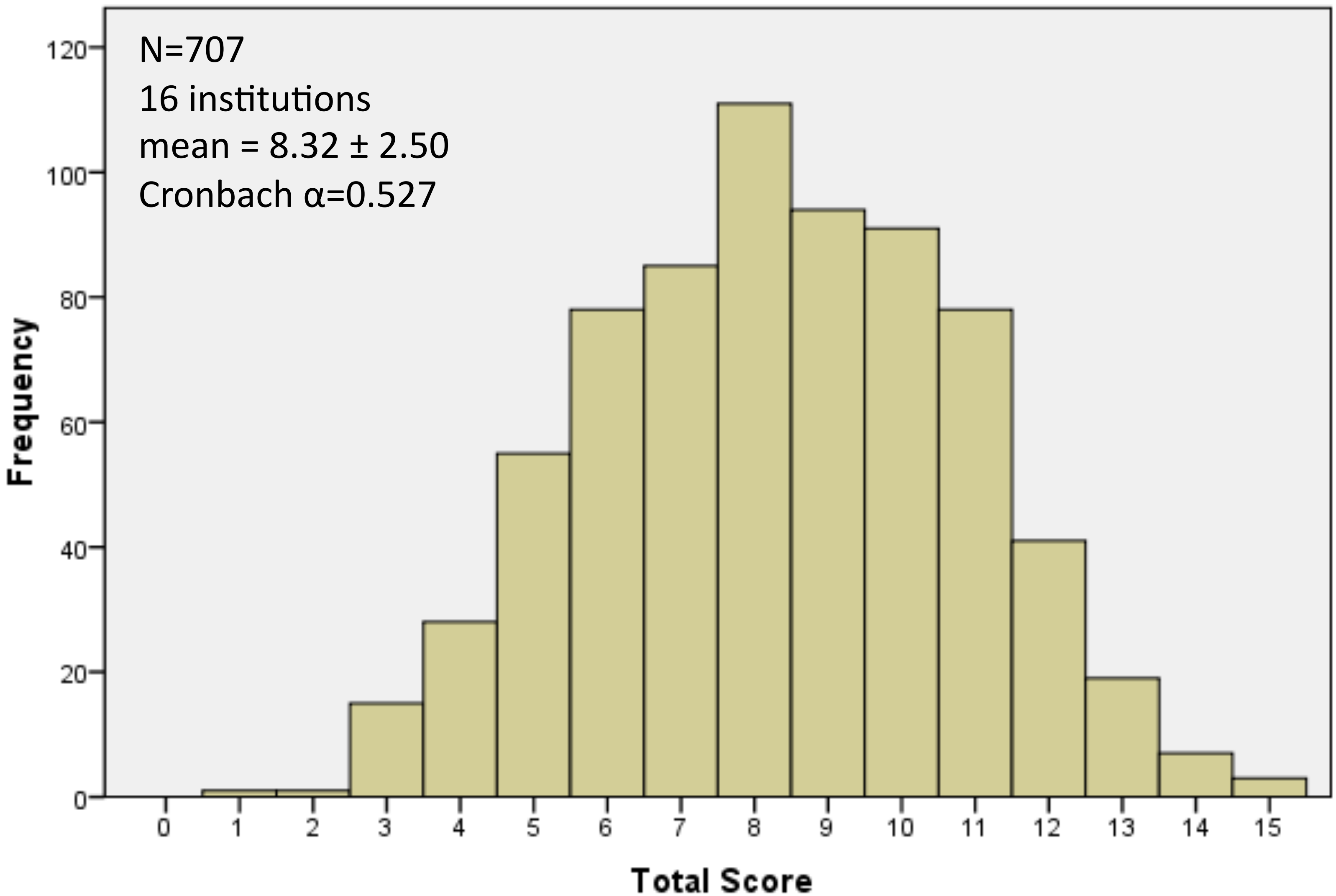
- 16 Institutions (N = 707)
  - 78% White/Caucasian
  - 57.3% Female
  - 81.2% 3rd & 4th year





•Bretz and Linenberger, "Development of the Enzyme-Substrate Interactions Concept Inventory," *Biochemistry and Molecular Biology Education*, EarlyView, DOI: 10.1002/bmb.20622

ESICI Descriptive Statistics



•Bretz and Linenberger, "Development of the Enzyme-Substrate Interactions Concept Inventory," *Biochemistry and Molecular Biology Education*, EarlyView, DOI: 10.1002/bmb.20622

Reliability & Factor Analysis

- Underlying assumptions about singularity of construct being measured
- Inter-item correlations assume coherent whole

How does this align with
what we know about students’ ***fragmented knowledge structures and misconceptions?***

Reliability & Factor Analysis

- Underlying assumptions about singularity of construct being measured
- Inter-item correlations assume coherent whole

"a low Cronbach's α would be quite reasonable, and a high Cronbach 's α does not guarantee that the test will be more reliable…may be an indication that there are redundant items that should be removed."

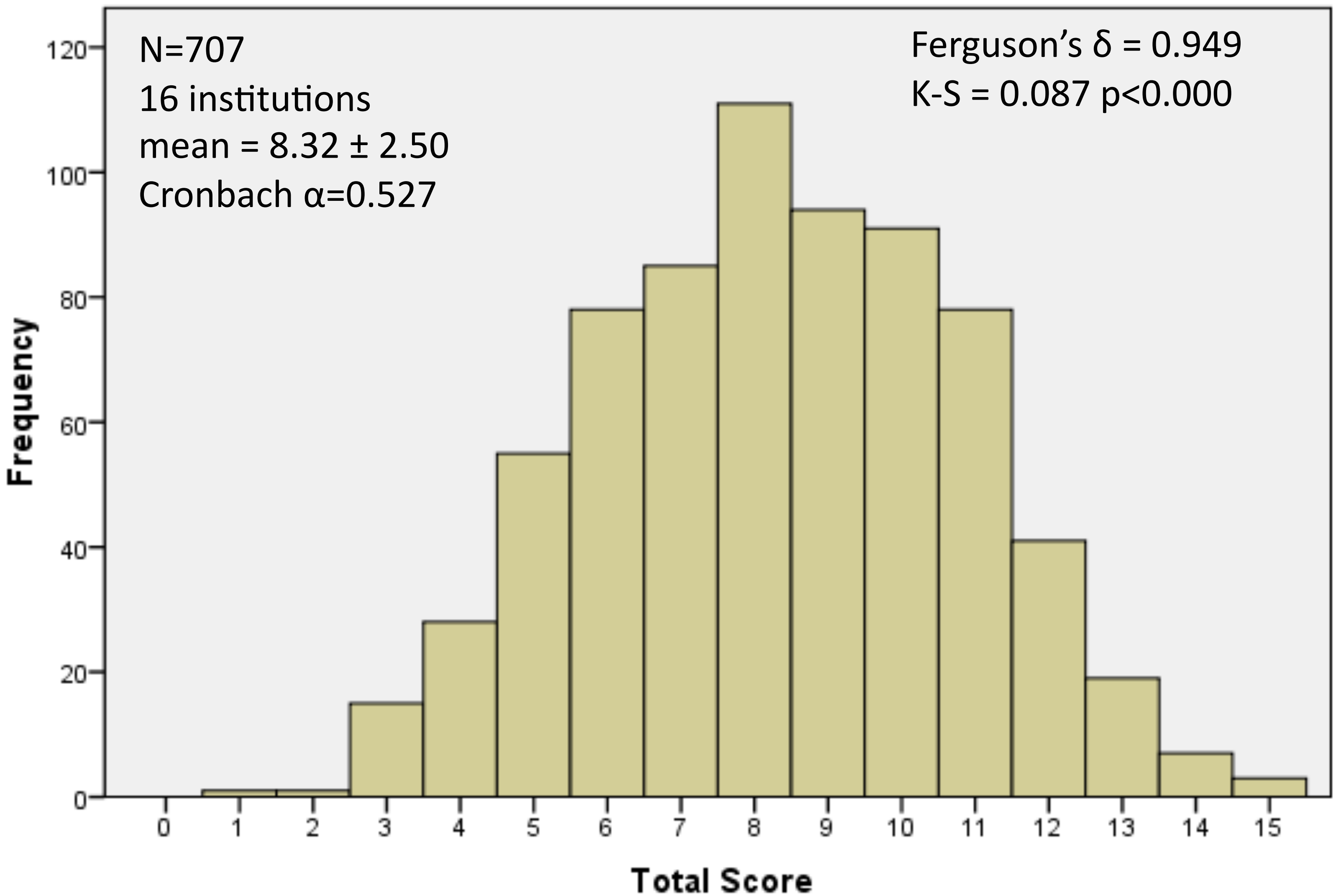
- Adams, W.K.; Weiman, C.E. "Development and Validation of Instruments to Measure Learning of Expert-Like Thinking," *Intl. J. Sci. Educ.*, 2010, iFirst 27 October 2010

More Meaningful Measures

- Kolmogorov-Smirnov value
- Item Response Theory
  - item difficulty, ρ
  - item discrimination, D
  - point-biseral index, r_{pbi}
- Ferguson's δ
- Item Response Curves
- Confidence & 4-Tier for strength

- Ding and Beichner, "Approaches to data analysis of multiple-choice questions." *Physical Review Special Topics Physics Education Research*, 2009, 5, 20103-1 – 20103-15.
- Morris, G.A.; Branum-Martin, L.; Harshman, N.; Baker, S.D.; Mazur, E.; Dutta, S.; Mzoughi, T.; McCauley, V. "Testing the Test: Item Response Curves and Test Quality," *Am. J. Phys.*, 2006, 74(5), 449-453.
- Caleon, I.S. & Subramaniam, R. "Do Students Know What They Know and What They Don't Know? Using a Four-Tier Diagnostic Test to Assess Students' Alternative Conceptions," *Research in Science Education*, **2010**, 20, 313 – 337

ESICI Descriptive Statistics



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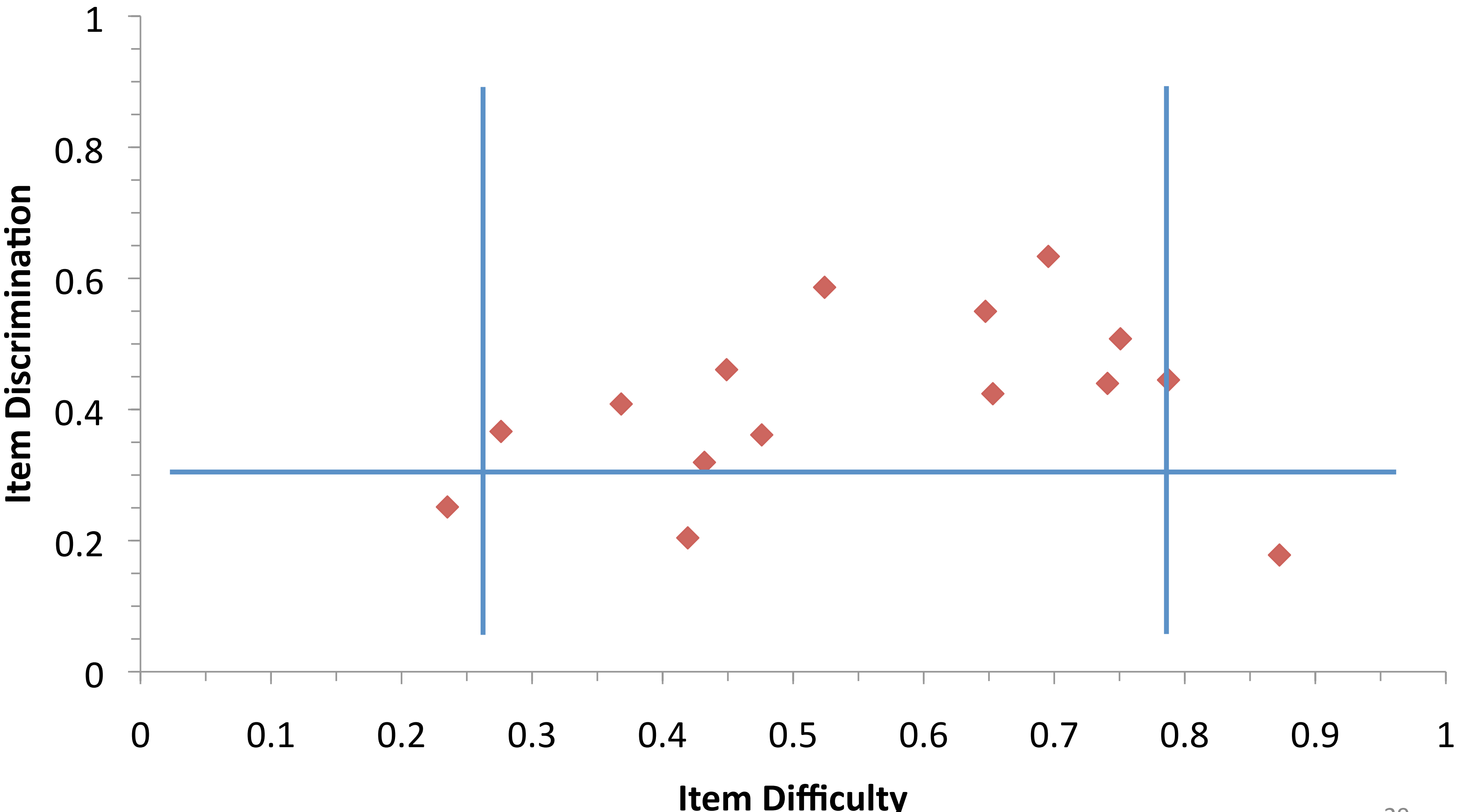
ESICI Item Difficulty & Discrimination



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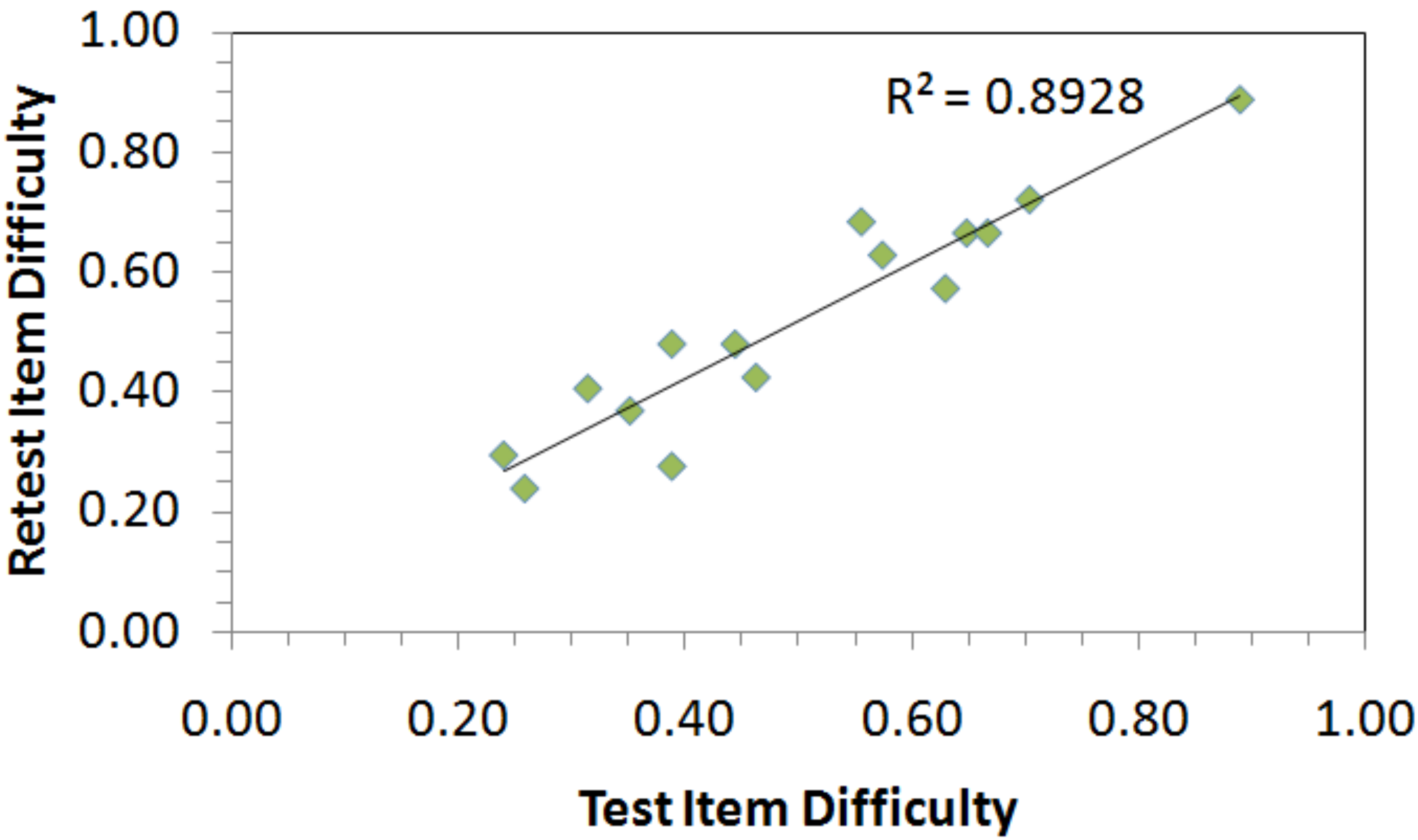
Test-Retest Difficulty



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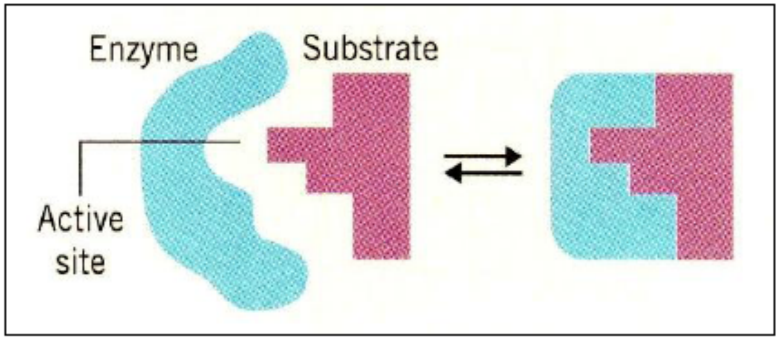

$\rho = 0.792$

$D = 0.345$

$r_{pbi} = 0.382$

14. Select the answer that best describes the binding in the image.

A. The enzyme changes shape before the substrate binds to the enzyme.
B. An activator always binds the enzyme to change its shape, after which the substrate can bind.
★ C. The enzyme changes shape as the substrate binds to the enzyme.
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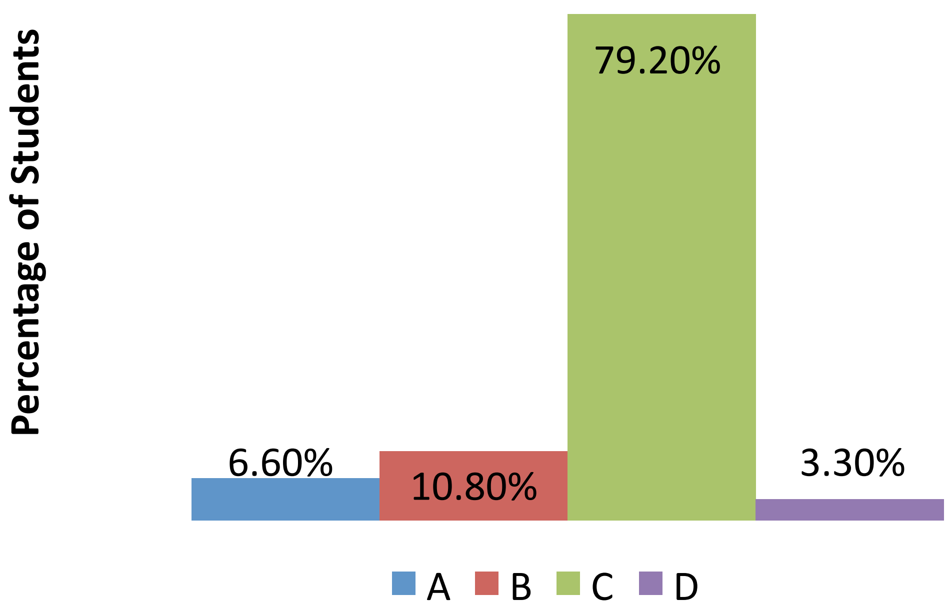

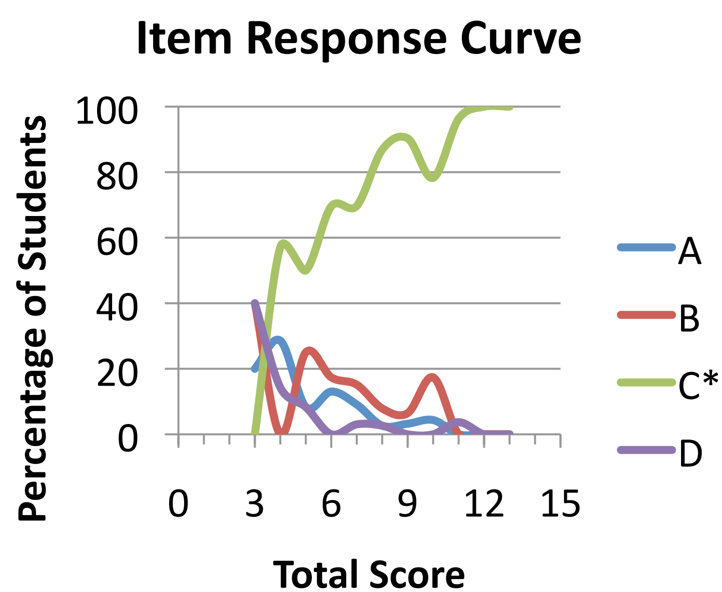

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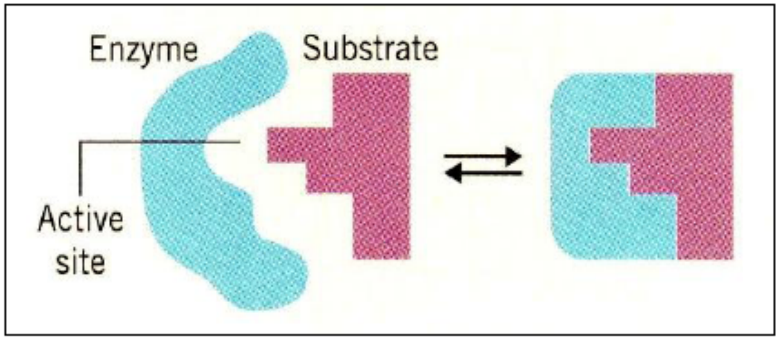


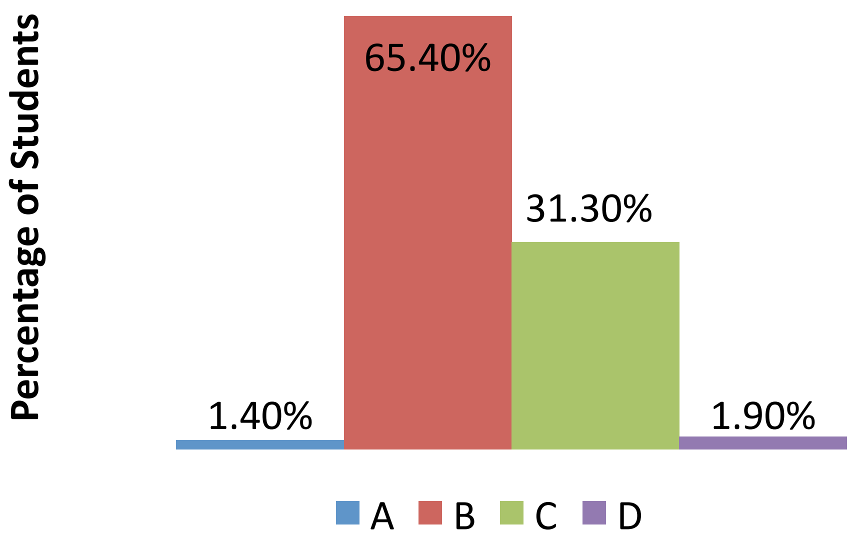
$\rho = 0.654$

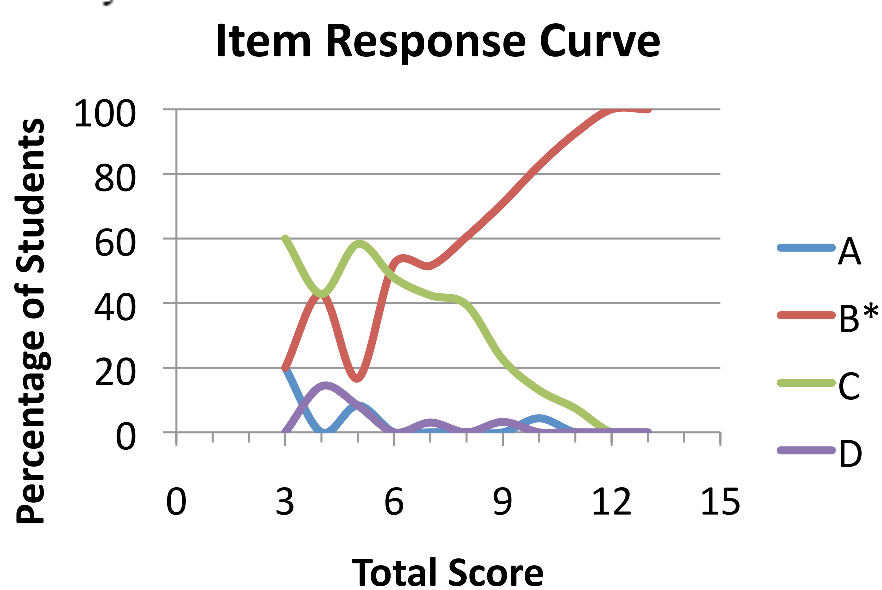
$D = 0.534$

$r_{pbi} = 0.435$

15. Which statement best explains how the enzyme in the image changes conformation?

A. Two additional molecules push on both the top and bottom of the enzyme.
★ B. Interactions with the substrate align the enzyme with the substrate.
C. A molecule binds to an allosteric site on the enzyme.
D. A molecule binds to a second active site on the enzyme.





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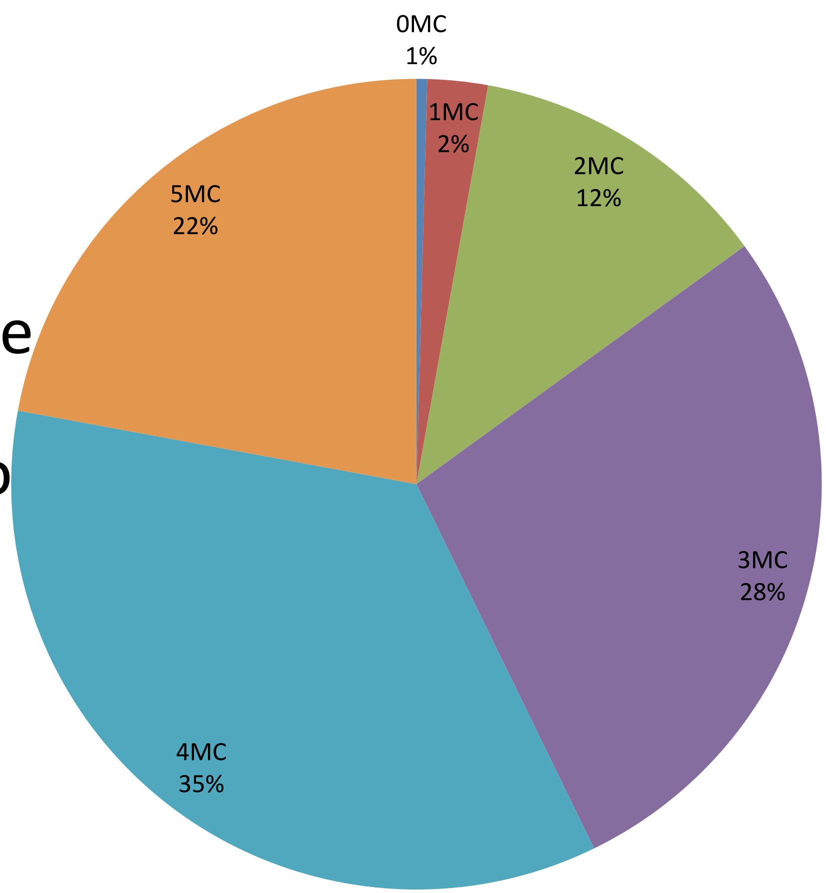
Enzyme-Substrate Interactions Concept Inventory

- Size/types of substrates
- Types of complementarities
- Enzyme conformational change
- Where and to what an inhibitor binds
- Where the enzyme binds/ interacts with the substrate



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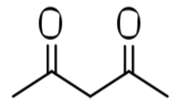
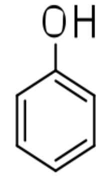
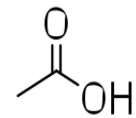
Acid Strength & Question "Tiers"



A



B



C

Q2. Compound C is the most acidic of the above three structures. Which of the following represents the correct trend in acid strength for compounds A and B?

1. A < B
2. B < A

Q3. Select or provide the ***best*** reason to justify your answer for question 2:

1. B is more acidic than A because B has a more electronegative acidic atom than A.
2. B is more acidic than A because the benzene better stabilizes the conjugate base than the carbonyl groups of A.
3. A is more acidic than B because the carbonyl groups better stabilize the conjugate base than the benzene of B.
4. A is more acidic than B because A has two oxygen atoms instead of one oxygen atom.

•Treagust, D.F. "Development and Use of Diagnostic Tests to Evaluate Students' Misconceptions in Science," *Int. J. Sci. Educ.*,**1988**, 10, 159 – 169.
•McClary, L.M. & Talaquer, V. "Heuristic Reasoning in Chemistry: Making Decisions about Acid Strength," *Int. J. Sci. Educ.*, iFirst 14 Dec 2010.
•McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433

Confidence & Question "Tiers"

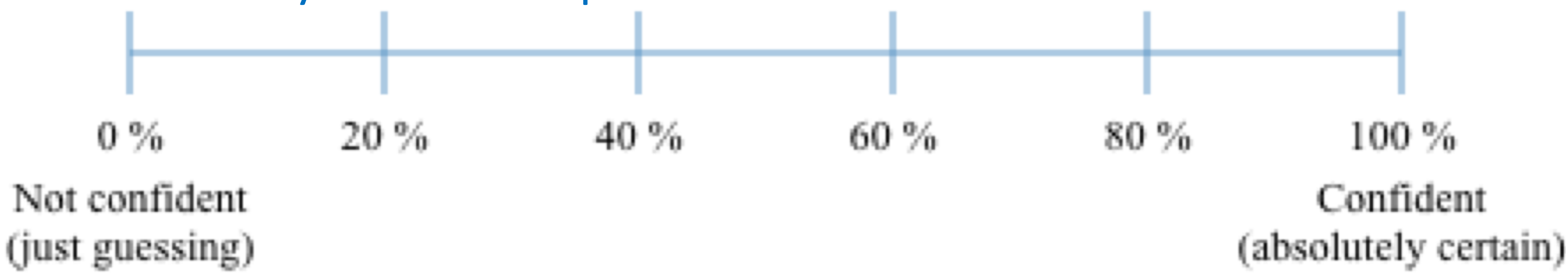
How confident are you about the ***answer*** you chose?

How confident are you about the ***reason*** you chose?

Genuine: significant,* mean confidence > 3.50 (or > 50%)

Spurious: significant,* mean confidence < 3.50 (or > 50%)

*chosen by >10% of respondents *above* chance



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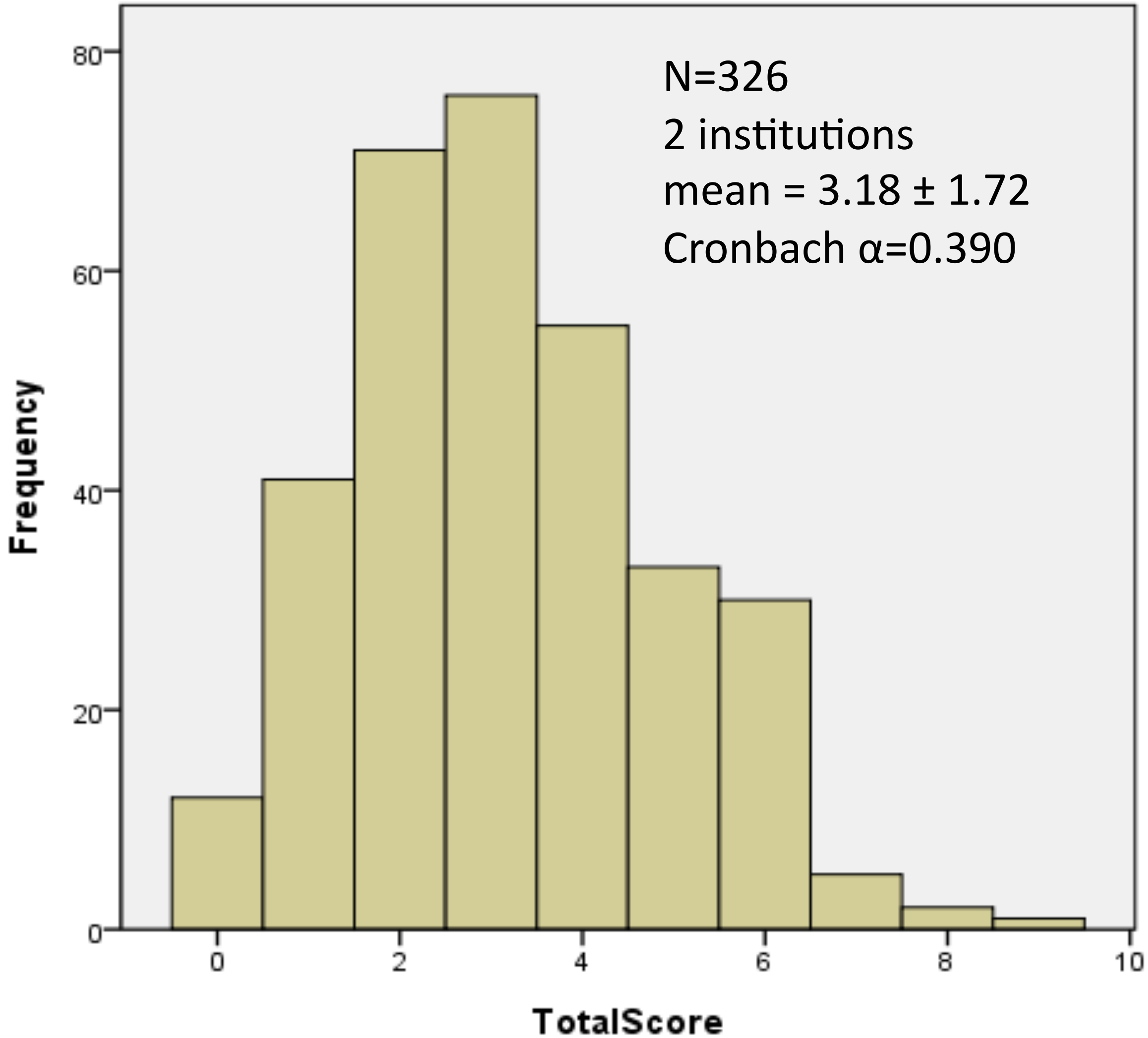
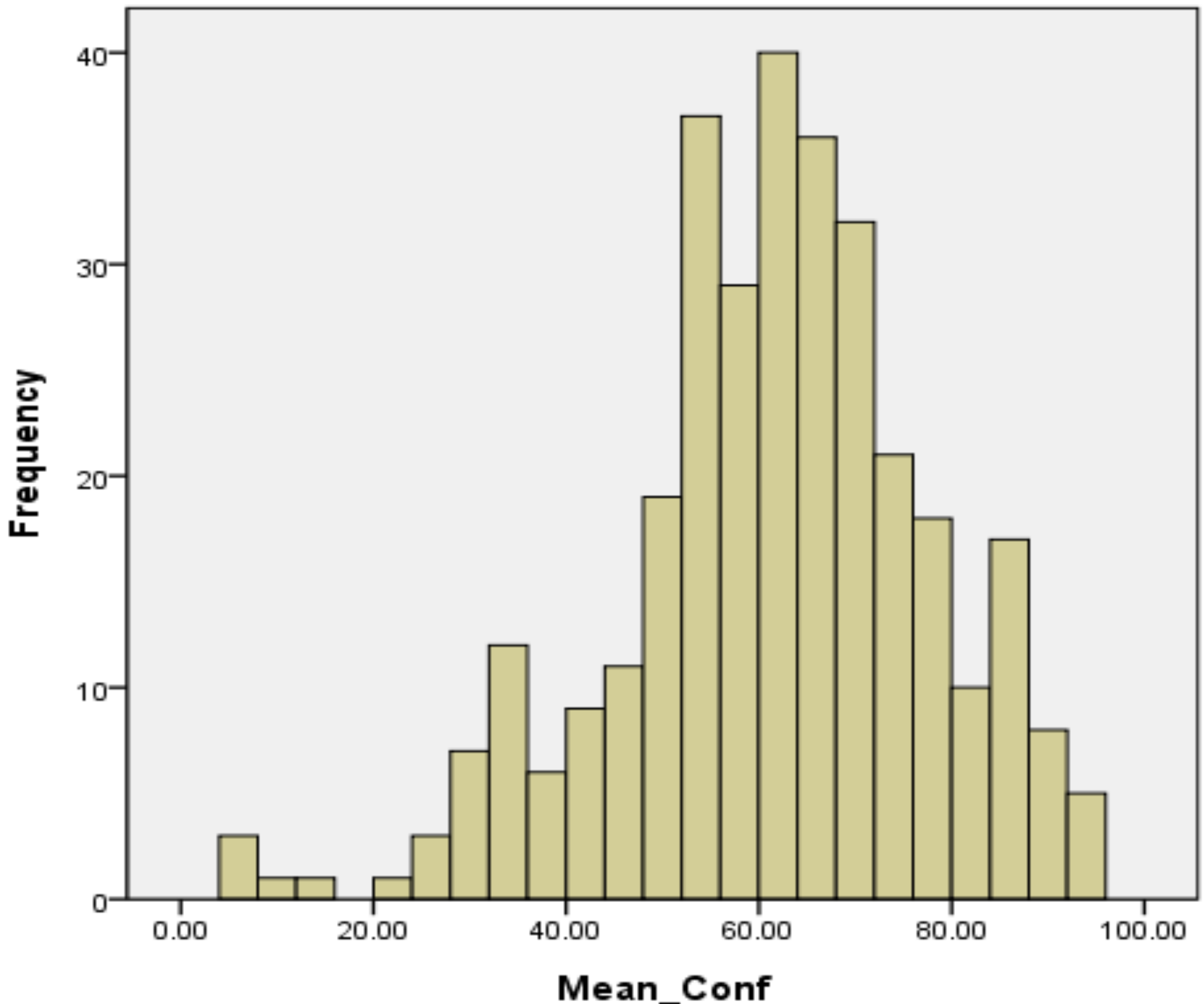
- McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433

ACID I Descriptive Statistics



- McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433

ACID I Mean Confidence



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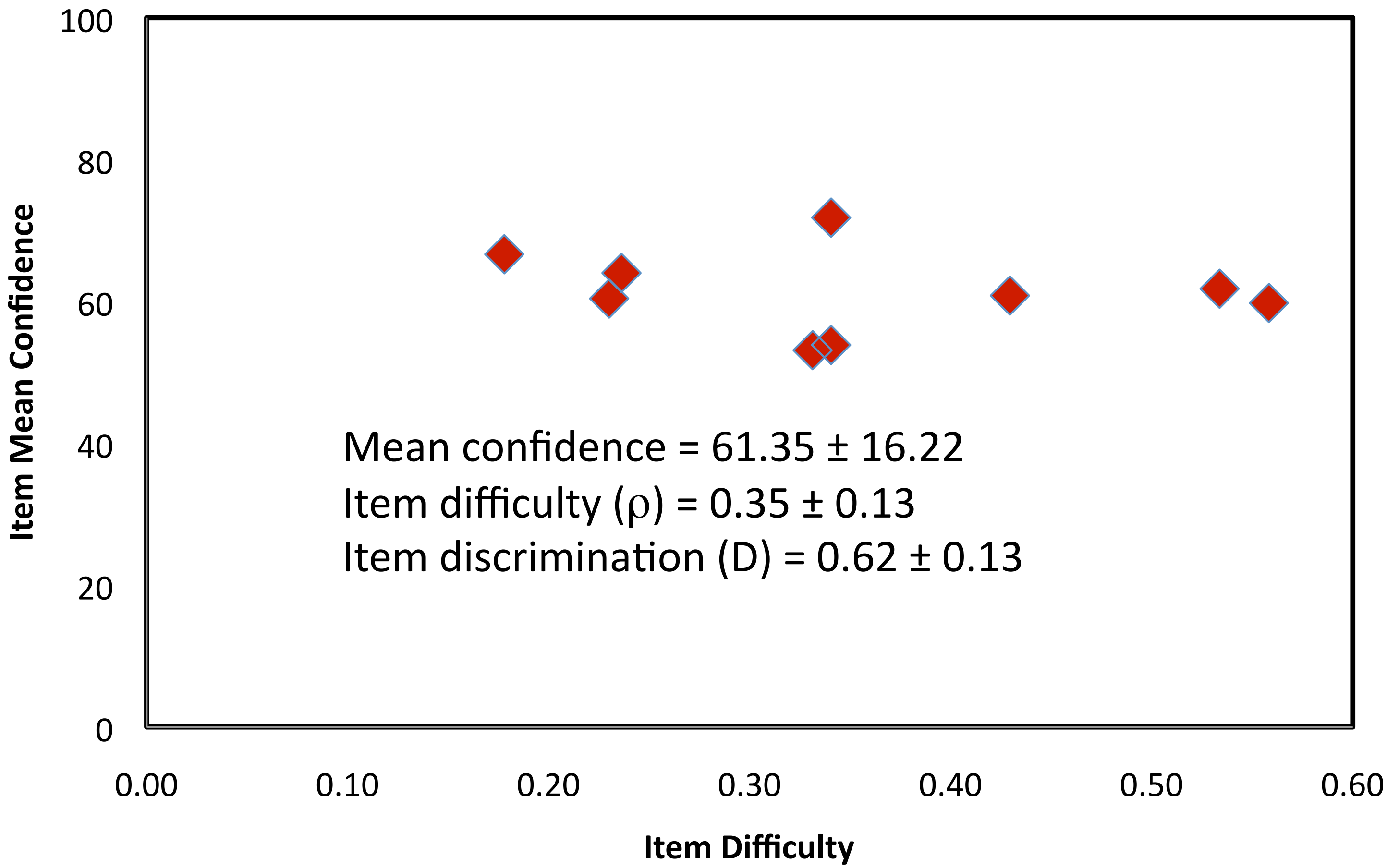
ACID I
Item Difficulty vs. Mean Confidence



- McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433

ACID I Strength of Misconceptions

Item	CF	CFC	CFW	CDQ
1	64.00	62.65	64.42	–0.086
2	71.81	68.42	73.55	–0.228
3	60.40	60.83	60.27	0.024
4	60.82	64.78	57.84	0.312
5	59.77	55.89	64.67	–0.397
6	53.86	56.35	52.57	0.166
7	66.64	67.56	66.44	0.050
8	61.78	66.63	56.23	0.440
9	53.12	58.35	50.53	0.334

- mean confidence (CF)
- mean confidence when answered correctly (CFC)
- mean confidence when answered incorrectly (CFW)
- mean confidence quotient (CDQ)

- McClary and Bretz, "Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength," *Intl. J. Sci. Educ.*, iFirst, DOI: 10.1080/09500693.2012.684433

Conclusions

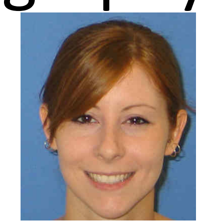
- Multiple representations elicit cognitive dissonance.
- Students have difficulty understanding representations in each of Johnstone's domains.
- Students have difficulty translating between Johnstone's domains.
- Misconceptions exist in all disciplines of chemistry.

Acknowledgements









- Acid-base reactions
- Acidity
- Atomic emission, flame tests & energy level diagrams
- Covalent & ionic bonding
- Enzyme-substrate interactions
- Intermolecular forces & chromatography
- Oxidation-reduction reactions

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Concept Inventories

- Acid-base reactions
- Acidity
- Atomic emission & flame tests
- Covalent & ionic bonding
- Enzyme-substrate interactions
- Intermolecular forces
- Oxidation-reduction reactions

Interested in using a
concept inventory in your classroom?
Contact
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