Why Good Students Fail
STAO 2010 Handout

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Abstract:

Each year, students arrive at U of T from high school with high grades and high expectations. Yet research shows that 25% of students completing their first undergraduate chemistry course see their grades drop by 30 to 60 percentage points from their high school grades! This presentation will discuss some of the factors contributing to this phenomenon uncovered by a recent three-year research study. Specific ways in which high school teachers can help prepare their students for this important academic transition will be presented. This will include a discussion of activities that incorporate necessary learning skills with curriculum content, and approaches to teaching and assessment that encourage the development of "scientific thinking" and problem-solving skills. Particular issues facing ESL/ELL students will also be raised. Although examples will be drawn from chemistry, the recommendations presented are broadly applicable to all physical science subjects.

About this handout:

There are numerous links throughout this handout; these have been added to the web page referenced above for your convenience. I have tried to select reference materials that are freely available as much as possible. Articles in *J. Chem. Ed.* should be accessible on-line to anyone registered full or part-time at an Ontario university through their institution's library. Please feel free to contact me with any questions or requests for additional information.

Note: This is an expanded and annotated version of the original handout, including some material that did not make it into the presentation due to time constraints.

Introduction & Background:

The presentation started with a brief summary of the chemical education research project data presented at previous STAO conferences and from a similar US study (see references 1-3). In essence, although some of a student's first-year chemistry grade is correlated with factors such as their high school math and science grades, SAT scores (in the US), level of their science & math courses, and basic demographic factors, some 60% of the variation in results between students remains unexplained from the primary surveys.

Some clues, however, lie in what students have to say about their study skills. For example, students who strongly felt that high school emphasized memorisation over understanding on average scored 10 percentage points lower in 1st-year chemistry than those who felt strongly that high school emphasized understanding. The former also had on average a 10-percentage point greater decrease relative to their high school grade than the latter. Yet both groups had the same average high school grade! Students who described using a course text, regularly completing homework, and managed their time effectively had better high school grades on average than those who did not, yet both groups had the same average 1st-year chemistry grades.

Most telling, students who felt that high school had prepared them well for university where just as likely to state that they had been forced to re-evaluate their study skills as those who felt that high school had left them unprepared. This emphasis on study skills has also been reported by the College Mathematics Project (see the reports on the page at link 3), and is supported by a considerable body of research into student approaches to learning and studying.

Teachers, students, and parents are be advised to pay more attention to "study skills" section of the Ontario report card than to specific course grades, as the development of *effective and appropriate* study skills and work habits is essential for success in any post-secondary education environment.

Specific areas of relevance to students intending to pursue a program that requires 1st-year undergraduate chemistry and/or physics include:

- Taking good lecture notes
  - Students should take notes, *not* dictation or transcription!
  - Note-taking helps to maintain concentration, and provides a first mental "pass" through the material
  - Note-taking is helped by *reading ahead*
  - Notes should be reviewed and elaborated soon after the lecture; summarising these notes is helpful when preparing for exams
- Using text books and other resources
  - Reading for comprehension (as opposed to simply reading or scanning) is key
  - Only underline or highlight the absolutely key words and phrases – don't end up highlighting the entire page (no text book author is *that* good!)
  - ELL/ESL students should read ahead and compile a glossary of key terms – especially when words have different meanings to their everyday ones
- Effective study and review habits

    - Although students who do a 4-hour “cram” session the night before an exam may do as well as those who did 4-hours spread out over several weeks, the latter have much better long-term recall of what they studied
    - “Little and often” is key, especially since the pace and amount of material at university is much greater; those who fall behind, stay behind.
- Effective use of time
    - Students should track how much time they spend actually studying (and what they do during that time) rather than trying to plan everything out beforehand; students often severely over-estimate.
    - Students should pay attention to deadlines, especially across different courses – these often coincide!
- Develop problem-solving skills

Including Note-taking in a Science Course:

Note–taking is an important **COMMUNICATION** skill. Normally, we all tend to think of communication assessments as being student presentations, but the *other* direction of communication is an equally important skill! How can this be done without sacrificing content, though?

An increasing number of university faculty are recording their lectures and posting them on-line, either through their institution’s web site, YouTube, or iTunes. In fact, there is a section of iTunes called iTunesU where you can freely access lectures on a variety of topics, including first-year chemistry.

Since this overlaps considerably with the high school curriculum, you could identify one of these lectures and assign it as homework: have students watch and take notes on the lecture, then submit their notes. You can evaluate these simply on accuracy and whether they include the key points. You can follow this up by having them elaborate on the notes from the text (or other sources), and follow up with a content test. This allows you to cover content while evaluating both **communication** and **inquiry** skills, and teach valuable study habits at the same time!

Why is Chemistry ‘Hard’?

One source of considerable variation in ability between students is in their learning style and ability to engage in higher-order thinking. By “learning style” I do **not** mean VAK or ‘hemispherical dominance’ (see references 4 and 5, and chapter 2 [available on-line] of book 1). Instead, we can categorize a student’s learning style in terms of whether it is ‘deep’, ‘strategic’, or ‘surface’. We can also use Piaget’s classification (refs. 6-8), particularly the concrete and formal operational levels of intellectual development. Many studies have shown that a significant proportion of grade 11 through 1st-year post-secondary students have *not* made the transition from concrete to formal thinking, yet an analysis of the typical high school chemistry curriculum for the same students demonstrates a significant degree of formal operational thinking skills are required. Since these include proportional reasoning and abstract thinking, it becomes obvious why some students struggle to master stoichiometry and mole calculations – a problem that persists into 2nd-year in some cases!

Using Questions as Diagnostics:

The following were all written for a self-assessment test issued at the beginning of a 2nd-year course in analytical chemistry, taken by a mixture of 2nd-4th year students in both chemistry and life science programs who had all taken the introductory general and organic chemistry 1st-year courses. Distractor items were based on common errors so that immediate feedback based on individual student answers could be provided. Personally, I avoid doing this on summative tests and final exams, but find it very helpful for formative assessment!

1. When correctly expressed in SI units, a density of 1.23 g/cm^3 is:
   a. 1.23×10^{-3} g/m^3
   b. 1.23×10^{-3} kg/m^3
   c. 1.23 g/m^3
   d. 1.23×10^{3} kg/m^3

Note: only 62% of students got this right. The most common incorrect answer (b) arises from confusing the conversion factors for $cm^3 \rightarrow m^3$ and $m^3 \rightarrow cm^3$

2. Consider the following balanced chemical reaction:
   $$2\ MnO_4^- + 16\ H^+ + 15\ I^- \rightarrow 2\ Mn^{2+} + 5\ I_3^- + 8\ H_2O$$
   What volume of 0.0525 M iodide would be required to exactly react with 20.0 ml of 0.0125 M permanganate?
   a. 0.63 ml ← *inverted stoichiometric coefficients*
   b. 4.76 ml ← *omitted stoichiometric coefficients*
   c. 35.7 ml
   d. 84.0 ml ← *inverted concentration values*

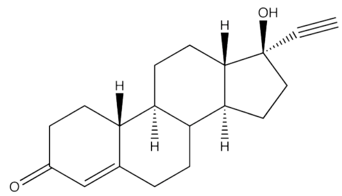
Note: 72% got this correct but 19% chose (b)

3. A solution of known iodine concentration may be prepared by mixing solutions of iodate and iodide under acidic conditions:
   $$a\ IO_3^- + b\ I^- + c\ H^+ \rightarrow p\ I_2 + q\ H_2O$$
   When correctly balanced, the stoichiometric coefficients in this reaction equation are:
   a. $a = 1, b = 1, c = 6, p = 1, q = 3$ ← *balanced elements only*
   b. $a = 1, b = 5, c = 6, p = 3, q = 3$
   c. $a = 3, b = 3, c = 6, p = 3, q = 3$ ← *balanced charge only*
   d. $a = 5, b = 1, c = 6, p = 1, q = 5$

Note: 52% chose (a), while 7% chose (c).

4. *Fill in the blanks:* Considering all the atoms in its the structure of norethindrone *except* H, there are [ ] sp^3, [ ] sp^2, and [ ] *sp* hybridized atoms.

[15, 4, & 2, respectively]



norethindrone

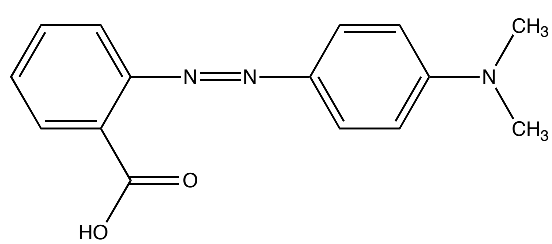
The above yielded a wide range of answers! In some cases, the omitted H atoms on the rings were not included, resulting in too high a count of sp^2 atoms.

The following is a slightly different style of question that can be presented in two ways to check conceptual understanding.

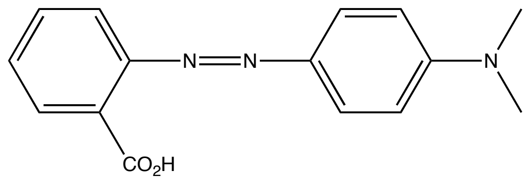
5. The compound methyl red is a common acid-base indicator, and has the structure shown below. Which *one or more* of the following groups can be found in methyl red?

	Group	Number	***Comments for marker***	*%s.*
T	methyl	2	methyl groups on tertiary amine N	61.0
	ethyl	0		0.0
	alkenyl	0	C=C bonds in benzene rings are not alkenes!	24.4
T	carboxyl	1	left-hand ring is benzoic acid derivative	87.8
T	amino	1	3° amine substituent on right-hand ring	58.5
	amido	0	requires a carbonyl with N	24.4
T	aryl	2	aromatic rings	80.5
	aldehyde	0		9.8
	alcohol	0	the carboxylic acid OH is *not* also an alcohol!	9.8
T	azo	1	–N=N– between the rings	70.7

Option 1: Using this structural representation, have students circle the relevant groups and either list them or check them of in the table



Option 2: Using this structural representation, have students indicate in the table how many of each group are present



Note: students seem to be confused about the concept of "group": depending on the way the question is asked, for example, they may end up counting the carboxylic acid three times – as a carbonyl, a carboxylic acid, and a hydroxyl (alcohol). The omitted H atoms on the tertiaary amine's methyl groups also tripped up some students.

6. Look again at the structure of methyl red from the previous question. How many of the atoms within this molecule have lone pairs of electrons?
   (a) 2 (4.9%) (b) 3 (17.1%) (c) 4 (7.3%) **(d) 5** (70.7%)

Note: Again, the way specific groups are drawn trips up some students, who missed lone pairs. A better way to ask this question would be to have the students draw in the lone pairs!

Problem solving group activity:

- Get into groups of about 5 or 6, and have one person volunteer to act as an observer. Turn to one of the following problems and solve it as a group.

- The observer should take notes on how the group goes about solving the problem, any difficulties they encounter, and how they resolve them.

  Note: if the problem is one you have seen before, volunteer to be the observer!

The Waterfall Problem

The Horseshoe Falls are 49 m high. Assuming that all the potential energy of the water is converted into heat, how much warmer is the water at the bottom of the falls than at the top? Comment on the magnitude of your answer. The flow of water over the falls is reduced at night as more is diverted through the hydroelectric generating station. What affect will this have? Give reasons for your answers.

Relevant Data:

Potential energy $E_p = mgh$ where m is mass (kg), g = 9.81 m s^{-2}, and h is height (m); the specific heat capacity of water s = 4.179 J/(g °C).

Solution:

First, we need to know how much energy is available to be converted into heat. This is the potential energy associated with the water being at the top of falls. Since we don't know how much water is going over the falls, the simplest approach is to calculate for unit mass:

$$E_p = mgh = 1 \times 9.81 \times 49 \text{ kg} \cdot \text{m s}^{-2} \cdot \text{m} = 481 \text{ kg m}^2 \text{ s}^{-2} \text{ or } 481 \text{ J}$$

Next, we need to convert this to a change in temperature. Remember that *changes in state* are always (final – initial), so $\Delta T = (T_{final} - T_{initial})$. We assume that all the potential energy is converted into heat, so that:

$$E_p = q = sm\Delta T \therefore \Delta T = \frac{E_p}{sm} = \frac{481}{4.179 \times 1 \times 10^3} \quad \frac{\text{J}}{\text{J g}^{-1}\ {}^{\circ}\text{C}^{-1} \cdot \text{kg} \cdot \text{g kg}^{-1}} = \mathbf{0.12\ {}^{\circ}C}$$

This is a small but reasonable value, given the assumptions made. When the flow of water is reduced overnight, the potential energy of each kilogram of water at the top of the falls is still the same, so the warming will be the same. Heat transfer to the surroundings will obviously be different at night, but we did not consider that in our initial calculation either.

Comments:

Some students don't even know where to start this problem, as they are unused to connecting concepts from different parts of the course (let along different courses!) Many make a common mistake with units and predict an extremely large temperature difference that is in excess of water's normal boiling point. Of these, some state that it "looks wrong" but many don't comment at all.

In discussing this question, point out that students need to identify the core concepts first, rather than simply 'plugging and playing' with the first equation that seems relevant. It is also very helpful to emphasize unit analysis for physical chemistry problems such as this, as errors can often be caught here. When presenting the solution, be sure to state the *thought process* at each step before the actual calculation! Finally, since the height is only given to 2 s.f., the final answer can only be stated to 2 significant figures.

The Pizza Problem

We all know that if you try and eat pizza too soon after it comes out of the oven you can burn your mouth. Is this because of the crust, the cheese, or the tomato sauce? Use your knowledge of the different phases of matter, molecular-kinetic theory, and thermochemistry to justify your answer.

Some relevant data:

- Assume that a 50 g slice of pizza consists of 25 g crust, 20 g cheese, and 5 g of sauce. Approximate values of the specific heat capacity are: Cheese = 3.0 J/(g °C); Crust = 2.0 J/(g °C); Sauce = 4.0 J/(g °C). The heat capacity of water = 4.2 J/(g °C).
- Pizza is cooked at ~ 450 °F (230 °C). Assume that, by the time it reaches your table, the pizza has reached a uniform temperature of about 150 °C. The soft tissue on the inside of your mouth (which has a very high water content) is 37 °C. Cheese melts at around 40 °C. The latent heat of fusion of milk fat ΔH_{fus} = 84 kJ/kg.

There are, in fact, two factors involved: the heat capacity (how much energy is stored in the materials and is available to be transferred to your cheek), and the thermal conductivity (how rapidly the heat energy can be transferred.) Since the heat energy is stored as random molecular kinetic motion, these are related. The key difference between crust, cheese, and sauce is the *water content*, which will generally tend to dominate the heat capacity. In other words, the higher the water content, the greater amount of heat that can be stored for the same rise in temperature. This is enhanced when a phase change (*i.e.* the cheese melting) occurs, since the energy added or lost during the phase change does *not* change the temperature!

Solution:

Calculate the heat energy available in each ingredient that can be transferred to your cheek. You can either (a) assume an initial starting temperature (either 21 or 25°C would be reasonable) to compare the total amount of energy stored by the time the pizza is a uniform 150 °C, or (b) simply look at how much heat energy can be transferred *i.e.* ΔT = (150 – 37) = 113 °C.

Since the temperature of the pizza is above the cheese melting point and that of your cheek below, include the amount of energy required to melt the cheese, *i.e.*:

$$q_{cheese} = q_{heat} + q_{melt} = sm\Delta T + (84 \times 20)$$

Note that units of kJ/kg are the same as J/g, so the conversion factors cancel! Ultimately, the most liquid component will transfer its heat the fastest, as this is accomplished by molecular collisions (refer back to molecular kinetic theory), so it is in fact the sauce that burns first, even though there is less of it. Having said that, the cheese will likely cause greater burning if you keep it in contact with your lip, tongue or cheek too long. So always have pop with your pizza!

The Water and Wine Problem

***Note**: this problem was originally proposed by a philosopher, in which the question and proof involved discussion of the **purity** of the water in the wine and vice versa. Dudley Herron changed this to amount when he presented it (see ref. 8 and book 3). I've used volume here, although this perhaps helps prevent students from slipping into the most common mistake, which is to assume that we have to calculate concentrations. You may want to try both wordings!*

You have a glass of water and a glass of wine. Assume that both are pure, homogeneous substances. (If it helps, consider the wine to be pure ethanol!)

1. Transfer exactly one teaspoon from the glass of water to the glass of wine and mix thoroughly.
2. Transfer exactly one teaspoon of this contaminated wine to the glass of water and mix thoroughly.

Consider the amount of water in the glass of wine, and the amount of wine in the glass of water: Which of the following statements is *true*?

a) The volume of water in the wine is greater than the volume of wine in the water
b) The volume of wine in the water is greater than the volume of water in the wine
c) The volume of water in the wine is equal to the volume of wine in the water

Solution:

Most people – including university faculty members – get this wrong, and many still don't believe the answer after seeing the proof until they've worked it for themselves. So this really is a challenging problem, and I'd save it for your most advanced (or most self-assured!) students. I would also note that I found the proof, as originally presented, extremely hard to follow and therefore difficult to accept. Here goes...

(i) Start with two containers, (1) and (2), containing pure A (water) and pure B (wine), so that:

$$V_1 = V_A^\circ \text{ and } V_2 = V_B^\circ$$

(ii) Let the volume transferred from A to B in the first step be $V_{1,2}$. We now have:

$$V_1' = V_A^\circ - V_{1,2} \text{ and } V_2' = V_B^\circ + V_{1,2}$$

(iii) The volume transferred from (2) back into (1) contains a small fraction of A (ΔV_A) from $V_{1,2}$. Both glasses now have their original liquid volumes; neither contains pure A or pure B:

$$V_1'' = V_A^\circ - V_{1,2} + V_{2,1} \text{ and } V_2'' = V_B^\circ + V_{1,2} - V_{2,1}$$

(iv) How much A is now in B in glass (2)? $V_{A,B} = V_{1,2} - \Delta V_A \therefore\ V_{1,2} = V_{A,B} + \Delta V_A$

How much B is now in A in glass (1)? $V_{B,A} = V_{2,1} - \Delta V_A \therefore\ V_{2,1} = V_{B,A} + \Delta V_A$

(v) But $V_{1,2} = V_{2,1}$ therefore equating and rearranging from (iv) gives:

$$\mathrm{V_{A,B} + \Delta V_A = V_{B,A} + \Delta V_A \ \therefore\ V_{A,B} = V_{B,A}} \quad \textbf{(Q.E.D)}$$

Problem Solving, Threshold Concepts and Troublesome Knowledge:

The preceding questions hopefully illustrated some of the problems students can run into with conceptual problems. One way to tackle this is to assign them as small group activities within the class; circulate to make sure students are on task and on track, and ask questions to prompt reconsideration of their underlying assumptions and process if they get stuck. Grappling with such problems plays an important role in helping students transition from concrete to formal operational thinking, as this is not (unlike either Piagetian stages) an automatic development. More information about problem–solving can be found in the article by George Bodner (ref. 12; see also book 4).

Related issues are threshold concepts (a term pioneered by Meyer and Land, ref. 10 and book 2) and troublesome knowledge (coined by David Perkins, ref. 11 and book 2). Threshold concepts are defined as "akin to a portal, opening up a new and previously inaccessible way of thinking ... *without which the learner cannot progress*" (emphasis added). There are many such concepts in the high school chemistry curriculum, including the mole, atoms, bonding, particle theory, *etc.*

The different forms of troublesome knowledge include naive or alternate conceptions (sometimes also called misconceptions). These are concepts arrived at by the student that *make sense to them*, but which are either incomplete, contain faulty assumptions, or are just flat out wrong. Not only do they hinder understanding and mastery of higher concepts, they are also incredibly stubborn and difficult to change. Considerable efforts have been made to catalogue these alternate conceptions in chemistry (and physics – see the Force Concept Inventory) and to understand how students come to develop them in the first place (refs. 13-16, book 5). It turns out that, to some extent, our use of models and analogies in teaching early chemistry may partly be to blame for the confusion! The *way* we ask questions, and *how* we ask students to answer them, can provide insights into where students are and provide challenges to help them redefine their conceptions.

Conceptual Problem – Gas Laws

This question is an example of conceptual vs. algorithmic ("algebraic") problem solving, and can be asked in one of two ways. Source: Lillian Bird, *J. Chem. Ed.*, **2010**, *87(5)*, 541-546.

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.

Concept text example: 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 in flask:	CH_4	Ne	N_2	CO_2
M_m **(g/mol)**	16.0	20.2	28.0	44.0

Note that it is entirely possible to answer the question by noting that *T*, *V*, and mass *m* are constant, under which circumstances the gas with the lowest molar mass *must* result in the highest pressure. Many students do not approach the problem this way, however, but start by calculating *n* and *P*. Some realise the key after the first calculation, but others relentlessly plug away until they have performed calculations for all four gases (adherence to memorized procedure = concrete operational thinking!)

For more examples, see the J. Chem. Ed. Question Bank (Link 6), particularly the conceptual questions, challenge problems, and the Chemical Concepts Inventories. Many of these can be used for small group discussion/problem-solving sessions to encourage active peer learning (!)

References:

1. David C. Stone, *Collected Essays on Learning and Teaching*, **2010**, *3*, 133-139. A more detailed account of the chemical education research project from which this presentation is partly derived. http://apps.medialab.uwindsor.ca/ctl/CELT/celtvol-3.html
2. R. H. Tai, P. M. Sadler and J. F. Loehr, *Journal of Research in Science Teaching*, **2005**, *42(9)*, 987-1012. The primary article on the chemistry component of the US *FICSS* research study. http://www.cfa.harvard.edu/smg/ficss/research/articles/Tai_Sadler.pdf
3. R. H. Tai and P. M. Sadler, *Journal of Chemical Education*, **2007**, *84(6)*, 1040-1046. Analysis of the data from the US *FICSS* study relevant to teaching practices. http://www.cfa.harvard.edu/smg/ficss/research/articles/JCE_Instruction_Prac.pdf
4. Frank Coffield, David Moseley, Elaine Hall and Kathryn Eccleston, "Learning Styles and Pedagogy in Post-16 Learning: A Systematic and Critical Review", *Learning & Skills Research Centre*, **2004**. Anyone interested in learning styles should read this review first! https://crm.lsnlearning.org.uk/user/order.aspx?code=041543
5. Frank Coffield, David Moseley, Elaine Hall and Kathryn Eccleston, "Should we be using learning styles? What research has to say to practice" *Learning & Skills Research Centre*, **2004**. A companion piece to the review article listed above. https://crm.lsnlearning.org.uk/user/order.aspx?code=041540
6. J. Dudley Herron, "Piaget for Chemists: Explaining what 'good' students cannot understand." *J. Chem. Ed.*, **1975**, *52(3)*, 146-150. This review discusses implications of Piaget's concrete versus formal operational development as it applies to the way we teach introductory chemistry, and students' ability to learn, understand, and perform on assessment tasks accordingly.
7. J. Dudley Herron, "Piaget in the classroom: Guidelines for applications." *J. Chem. Ed.*, **1978**, *55(3)*, 165-170. This paper is a follow-up to the author's widely cited article, "Piaget for Chemists" (*J. Chem. Ed.* 1975). In it he responds to many questions received by the author, and provides numerous examples to clarify what is meant by concrete and formal operational development within a chemistry context. Perhaps most importantly, the author argues for research on the order and manner in which topics are taught, so as to improve outcomes for all students regardless of their developmental level at the beginning of a course in chemistry.

8. J. Dudley Herron and Susan C. Nurrenbern, "Chemical education research: Improving chemistry learning." *J. Chem. Ed.*, **1999**, *76(10)*, 1354-1361. This review describes changes in chemical education research over about 50 years. The shift from behaviourist to constructivist theory is described, along with the corresponding changes in research methodology. Amongst the general findings described is the important area of naive conceptions or misconceptions, the use of cooperative learning, and the evaluation of laboratory experiments, animations, and virtual labs.
9. Keith E. Stanovich, "Rational and Irrational Thought: The Thinking that IQ Tests Miss", *Scientific American Mind*, **2009**, Nov/Dec. issue, 34-39. http://www.scientificamerican.com/sciammind/?contents=2009-11
10. Jan Meyer and Ray Land, "Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines", *ETL Occasional Report Number 4*, **2003**. This paper provides a useful introduction to the ideas of threshold concepts and troublesome knowledge in education. It provides numerous examples from various disciplines that illustrate what these are and how they can affect student learning. The work is from the "Enhancing teaching-learning environments in undergraduate courses" project of the Teaching and Learning Research Program (TLRP) in the UK. http://www.tlrp.org/dspace/handle/123456789/177
11. David Perkins, "The Many Faces of Constructivism", *Educational Leadership*, **1999**, *57(3)*, 6-11. This paper first introduced the concept of different forms of "troublesome knowledge", and is included in expanded form in the book edited by Meyer and Land referenced above. It can also be found on-line: http://www.scribd.com/doc/32920521/Perkins-The-Many-Faces-of-Constructivism
12. George M. Bodner, "Problem solving: the difference between what we do and what we tell students to do", *University Chemical Education*, **2005**, *7(2)*, 37-45. This article is contained in http://www.rsc.org/Publishing/Journals/RP/issues/2003Issue2/index.asp
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14. Douglas R. Mulford and William R. Robinson, "An inventory for alternate conceptions among first-semester general chemistry students." *J. Chem. Ed.*, **2002**, *79(6)*, 739-744. See also link 6 below.
15. Keith S. Taber, "Mediating mental models of metals: Acknowledging the priority of the learner's prior learning." *Science Education*, **2003**, *87(5)*, 732-758. See also book 5 below.
16. Vincente Talanquer, "Commonsense chemistry: A model for understanding students' alternative conceptions." *J. Chem. Ed.*, **2006**, *83(5)*, 811-816.

Books:

1. Paul Howard-Jones, *Introducing Neuroeducational Research: Neuroscience, education and the brain from contexts to practice*. Routledge/Taylor & Francis Group, 2010. You

might be surprised at the list of educational concepts and practices you think have a basis in neuroscience that actually don't! Chapter 2, titled "Neuromyths", is available on-line at http://www.bristol.ac.uk/education/people/academicStaff/edpahj/neuromyths.pdf

2. Jan H. F. Meyer and Ray Land (eds.), *Overcoming Barriers to Student Understanding: Threshold concepts and troublesome knowledge*, Routledge/Taylor & Francis Group, 2006. This book brings together many of the original papers on this subject together in one volume.
3. J. Dudley Herron, *The Chemistry Classroom: Formulas for Successful Teaching*, American Chemical Society, Washington DC, 1996. This book includes much useful material, including a chapter on "Scientific Reasoning", which includes a full explanation of the 'Water & Wine' problem. The latter is also covered in reference 8 above.
4. J.K. Gilbert (Ed.), *Problem Solving in Chemistry, in Chemical Education: Research-Based Practice*, Kluwer Academic Publishers, 2002. A detailed look at many aspects of chemistry teaching at both the secondary and post-secondary levels from a research perspective. Chapters 9-15 are of particular relevance for high school teachers and 1st-year instructors. Includes chapters by many of the authors cited in this handout.
5. K. Taber, *Chemical misconceptions – prevention, diagnosis and cure, Volume 1* and *Volume 2*, London: Royal Society of Chemistry, 2002. These books are based on extensive research and trialled in both middle and high schools in the UK. Between them, they address students' alternate (or naive) conceptions, misconceptions, and teaching strategies to deal with these. (Available from Springer in North America?)

Links:

1. FICSS Study Published Articles: pdf copies of the articles from the US *Factors Influencing College Science Success study*.
http://www.cfa.harvard.edu/smg/ficss/research/publication.html
2. FICSS Study main web site: includes an interesting video quiz on science teaching practices. http://www.ficss.org/
3. CMP Publications: final reports from each year of the *College Mathematics Project*. The statistical parts can be a little dense, but the discussion of the town hall meetings that were part of the project provides very useful insights.
http://collegemathproject.senecac.on.ca/cmp/publications.php
4. Chem13 News: published nine times a year, this magazine for high school chemistry teachers contains useful tips, activities, and information.
http://www.chem13news.uwaterloo.ca/
5. "The Invisible Ingredient in Every Kitchen": article by Harold McGee in the New York Times on heat (!) http://www.nytimes.com/2008/01/02/dining/02curi.html?_r=2
6. Journal of Chemical Education Question Bank: This site includes many concept-based questions that can be incorporated into lessons or used in both formative and summative assessments. The *Chemical Concepts Inventory* questions may also be useful for teachers in higher grades to evaluate students' alternate or naive conceptions.
http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/index.html

Professional Development Teacher Survey:

A group of faculty members at the University of Toronto is currently considering holding a half or one day mini-conference for high school chemistry teachers. We would greatly appreciate it if you would take a few moments to complete this short questionnaire!

Would you be interested in attending a short (half- or one-day) mini conference for chemistry teachers, if it were within reasonable travelling distance?

NO YES If yes, how far is "reasonable"?

When do you think would be the best time to hold such an event for area high school teachers?

__ Weekday during the school term

__ Weekend during the school term

__ During the summer

__ At the end of the school year

__ Anytime during March break

__ Other:

Please rank the following topics for potential interest, and add any you think we should consider but are missing from the list:

__ Biological chemistry

__ Environmental chemistry

__ Green chemistry

__ Nanoscience and chemistry

__ Naming organic compounds

__ Organic reactions

__ Thermochemistry

__ Atomic theory

__ Lab safety and experiments

__ Alternate & Threshold concepts

__ Study skills for chemistry

__ Problem solving in chemistry

__ Stereochemistry

__ Electrochemistry

__ Reaction Kinetics

__ Chemical bonds & properties

Please return to Dr. David C. Stone, 80 St. George Street, Toronto ON, M5S 3H6