Teaching Introductory Chemistry through Concept Development Studies

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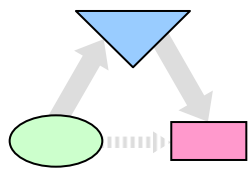
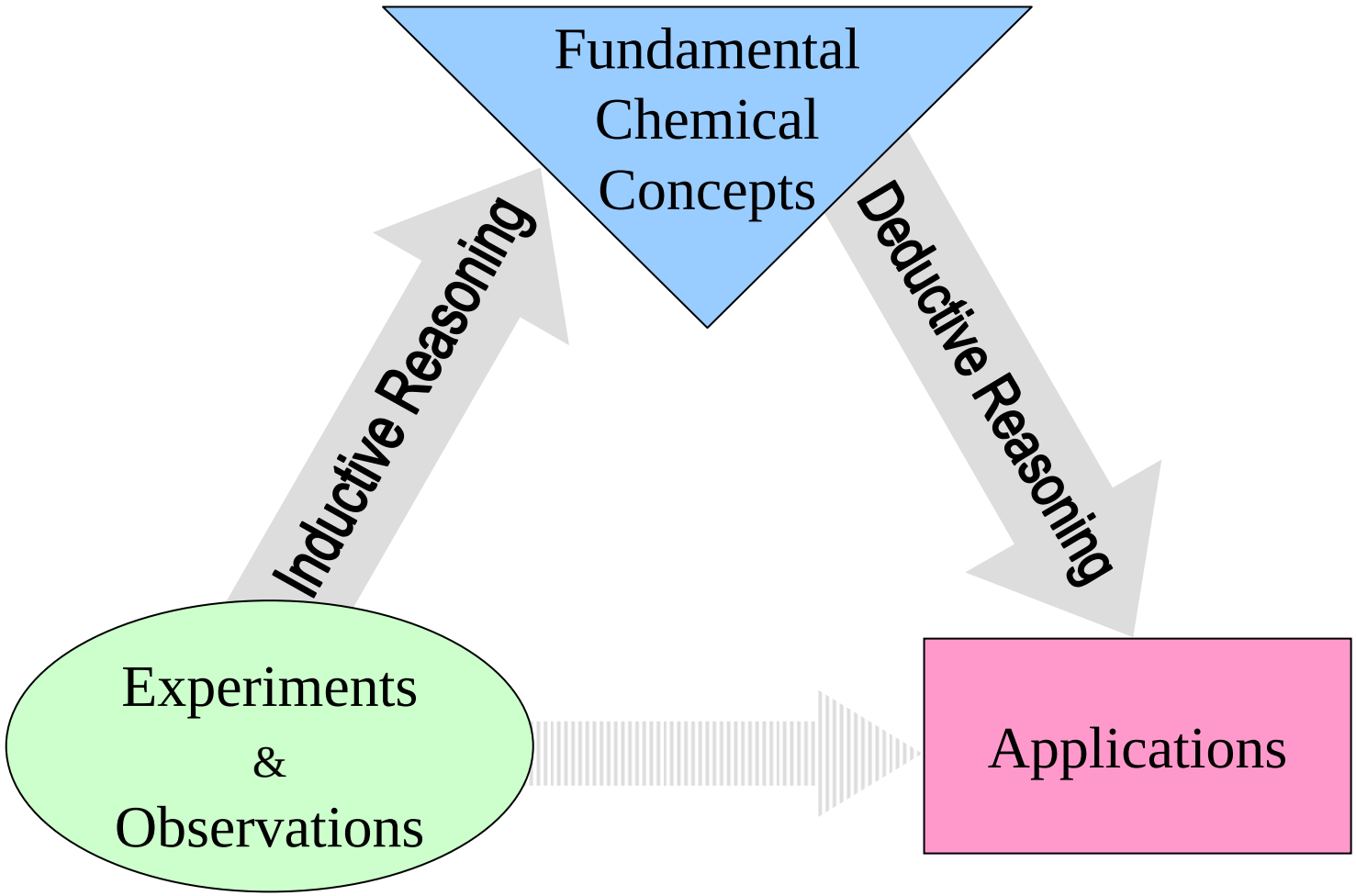


Goals in General Chemistry: What should students gain?

- Fundamental Chemical Knowledge
  - Descriptive Chemistry (facts)
  - Chemical Concepts (theories, models)
  - Problem Solving (applications)
- Critical Thinking Skills
  - Scientific Philosophy
  - Argumentation, Discussion, Rhetoric
  - Writing
- Intellectual Growth
  - Intellectual engagement
  - Independence: “life long learning”

What students should gain



Learning Styles

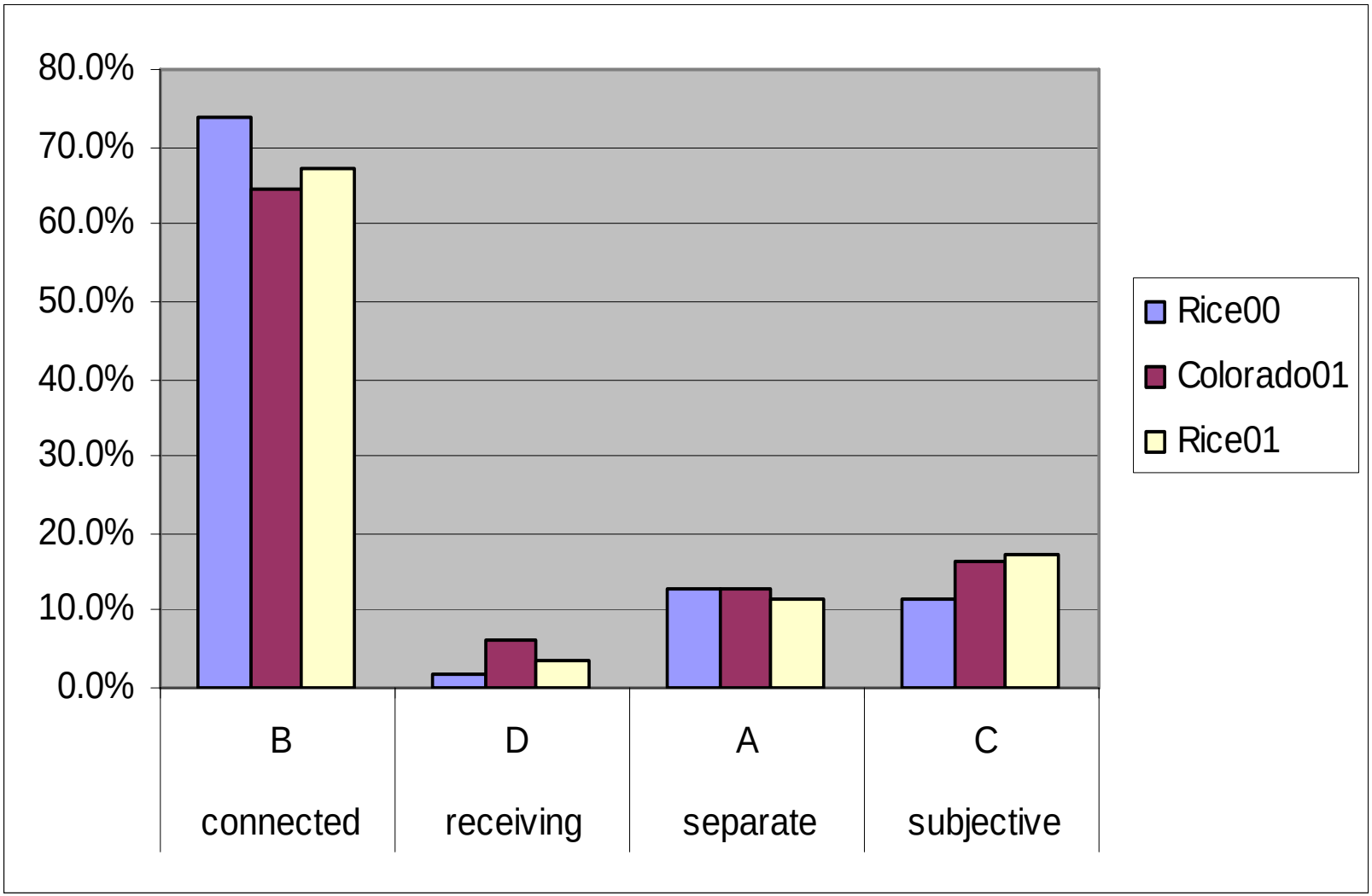
- I like to argue just for the sake of arguing. Sometimes I will take the "Devil's advocate" role, arguing the opposite to an opinion just to see what someone will say. That keeps the discussion lively. If someone presents a really convincing argument, sometimes they change my mind, or make me really think about my reasoning.

- I like to hear the reasons behind statements people make, and will ask them to tell me their chain of thought. Hearing how people reach their opinions helps me to understand how they think and sometimes clarifies my own thoughts. If their reasons make more sense then mine, I will sometimes change my point of view.

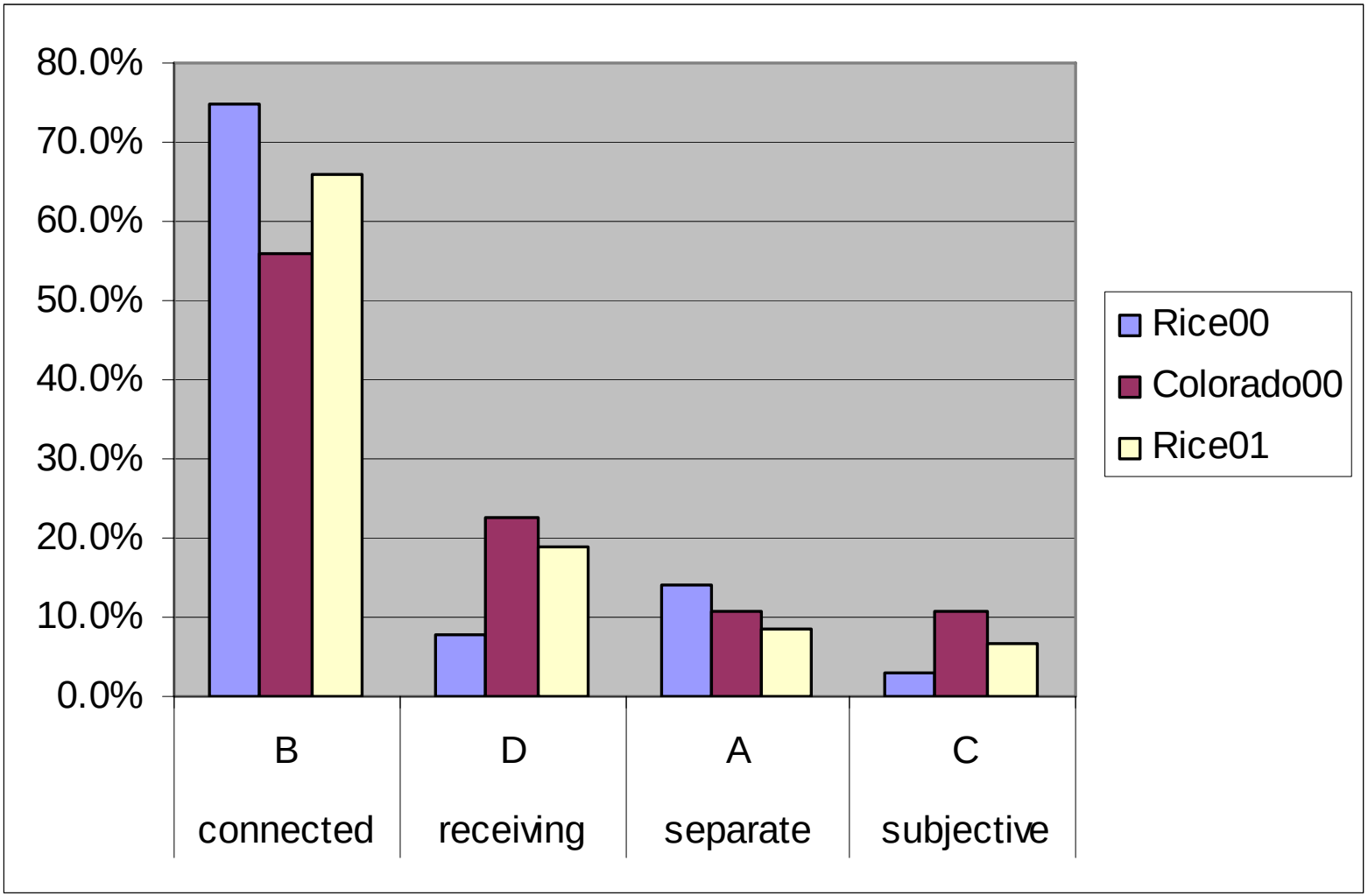
- Discussing opinions and how people reached their conclusions is fine, and can be fun, but just talking never changes my mind. I have to experience something myself before I really believe it. Otherwise it is just their opinion against mine. I know in my gut when something is right.

- I do not really like arguments, and I am not that interested in the opinions of other people, unless they are experts. I respect and accept expert opinions on most things. I prefer lectures to discussions; only people who really know what they are talking about are worth listening to.

Learning Styles: Self-Description



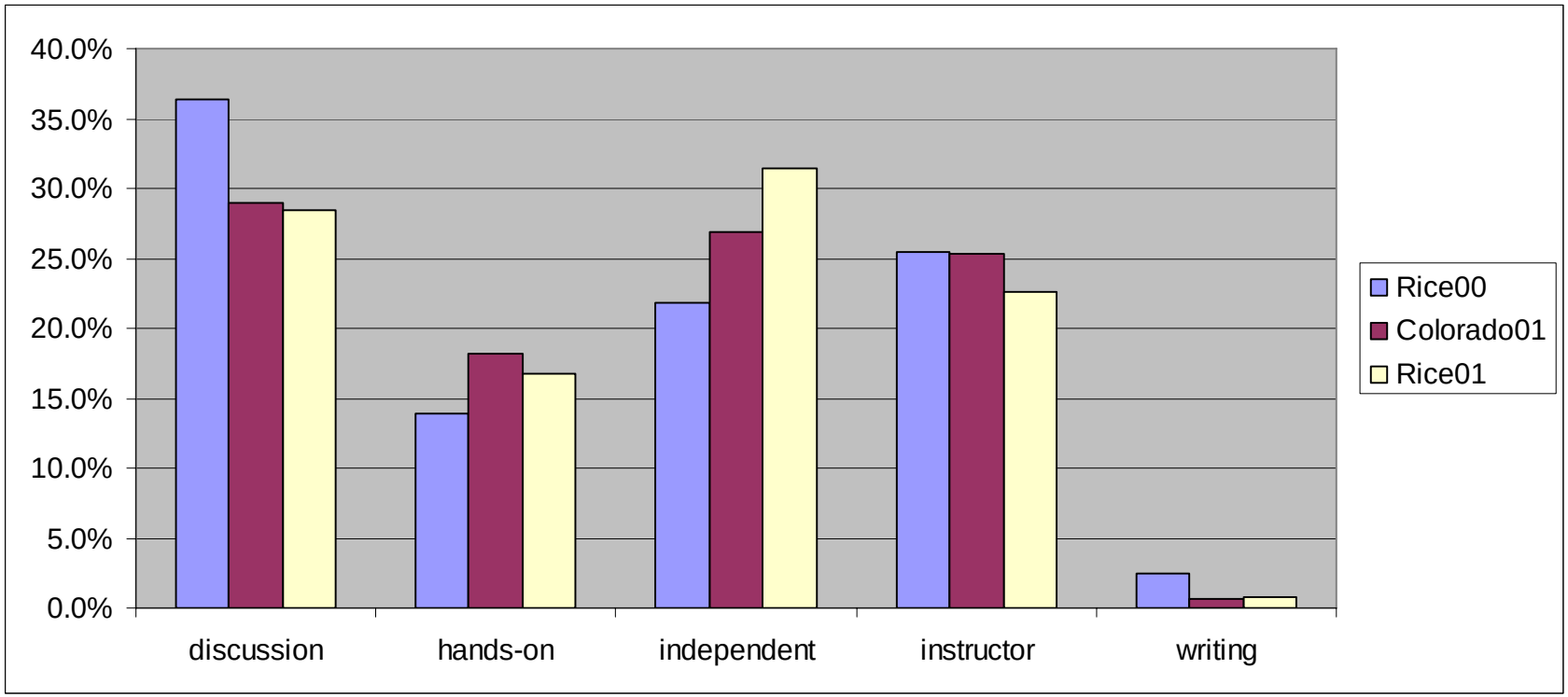
Learning Styles: Classroom Preferences



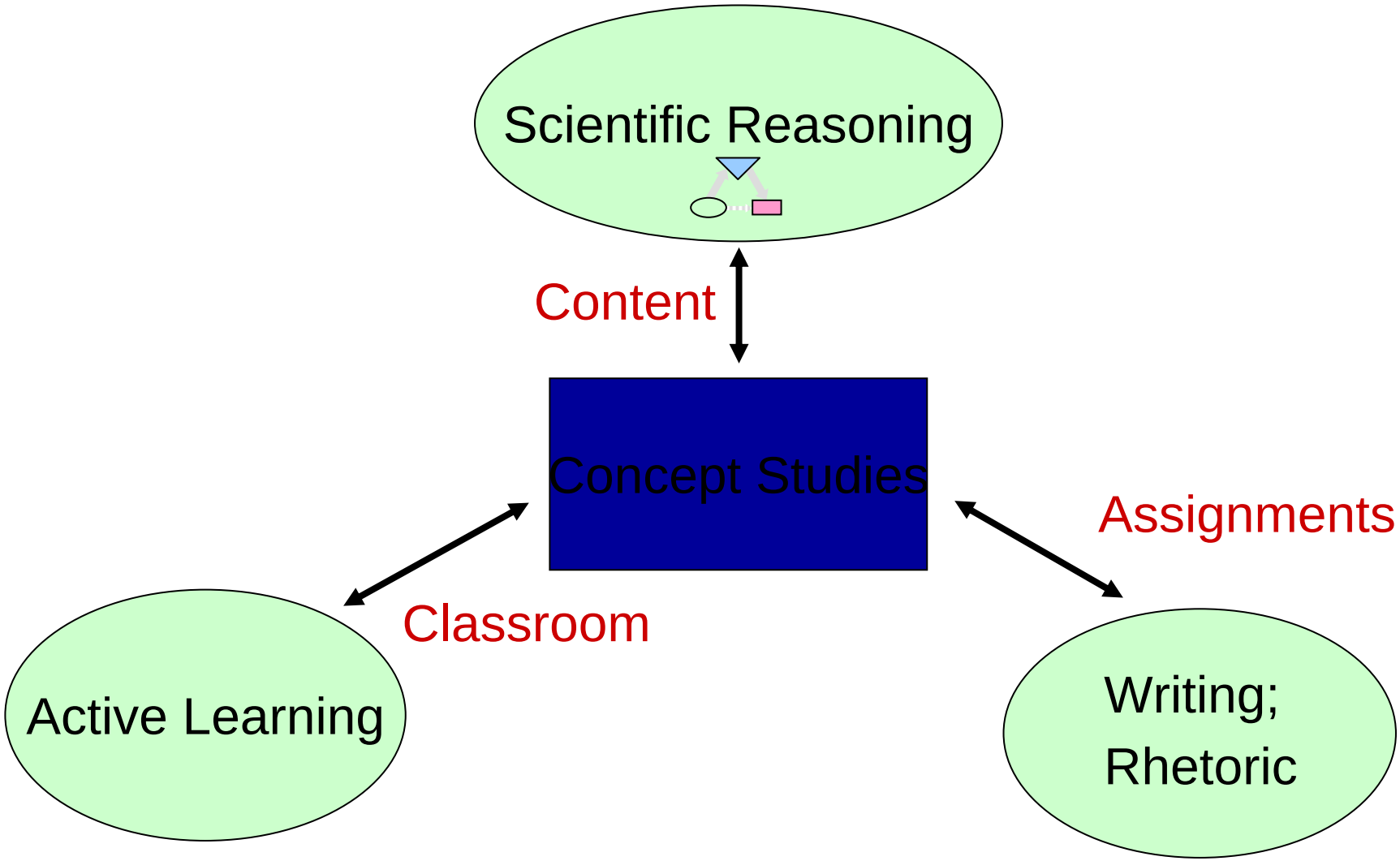
Which do you find most useful or efficient for learning material?

- Reading and working problems by myself
- Discussing concepts and problems with other students
- Listening to the teacher lecture and asking questions
- Hands-on stuff, building models or doing experiments
- Writing essays or papers developing my reasoning

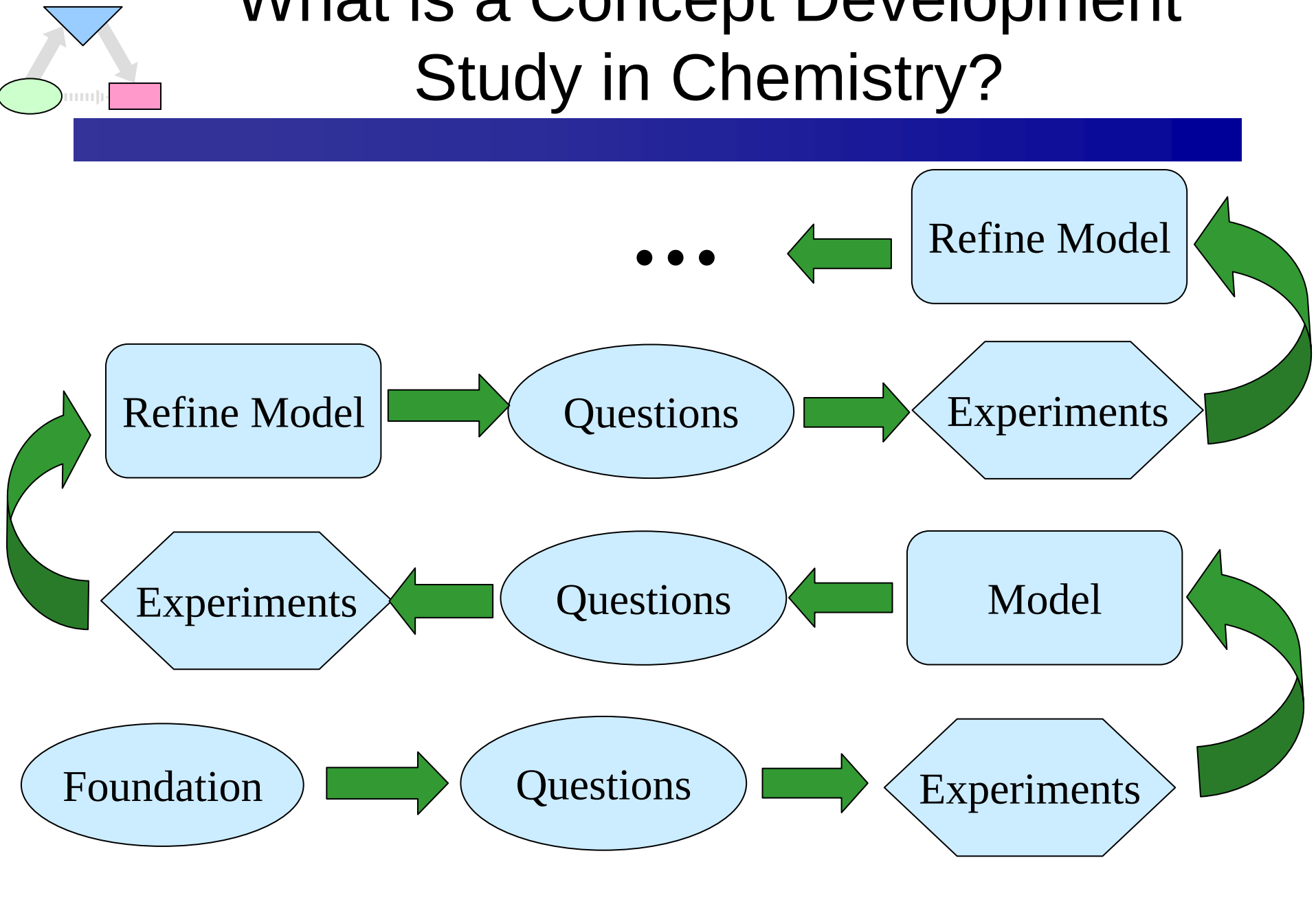
Learning Approaches: Two Universities



Putting it Together with *Concept Development Studies*



What is a Concept Development Study in Chemistry?



Writing Assignments

- Connecting observations to models
- Reconciling apparent contradictions
- Assessing and correcting fallacies

Concept Development Studies in Chemistry

- The Atomic Molecular Theory
- Relative Atomic Masses and Empirical Formulae
- The Structure of the Atom
- Quantum Energy Levels in Atoms
- Covalent Bonding and Electron Pair Sharing
- Molecular Geometry and Electron Domain Theory
- Molecular Structure and Physical Properties

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http://chemed.rice.edu/ConceptStudies

Concept Development Studies in Chemistry

- Energetics of Chemical Reactions
- Ideal Gas Law
- Kinetic Molecular Theory
- Phase Equilibrium and Intermolecular Interactions
- Reaction Equilibrium in the Gas Phase
- Acid-Base Equilibrium
- Reaction Rates
- Equilibrium and the Second Law of Thermodynamics

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Concept Development Study Example Valence Shell Model of Bonding

- Foundation
  - Atomic Molecular Theory
  - Atomic weights; molecular formulae
  - Atoms contain electrons
- Questions
  - What determines valence of an atom?
  - What forces hold atoms together in a molecule?
  - How can diatomic molecules exist?

Valence Theory of Bonding

- Observation: Groups of Elements
- Observation: Periodicity of Groups
- Observation: Rutherford α-particle scattering
- Model: Nuclear structure of atom
- Observation: X-ray emission from elements
- Model: Atomic number = number of charged particles

Valence Theory of Bonding

- Model: electrons determine reactivity
  - But elements in same group have vastly varying numbers of electrons
  - Therefore, electrons must be grouped:
    - Valence shell (same for elements in same group)
    - Core
  - How many valence electrons in each group?
  - Reference to Nobel Gases: Equal to group number

Valence Theory of Bonding

- Observation: Valences are periodic
  - Group 4, valence is 4
  - Group 5, valence is 3
  - Group 6, valence is 2
  - Group 7, valence is 1
  - Group 8, valence is 0
- Observation: Number of valence electrons + valence = 8 (groups IV to VIII only)

Valence Theory of Bonding

- Model: “Octet rule” – atoms bond so as to have or share eight valence electrons
- Model: requires electrons to be shared in pairs – “covalent bond”

Concept Development Study Example Spontaneous Chemical Reactions

- Foundation
  - Atomic Molecular Theory
  - Kinetic Molecular Theory
- Questions
  - $2\ H_2 + O_2 \rightarrow 2\ H_2O$ occurs readily
  - $2\ N_2 + O_2 \rightarrow 2\ NO$ does not (fortunately!)
  - $2\ N_2 + O_2 \rightarrow 2\ NO$ does occur in car engines (unfortunately!)
  - $2\ NO + O_2 \rightarrow 2\ N\ O_2$ does occur (unfortunately!)
  - What determines whether a reaction occurs?
  - What determines the conditions under which a reaction occurs?

Probability and Spontaneity

- Observation 1: Nature of Spontaneous Processes
  - Shuffled deck is always disordered
  - Ink always disperses
- Model: Probability drives spontaneity
  - “That which happens is that which is most probable.”
  - “Disorder increases.”
- Model: Define Entropy
  - W is the number of “ways” : microstates
  - $S = k \ln W$

	T (°C)	S (J/mol°C)
H_2O (g)	25	188.8
H_2O (l)	25	69.9
H_2O (l)	0	63.3
H_2O (s)	0	41.3
NH_3 (g)	25	192.4
HN_3 (l)	25	140.6
HN_3 (g)	25	239.0
O_2 (g)	25	205.1
O_2 (g)	50	207.4
O_2 (g)	100	211.7
CO (g)	25	197.7
CO (g)	50	200.0
CO_2 (g)	24	213.7
CO_2 (g)	50	216.9
Br_2 (l)	25	152.2
Br_2 (g)	25	245.5
I_2 (s)	25	116.1
I_2 (g)	25	260.7
CaF_2 (s)	25	68.9
$CaCl_2$ (s)	25	104.6
$CaBr_2$ (s)	25	130
C_8H_{18} (l)	25	361.1

Entropy

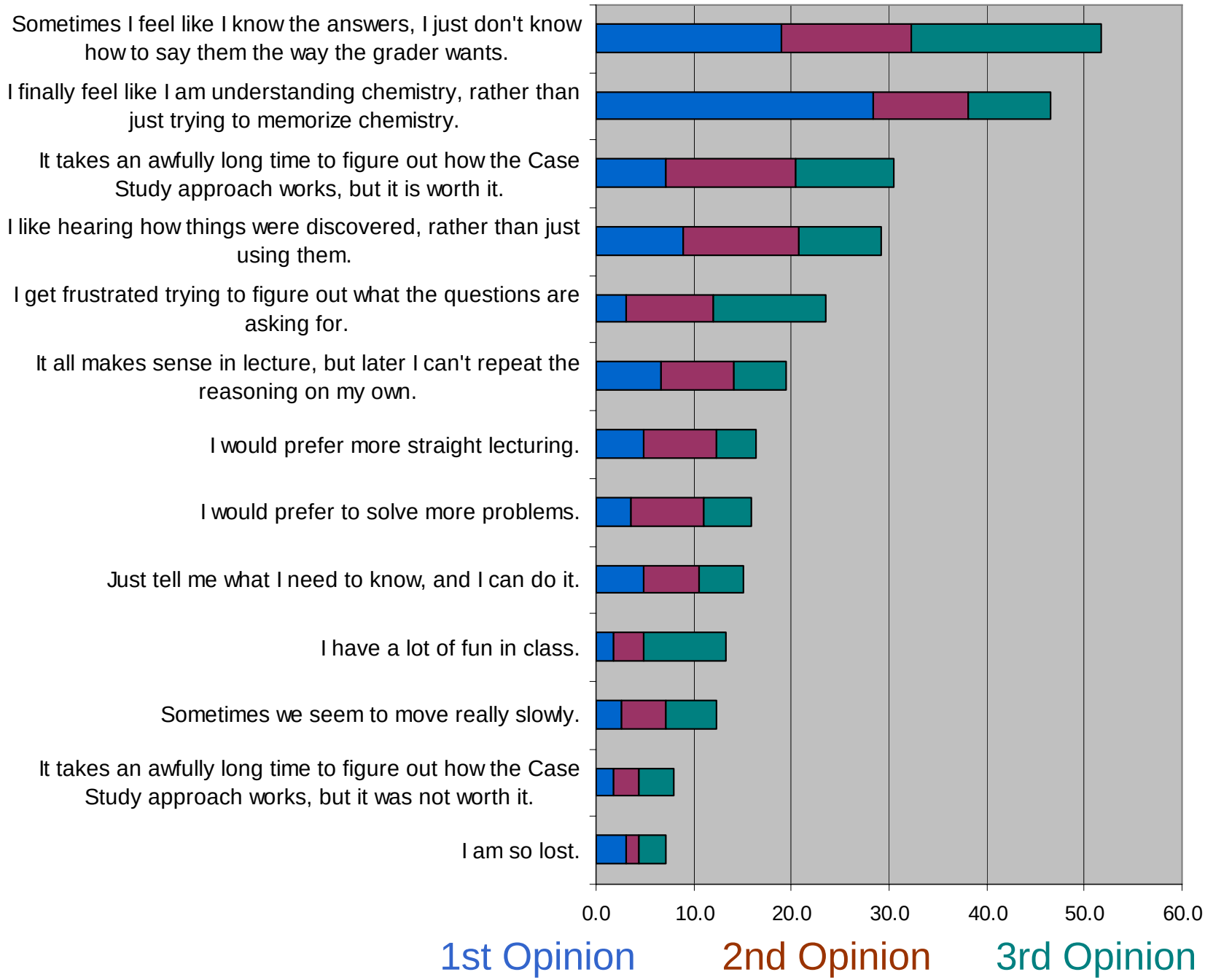
- Observation 2: Entropies of Substances
  - Entropy of Gas >> Liquid > Solid
  - Entropy increases with Temperature
  - More complex molecules have greater entropy
  - Entropy increases with molecular weight
- Observation 3: Evaporation vs. Condensation
  - Spontaneity depends on Temperature
  - How can Gas $\rightarrow$ Liquid be probable?

Free Energy

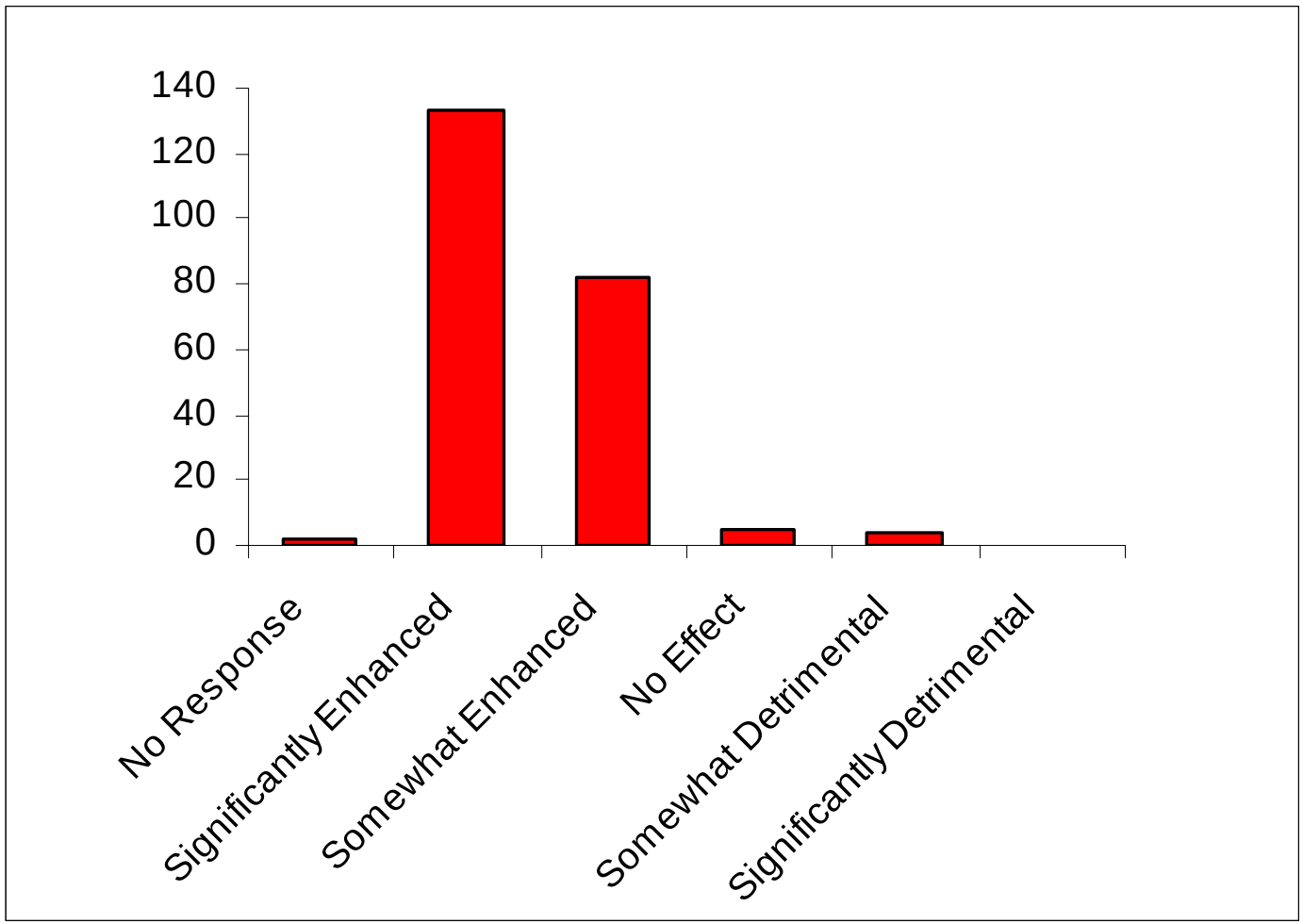
- Model: must include entropy of surroundings
  - ΔS (universe) must increase
  - ΔS (universe) = ΔS (system) + ΔS (surroundings)
  - Why does S(surroundings) change?
- Observation 4: Energy flow
  - Evaporation absorbs energy; condensation releases energy
  - Energy release increases S(surroundings)
  - ΔS (surroundings) = - ΔH (surroundings)/T
- Free energy
  - $\Delta G = \Delta H$ (surroundings) - T $\Delta S < 0$

Analysis of the Concept Development Study Method

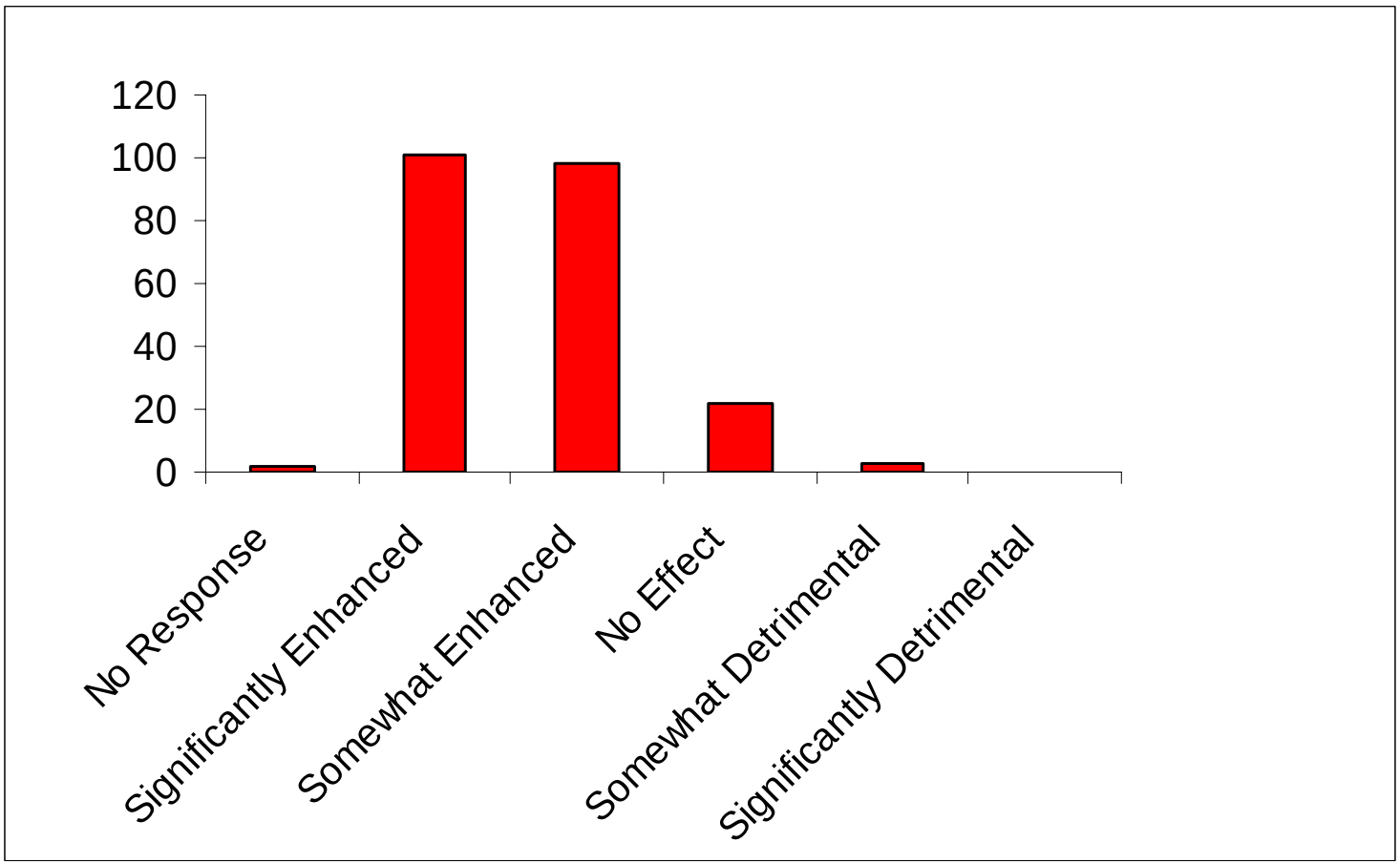
- Student Surveys
  - What would your students say?
  - Do you believe the results?
- Pre-test, Post-test Comparisons
- Diagnostic Tests
  - Pre-instruction base-line assessment
  - Results available on-line: chemed.rice.edu/Chem121/diagnostics/Fall2000/results.htm


Sometimes I feel like I know the answers, I just don't know how to say them the way the grader wants.
I finally feel like I am understanding chemistry, rather than just trying to memorize chemistry.
It takes an awfully long time to figure out how the Case Study approach works, but it is worth it.
I like hearing how things were discovered, rather than just using them.
I get frustrated trying to figure out what the questions are asking for.
It all makes sense in lecture, but later I can't repeat the reasoning on my own.
I would prefer more straight lecturing.
I would prefer to solve more problems.
Just tell me what I need to know, and I can do it.
I have a lot of fun in class.
Sometimes we seem to move really slowly.
It takes an awfully long time to figure out how the Case Study approach works, but it was not worth it.
I am so lost.
0.0
10.0
20.0
30.0
40.0
50.0
60.0
1st Opinion
2nd Opinion
3rd Opinion

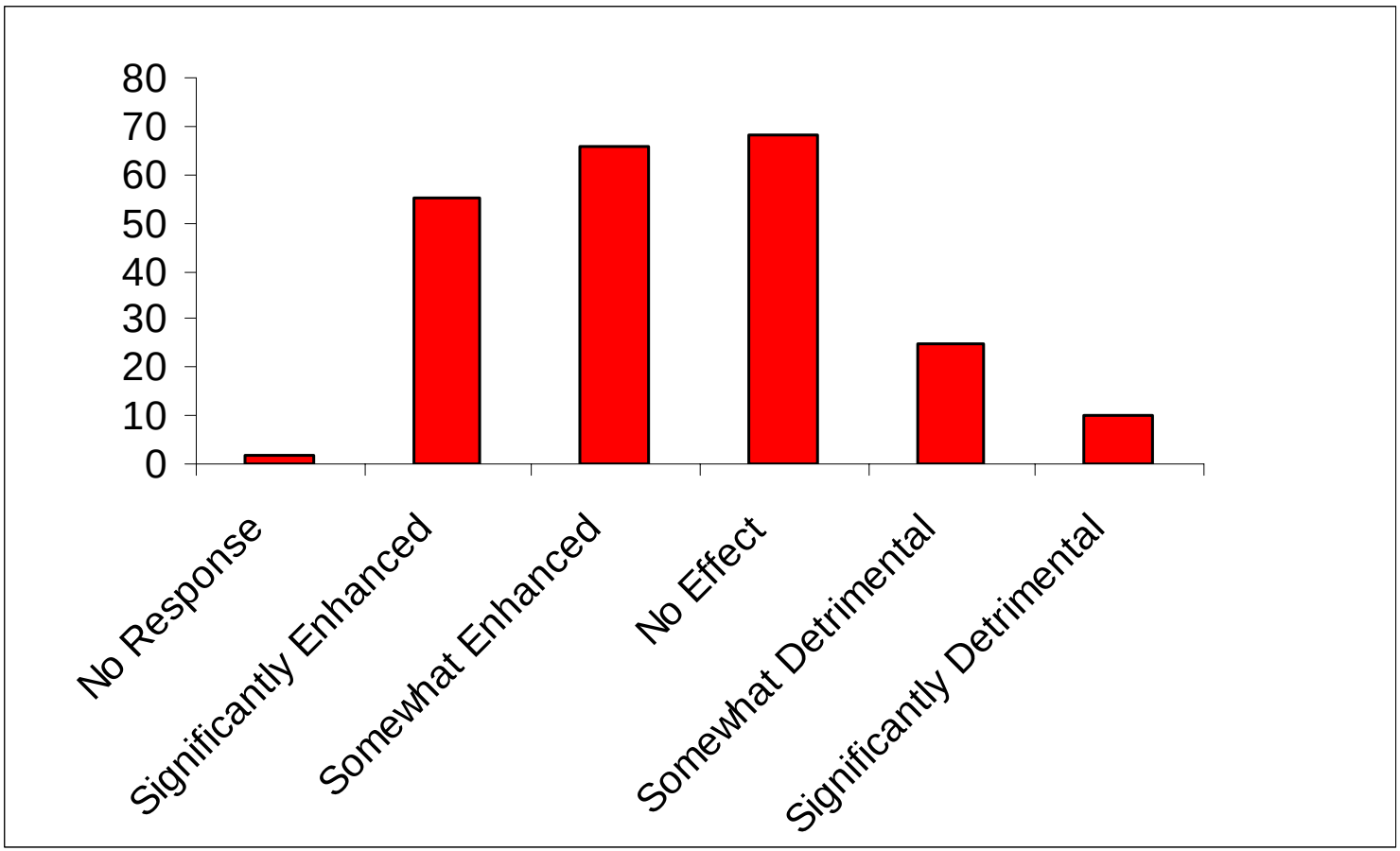
Contribution of “Case Studies in Chemistry” to Understanding of Chemical Concepts



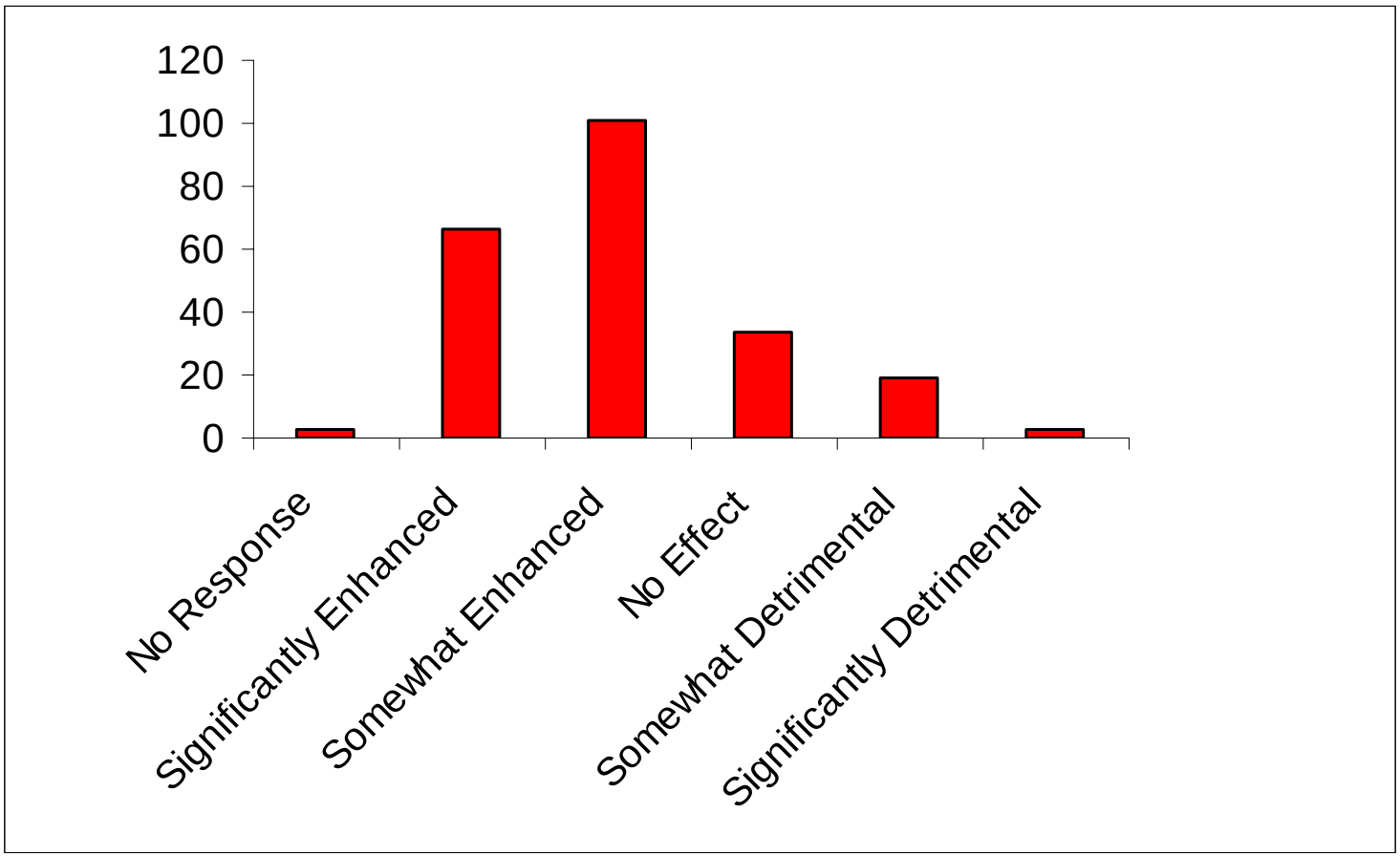
Contribution of “Case Studies in Chemistry” to Retention of Chemical Concepts



Contribution of “Case Studies in Chemistry” to Interest in Learning Chemistry



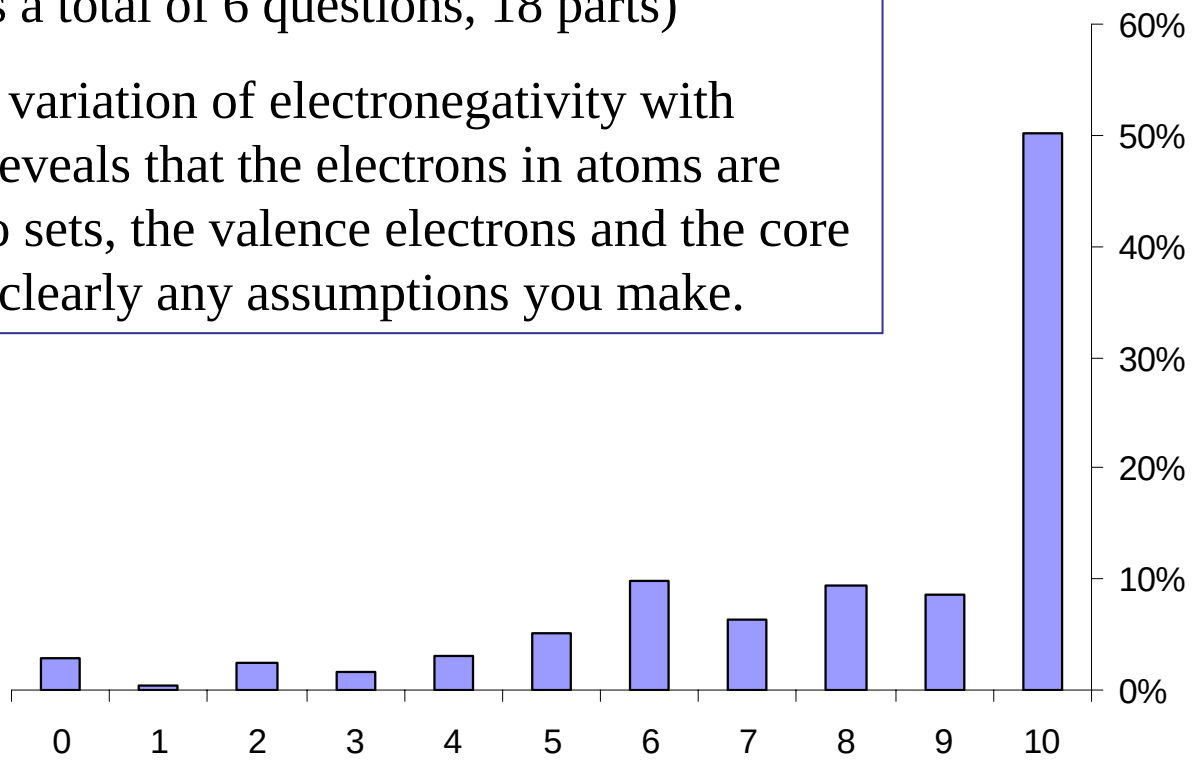
Contribution of “Case Studies in Chemistry” to Success in Learning Chemistry



A Sample Exam Question

Midterm 2, Question 1d:
(the midterm has a total of 6 questions, 18 parts)

Explain how the variation of electronegativity with atomic number reveals that the electrons in atoms are grouped into two sets, the valence electrons and the core electrons. State clearly any assumptions you make.

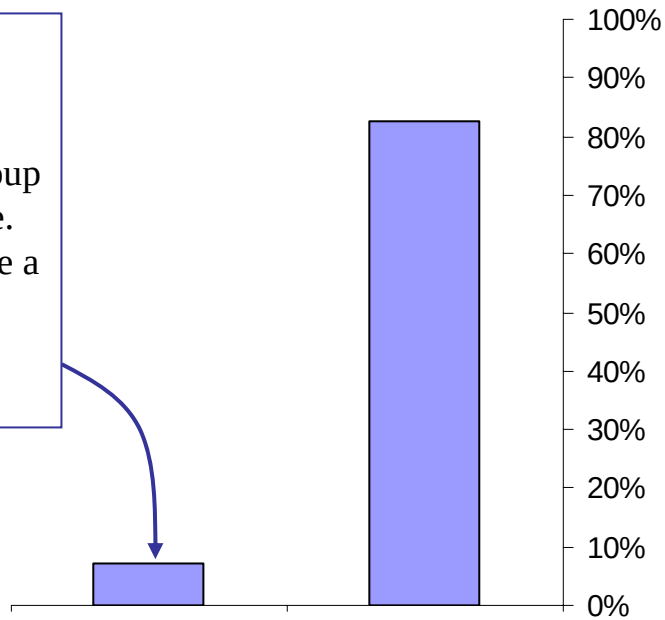


N=253

VSEPR Theory

Pre-instruction:

Nitrogen (a group 5 element) combines with bromine (a group 7 element) to form a molecule. This molecule is likely to have a shape which is best described as: (*3 choices*)
Reason: (*4 choices*)

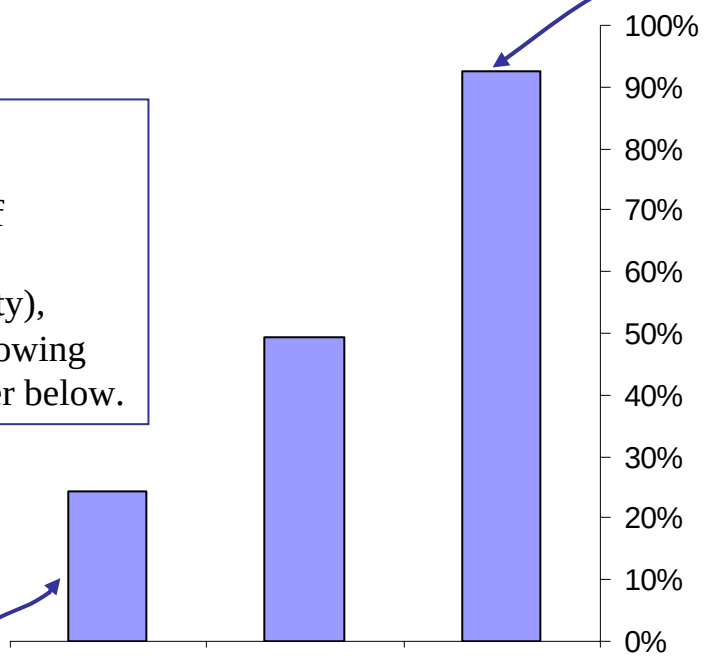


Post-instruction, score 15 of 15:

Assess the accuracy of the following statement and explain your assessment: "In Nitrogen Tribromide (NBr_3), the three N-Br bonds are identical. The three electron pairs in these bonds repel each other equally, resulting in a planar molecule with equal 120° bond angles."

N=214

Calculation of ΔH



Pre-instruction:

Given the following heats of formation (rounded to one significant digit for simplicity), calculate the ΔH for the following reaction and enter the answer below.

Post-instruction, score 5-9 of 9:

Data adjusted to reflect all those who probably (based on point totals) correctly determined the ΔH°

Post-instruction, score 9 of 9:

Using the thermodynamic data given, calculate ΔH°, ΔS°, and ΔG° at 298 K for the reaction below. Predict whether the reaction will be spontaneous at low temperature, at high temperature, at any temperature, or not at any temperature.

N=202

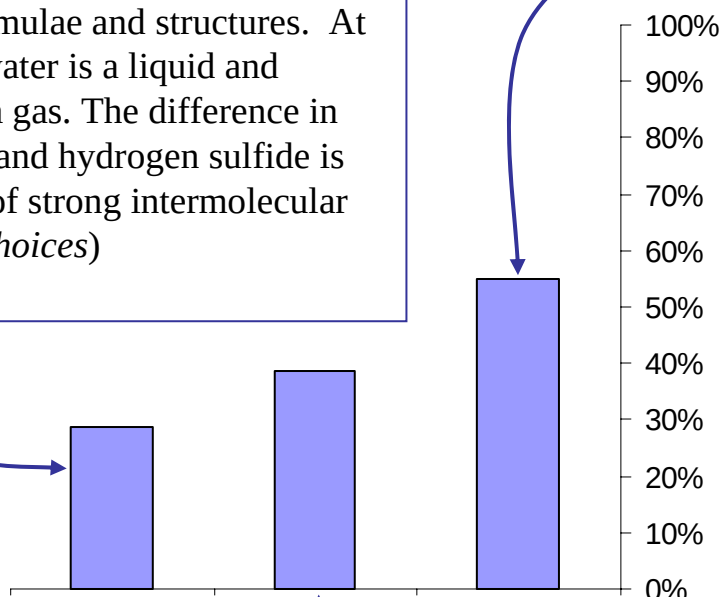
Intermolecular Forces

Pre-instruction:

Water (H_2O) and hydrogen sulfide (H_2S) have similar chemical formulae and structures. At room temperature, water is a liquid and hydrogen sulfide is a gas. The difference in state between water and hydrogen sulfide is due to the presence of strong intermolecular forces between: (*2 choices*)
Reason: (5 *choices*)

Post-instruction, score 8 of 8:

Why is the boiling point of H_2Te (-2.2°C) greater than that of H_2S (-60.7°C) but much less than that of $H_2$2O (100°C)? Explain in terms of the relevant intermolecular forces, including a description of the origin of those forces in your answer.

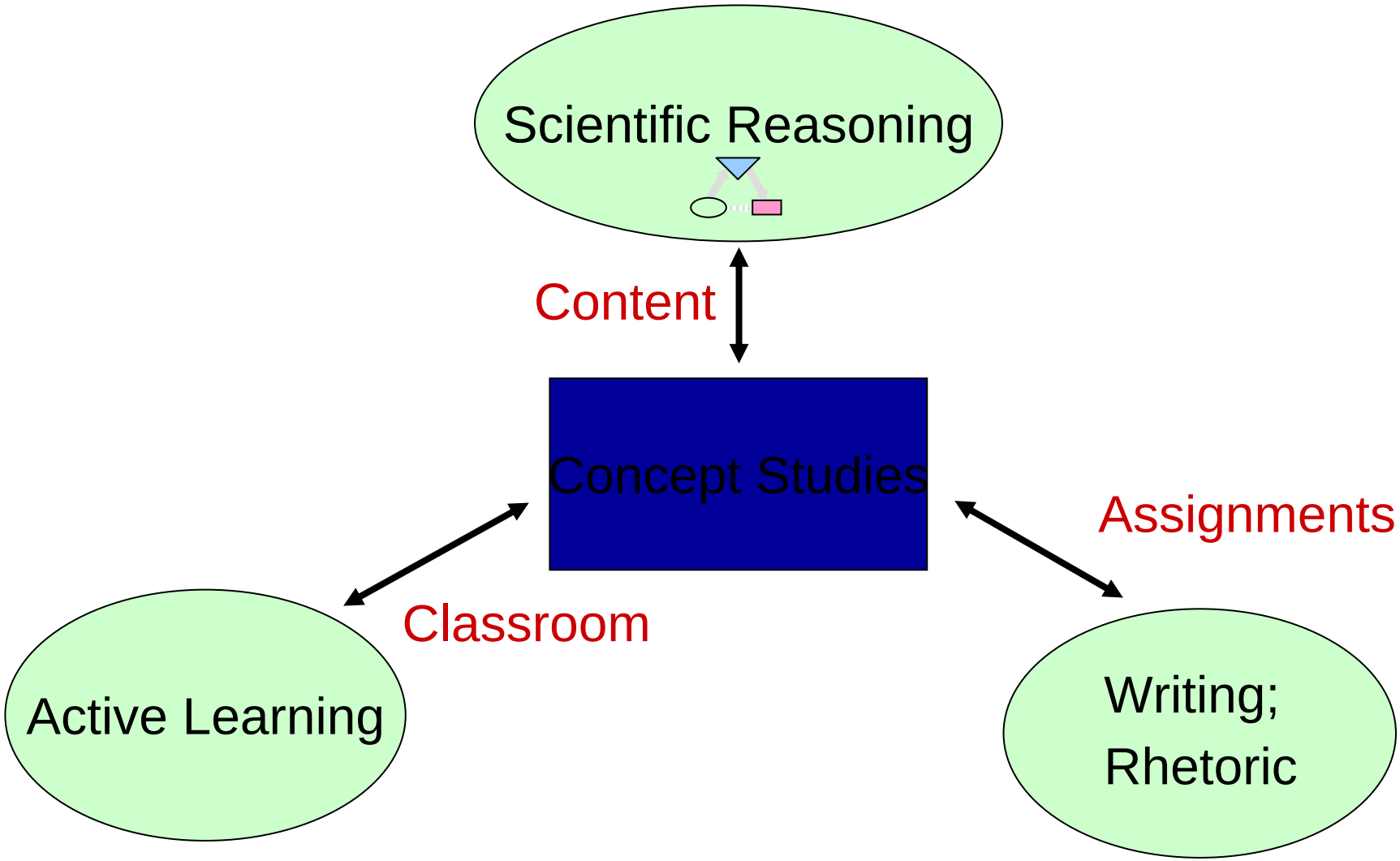


Post-instruction, score 8 of 8:

In each of the following pairs of molecules, determine which has the higher boiling point. Explain your reasoning by identifying all intermolecular forces relevant, stating which interaction type dominates the difference between the two types of molecules, and stating why. H_3CNH_2 H_3CSH

N=202

Putting it Together with *Concept Development Studies*



Conclusions

- Possible to teach inductive reasoning effectively using Concept Development Studies
- Doing so enhances student understanding and problem solving, does not interfere
- Student Response is very positive

more information

- John S. Hutchinson. "Teaching Introductory Chemistry using Concept Development Case Studies: Interactive and Inductive Learning," *University Chemistry Education*, April 2000.
- The *Concept Development Studies in Chemistry* text online: http://chemed.rice.edu/ConceptStudies/

  http://cnx.org/content/col10264/latest/
- More information about our research: http://chemed.rice.edu/IEinCE/default.cfm