# Pathways to Success: Barriers and Catalysts in Chemical Education

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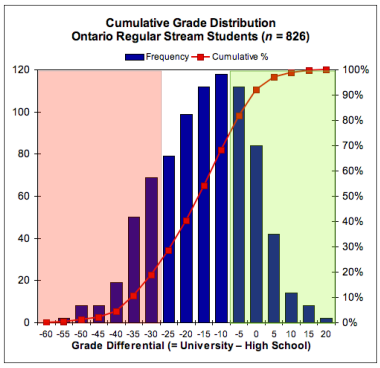
http://www.chem.utoronto.ca/~dstone/Research/survey.html



## The first-year experience:



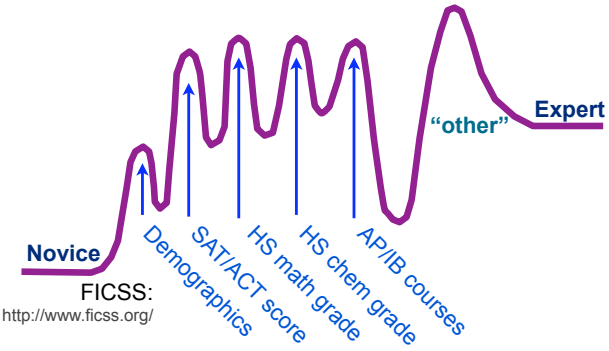

Aggregate student data for 2006–2010 (WD and DNW omitted)

- **Overall**:
  - GD = -17 ± 13
- **Upper quartile:**
  - GD = -9 to +20
- **Lower quartile:**
  - GD = -60 to -30

http://www.chem.utoronto.ca/~dstone/Research/survey.html



## Pathways & barriers to success:




FICSS:
http://www.ficss.org/

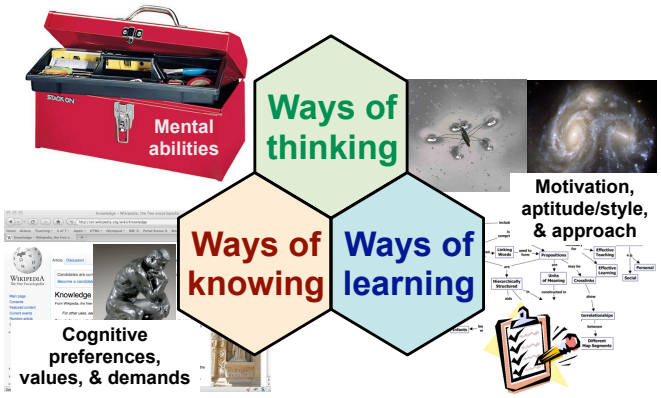


## Explaining the "other":

- Alternative conceptions (misconceptions)
- Intellectual development
- Learning style (approach, aptitude)
- Perceived learning environment
- Problem-solving skills
- Study skills
- Temperament/personality

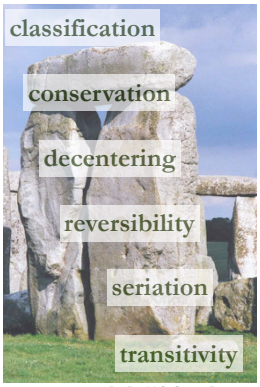


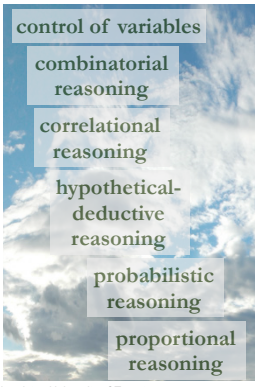
## Framework for discussion:






## Ways of thinking (Piaget):



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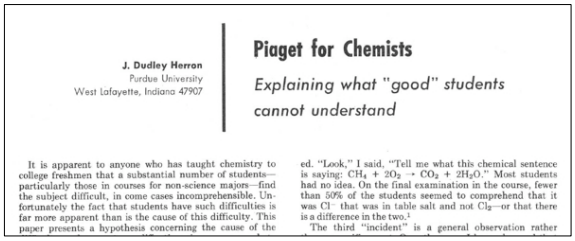

J. Dudley Herron
Purdue University
West Lafayette, Indiana 47907

**Piaget for Chemists**

*Explaining what "good" students cannot understand*

It is apparent to anyone who has taught chemistry to college freshmen that a substantial number of students—particularly those in courses for non-science majors—find the subject difficult, in come cases incomprehensible. Unfortunately the fact that students have such difficulties is far more apparent than is the cause of this difficulty. This paper presents a hypothesis concerning the cause of the

ed. "Look," I said, "Tell me what this chemical sentence is saying: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$." Most students had no idea. On the final examination in the course, fewer than 50% of the students seemed to comprehend that it was $Cl^-$ that was in table salt and not $Cl_2$—or that there is a difference in the two.[1]

The third "incident" is a general observation rather

J. Dudley Herron, J. Chem. Ed., 1975, 52(3), 146-150

HS+ chemistry needs "formal operational development"
Good proportion of 1st-year students "not there yet"



## Rationality (Piaget redux)

- A bat and a ball cost $1.10. The bat costs $1 more than the ball. How much does the ball cost?
  a) 10 cents
  b) 5 cents
  c) other amount

Keith E. Stanovich, *Sci. Amer. Mind*, 2009, Nov/Dec., 34-39



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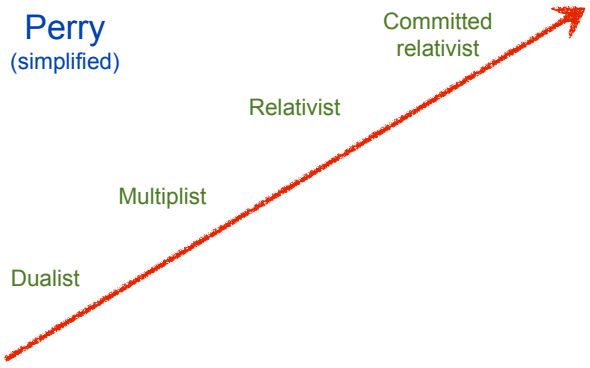
## Ways of knowing:






## Dualism versus relativism:

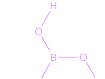
Acid–base theories

Lewis – electron transfer $Cu^{2+}_{aq} + NH_3 \rightleftharpoons [Cu(NH_3)]^+_{aq}$

Brønsted-Lowry – proton transfer (hydrolysis)

Arrhenius – dissociation $HCl_{aq} \longrightarrow H^+_{aq} + Cl^-_{aq}$

$NH_3 + HOH \rightleftharpoons NH_4^+ + OH^-$

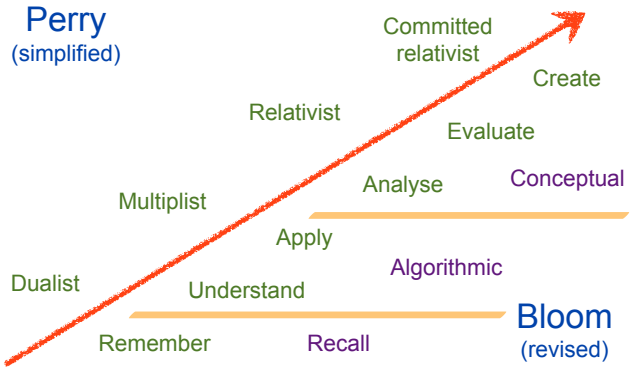

boric acid

Litmus






## Ways of knowing:



## Diagnostic example:

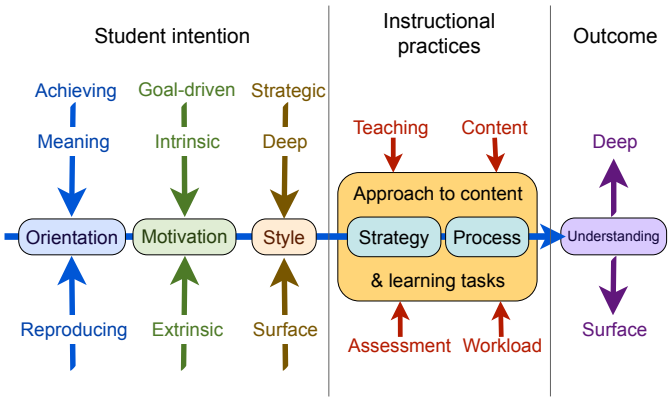
- Individual 0.200 g samples of each of the following gases were placed in four separate 1.00 L stoppered flasks at 298 K. In which flask do you expect the gas to exert more pressure? Explain your answer.

| Flask: | A | B | C | D |
|---|---|---|---|---|
| Gas: | $CH_4$ | Ne | $N_2$ | $CO_2$ |
| $M_m$ (g/mol) | 16 | 20 | 28 | 44 |

Lillian Bird, *J. Chem. Ed.*, 2010, 87(5), 541-546

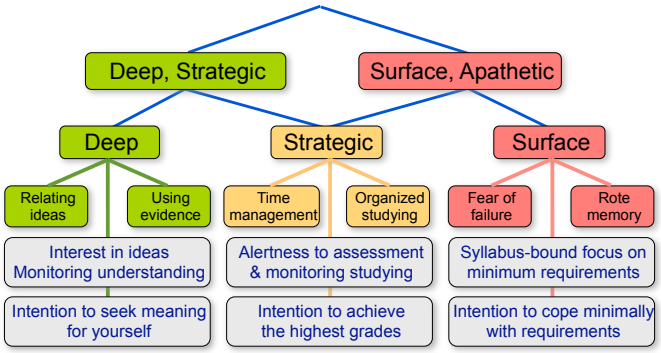


## Ways of learning:






## ASSIST Inventory structure:




http://www.etl.tla.ed.ac.uk/questionnaires/ASSIST.pdf



## ASSIST Main scale correlations

- Pearson's *r* values (*n* = 394):

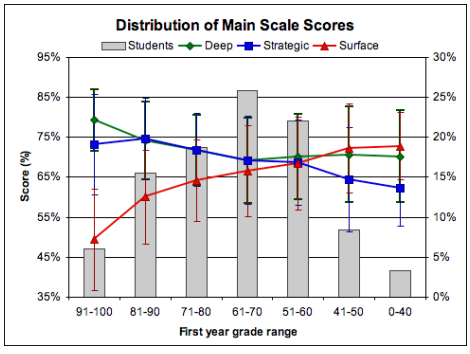
| Scale: | Deep | Strategic | Surface |
|---|---|---|---|
| 1st-year | 0.1960 | 0.2859 | **–0.4060** |
| Deep | | **0.4561** | **–0.3545** |
| Strategic | | | –0.2528 |

All *r* values statistically significant @ 99.99% CL ($p < 10^{-4}$)

$$t = \frac{|r|\sqrt{n-2}}{\sqrt{1-r^2}};\ H_0(r=0)$$



## ASSIST Scores and grades




1st-year chemistry (life sciences) *n* = 394



## ASSIST Deep scale:

- Interest in ideas (II)

*"I sometimes get 'hooked' on academic topics and feel I would like to keep on studying them"*

- Relating ideas (RI)

*"I like to relate ideas I come across to those in other topics or courses"*

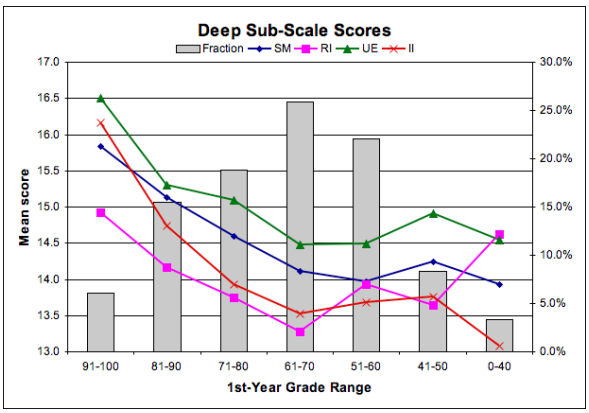
- Seeking meaning (SM)

*"When I'm reading an article or book, I try to find out for myself exactly what the author means"*

- Use of evidence (UE)

*"It's important for me to be able to follow the argument, or to see the reason behind things"*

# ASSIST Deep scale:






# ASSIST Strategic scale

- Achieving orientation (AO)

  *"I put a lot of effort into studying because I'm determined to do well"*

- Alertness to assessment demands (AA)

  *"I keep an eye open for what lecturers seem to think is important..."*

- Monitoring effectiveness (ME)

  *"I think about what I want to get out of this course to keep my studying focussed"*

- Organised studying (OS)

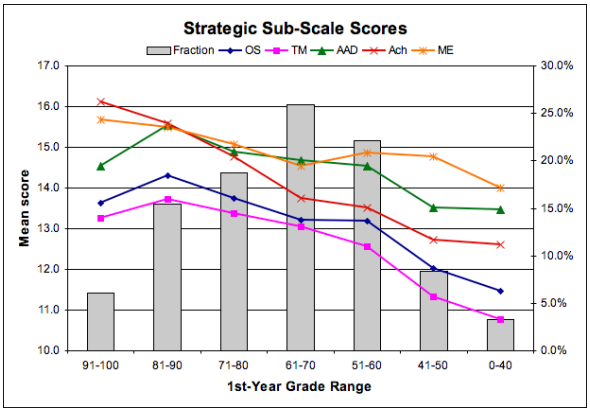
  *"I usually plan out my week's work in advance, either on paper or in my head"*

- Time management (TM)

  *"I'm pretty good at getting down to work whenever I need to"*
  *"I work steadily through the semester, rather than leave it all until the last minute"*



# ASSIST Strategic scale






# ASSIST Surface scale

- Fear of failure (FF)

  *"I often worry about whether I'll ever be able to cope with the work properly"*

- Lack of purpose (LP)

  *"Often I find myself wondering whether the work I am doing here is really worthwhile"*
  *"I'm not really interested in this course, but I have to take it for other reasons"*

- Syllabus boundness (SB)

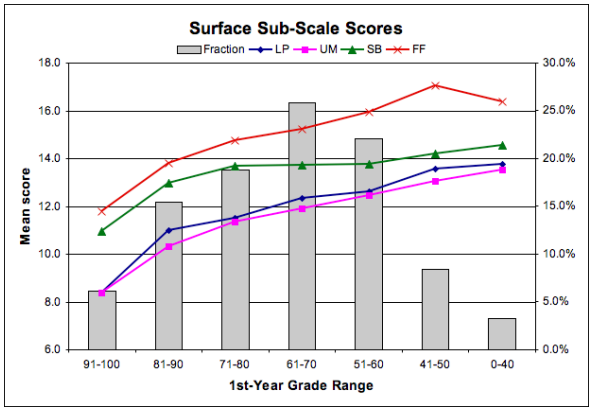
  *"I concentrate my learning just on those bits of information I have to know to pass"*

- Unrelated memorising (UM)

  *"Much of what I'm studying makes little sense: it's like unrelated bits and pieces"*
  *"I'm not really sure what's important in lectures, so I try to get it all down"*



# ASSIST Surface scale






# Learning pathologies

- Improvidence (surface):
  - failure to use valid analogies
  - failure to make connections
- Globe-trotting (deep):
  - use of vacuous analogies (bad connections)
  - misunderstanding of valid analogies

## Alternative conceptions:

- Douglas Mulford & William Robinson:

"If anomalous new information is presented in a learning situation where the student is rewarded (with grades) for remembering it, the information may be memorised in order to earn the reward, but it is likely to be quickly forgotten because it does not make sense"

Mulford & Robinson, *J. Chem. Ed.*, 2002, 79(6), 739-744 (emphasis added)

http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/



## Alternative conceptions:

- Vincente Talanquer:

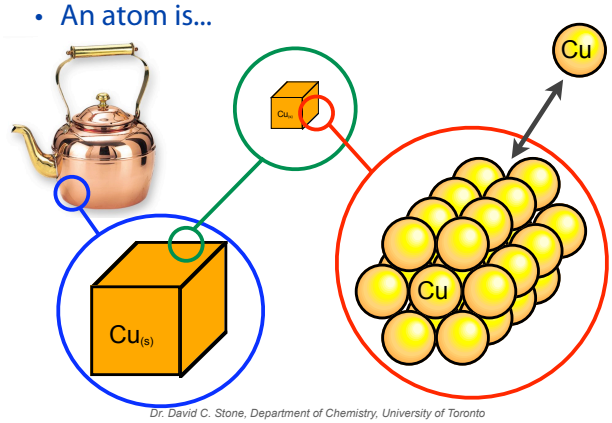
"[alternative conceptions] seem to result from the confident and impulsive application of a crude, incomplete, limited, and superficial explanatory framework about chemical substances and phenomena. This knowledge system ... creates the illusion of explanatory depth: students believe that they understand more than they actually do."

Talanquer, *J. Chem. Ed.*, 2006, 83(5), 811-816 (emphasis added)



## Origin of alternative conceptions

- An atom is...






## Testing alternative conceptions

- A metallic wire has the following properties:
  - a) conducts electricity
  - b) brown colour
  - c) density of 8.93 g/cm$^3$
  - d) malleable & ductile
  - e) expands on heating

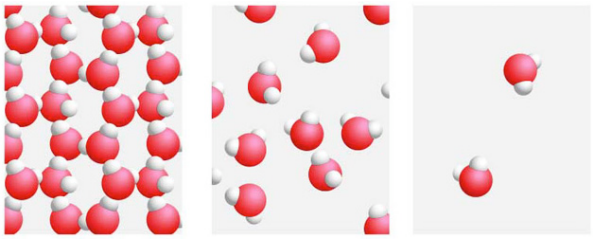
Suppose you could isolate **one** single atom from the metallic wire: which of the above properties would it have?

Adapted from Ben-Zvi, Eylon & Silberstein, *J. Chem. Ed.*, 1986, 63(1), 64-66



## Origin of alternative conceptions

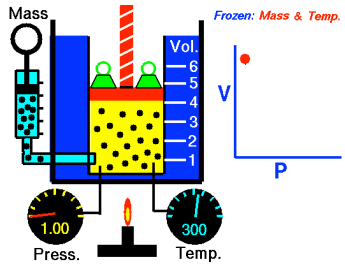
- Textbook representations:





## Theory to practice

- Implications for teaching technology:
  - Animations




http://en.wikipedia.org/wiki/File:Boyles_Law_animated.gif

## Theory to practice

- Implications for technology in teaching:
  - Animations
  - Clickers/quizzes

In SI units, a density of 1.76 g/cm$^3$ is
a) 1.76 $10^{-3}$ g/m$^3$
b) 1.76 $10^{-3}$ kg/m$^3$
c) 1.76 $10^{0}$ g/m$^3$
d) 1.76 $10^{3}$ kg/m$^3$

Recall (33%)
Algorithmic (33%)
Conceptual (33%)

Four identical sealed containers are filled with a different gas as indicated below until each contains exactly the same mass. If all four are held at the same temperature, which flask contains gas at the greatest pressure?

| Flask: | A | B | C | D |
|---|---|---|---|---|
| Gas: | $CH_4$ | Ne | $N_2$ | $CO_2$ |
| $M_w$ (g/mol) | 16 | 20 | 28 | 44 |

http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/



## Theory to practice

- Implications for teaching technology:
  - Animations
  - Clickers/quizzes
  - Pre-labs

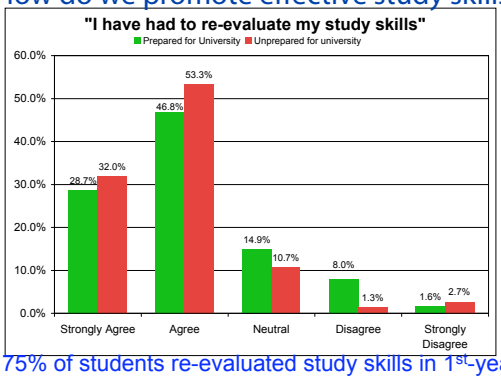
Burewicz & Mrianowicz, "Effectiveness of multimedia laboratory instruction" *Chem. Ed. Research & Practice* **2006**, *7(1)*, 1-12.





## And a final question...

- How do we promote effective study skills?




> 75% of students re-evaluated study skills in 1st-year



## Study skills catch 22:

- High school

  "Not teaching study skills since there is only time for curriculum content"

- University

  "Not teaching study skills since students must have them as they gained admission"

Tait & Entwistle, *Higher Education*, **1996**, *31*, 97-116



## Research teams:

- 2006-7:
  - Robin Baj, Michael Lebenbaum, Sujan Saundarakumaran, Derrick Tam, & Jakub Vodsedalek
- 2007-8:
  - Mena Gewarges, Cindy Hu, Gordon Ng, Jana Pfefferle, and Curtis Wang
- 2008-9:
  - Marlena Colasanto, Lauren Cosolo, Darrin Gao, Inna Genkin, Kelly Hoang, Justina Lee, Bryan Nguyen, and Emily Plobner
- 2010-11:
  - Shirin Dason, Xi Nuo Gao, James Hong, Jing Lu, He Zhen Ren, and Heba Shamsi



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