Chemical Education: An Annotated Reference List

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Teaching, Learning and Knowledge:

1. 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.
2. D. W. Beistel, "A Piagetian approach to general chemistry." *J. Chem. Ed.*, **1975**, *52(3)*, 151-152. This paper discusses the development level of incoming undergraduate students in terms of their Piagetian developmental level, and the implications this has for the list and order of topics appropriate for an introductory chemistry course. The struggles some students have are identified by the author in these terms: "... stage 2 children are found in abundance at the freshman level in college. Those students have crossed the thresholds of high school science and mathematics without learning to conceptualize and theorize, the skills of a formal operational child."
3. J. Dudley Herron, Luis L. Cantu, Richard Ward and Venu Srinivasan, "Problems associated with concept analysis." *Science Education*, **1977**, *61(2)*, 185-199. "Concept analysis is a formal procedure for examining concepts to determine how they might be taught." Numerous examples of relevance to chemistry are included in appendices, including analyses of the concepts of "element", "atom", and "mole"; these serve to illustrate problems encountered in concept analysis since some of them are identified as flawed (for reasons explained in the text.) The authors argue that correct concept analyses are useful in identifying ways of both teaching and assessing student understanding. Analyses should comprise a definition, list of critical and variable attributes, and additional information dependent on the type of concept (including concrete, symbolic, processes, attributes, and properties.)
4. 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.
5. A. H. Johnstone, F. Percival, and N. Reid, "Is knowledge enough?" *Studies Higher Ed.*, **1981**, *6*, 77-84. Designing exercises to develop key skills in chemistry students, over and above simple factual recall and subject content mastery.
6. Kenneth G. Tobin and William Capie, "The development and validation of a group test of logical thinking", *Educ. Psychol. Meas.*, **1981**, *41(2)*, 413-423.
7. Frank L. Wiseman Jr., "The teaching of college chemistry: Role of student development level." *J. Chem. Ed.*, **1981**, *58(6)*, 484-488. This University of Kentucky study used a test instrument devised and validated by Anton Lawson (JRST 1978) as a means of assessing Piagetian development level of students enrolled in several different 1st-year chemistry programs, and applied correlation analysis to examine the relationship

between a student's "Lawson level" and their test, final exam, and course grades. The findings underline that more sophisticated concepts in chemistry require formal operational development on the part of the students; teaching methods therefore need to take into account the developmental stage of the student population taking that course.

8. Vantipa Roadrangka and Russell H. Yeany, "A study of the relationship among type and quality of implementation of science teaching strategy, student formal reasoning ability, and student engagement", *J.Res. Sci. Teach.*, **1985**, *22(8)*, 743-760. This study looks at the influence of both teaching strategy and student characteristics on time-on-task, which is known to affect student achievement. Ten students each in classes taught by five different teachers were observed on multiple occasions, and both the student's and teacher's classroom behaviours noted and coded. The Test of Logical Thinking was used to assess the students' level of formal operational development level. Multiple regression analysis showed that the type and quality of teaching was more important than formal thinking in determining student engagement.

9. George M. Bodner, "Constructivism: A theory of knowledge." *J. Chem. Ed.*, **1986**, *63(10)*, 873-878. A good general introduction to constructivist theory, derived primarily from the work of Piaget on the development of thought in children and adolescents.

10. David C. Finster, "Developmental instruction Part I: Perry's model of intellectual development." *J. Chem. Ed.*, **1989**, *66(8)*, 659-661. An introduction to Perry's work and early research relating to the scheme of intellectual development.

11. David C. Finster, "Developmental instruction Part II: Application of the Perry model to general chemistry." *J. Chem. Ed.*, **1991**, *66(9)*, 752-756. Further develops the concepts of the first article, and presents specific strategies for lectures, labs, tests, writing, and first classes. Although these relate to 1st-year general chemistry, the practical illustrations would be helpful to any physical science context.

12. Betty L. Bitner, "Formal operational reasoning modes: predictors of critical thinking abilities and grades assigned by teachers in science and mathematics for students in grades nine through twelve", *J. Res. Sci. Teaching*, **1991**, *28(3)*, 265-274. This paper looks at the relationship between students' level of intellectual development (in Piagetian terms) and their ability to engage in critical thinking skills. The former were assessed using the paper-and-pencil Group Assessment of Logical Thinking (GALT) instrument, while the latter were measured with the Watson-Glaser Critical Thinking Appraisal (WGCTA) test. The reliability and validity of both instruments were evaluated statistically, and a correlation found between students' Piagetian development (as measured by the five types of thinking that characterize formal operational abilities) and the types of critical thinking skills they could employ. Further, the five formal operational thinking abilities correlated with grades in science and mathematics courses.

13. Michael R. Abraham, Eileen Bross Grzybowski, John W. Renner and Edmund A. Marek, "Understandings and misunderstandings of eighth graders of five chemistry concepts found in textbooks." *J. Res. Sci. Teaching*, **1992**, *29(2)*, 105-120.

14. Uri Zoller, "Are lecture and learning compatible? Maybe for LOCS: unlikely for HOCS" *J. Chem. Ed.*, **1993**, *70(3)*, 195-197. This paper examines how instructors might improve students use of higher-level cognitive skills (HOCS) over lower order ones (LOCS). The

principal conclusion is that the traditional lecture with an emphasis on equations, facts, and algorithms (with corresponding assessments) is antithetical to such aims. Realizing high level learning goals (such as the development of critical thinking and problem-solving skills) therefore requires a different approach to the teaching of chemistry, as well as new ways of assessing student learning. Examples are given in the article and associated references.

15. D. C. Philips, “The good, the bad, and the ugly: The many faces of constructivism.” *Educational Researcher*, **1995**, *24(7)*, 5-12. This review article provides a framework for discussing the work of different constructivist authors and considers the way knowledge is constructed by both individual learners and within the “communities of practice” of the different academic disciplines. The author includes many workers outside the traditional cannon of constructivist theorists, demonstrating the breadth and complexity surrounding the issue of how knowledge is constructed at both extremes. In the process, he draws attention to both the “good” and the “ugly”, the latter being defined as a “descent into sectarianism, and the accompanying growth in distrust of [rival views]”. The article thus serves as a good introductory survey of constructivist thought and writing.

16. Orlando Lourenço and Armando Machado, “In defense of Piaget’s theory: A reply to 10 common criticisms.” *Psychological Review*, **1996**, *103(1)*, 143-164. This review makes the case that the most common criticisms levelled against Piaget’s theory are based on misunderstandings of the theory, its intent, and its development over an extended period. The methodologies behind some of the experiments offered as evidence against Piaget are also called into question as not actually measuring what was claimed. Overall, this paper serves as an excellent review of the key debates concerning Piaget’s theory, particularly in the area of his “formal operational” development stage

17. Alex H. Johnstone, “Chemistry teaching – Science or alchemy?” *J. Chem. Ed.* **1997**, *74(3)*, 262-268. This 1996 Brasted Award lecture discusses students’ ability to cope with information flow during labs and lectures and describes the implementation of a simple learning model to both areas to enhance student learning.

18. John Garratt, “Inducing people to think.” *U. Chem. Ed.*, **1998**, *2(1)*, 29-33. This article provides a reflection on teaching and learning within the context of university chemistry education. It discusses barriers to student learning, difficulties, and a student-centred approach to learning. In this regard, reference is made to a modified Bloom’s taxonomy of learning that highlights different levels of competence. “The use of pictorial representations to aid visualisation at the molecular level does not help all individuals equally. However, using and creating models (visual or conceptual) is a key feature of ‘thinking like a scientist’, and many students have difficulty coming to terms with the idea that most of what we ‘know’ about chemistry *is really a model which usefully represents reality*” (emphasis added.)

19. Patricia K. Cross, “Learning is about making connections”. *The Cross Papers Number 3* **1999**, publ. League for Innovation in the Community College, available *via* ERIC/EDRS. This seminal review summarises the findings of neuroscience and cognitive psychology as it relates to teaching and learning; highly informative and easy to read! In part, it

highlights the parallels between constructivist thought in education, and findings about memory and information processing from neuroscience and cognitive psychology.

20. D. Gabel, "Improving teaching and learning through chemistry education research: A look to the future." *J. Chem. Ed.*, **1999**, *76*, 548-554. An overview of the current state of chemistry education research on teaching and learning, identifying areas that need research to move forward. Provides useful references to research on science misconceptions (Refs 1-9).

21. 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.

22. Diane M. Bunce, "Does Piaget still have anything to say to chemists?" *J. Chem. Ed.*, **2001**, *78(8)*, 1107 (Special on-line symposium). This review summarizes what has been learned primarily from the work of Jean Piaget but also Lev Vygotsky, and work on information processing. It then applies this understanding of how students learn to the chemistry classroom and laboratory. We are asked to consider 'whether we are teaching to satisfy our own logical understanding of chemistry or to help students formulate their understanding.' The article argues for an increased focus on the student, peer interactions, active learning, and assessment of understanding rather than recall of facts and procedures.

23. Susan C. Nurrenbern, "Piaget's theory of intellectual development revisited" *J. Chem. Ed.,* **2001**, *78(8)*, 1107 (Special on-line symposium). A short summary of Piaget's theories as it applies particularly to high school and post-secondary students. This overview was provided as part of a special on-line symposium hosted by the Journal of Chemical Education titled "Piaget, Constructivism, and Beyond".

24. J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, and J. H. Van Driel, *Chemical Education: Towards research-based practice*, Kluwer Academic Publishers, **2002**. An excellent contemporary book on current directions in chemical education. Available in paperback (ISBN: 1-4020-1028-1).

25. Michael Shayer, "Not just Piaget; not just Vygotsky, and certainly not Vygotsky as alternative to Piaget." *Learning and Instruction*, **2003**, *13*, 465-485. This review compares the theoretical and experimental work of Piaget and Vygotsky and presents the conclusion that their positions on child development were highly similar and, in fact, complementary. The paper draws in evidence from the author's own experimental action research studies in school science and math education, which exploit Vygotsky's zone of proximal development as a means of encouraging students to progress from concrete to formal operational stages of development. The numerous quotations from Vygotsky throughout serve to illustrate the development of his ideas.

26. Anton E. Lawson and Warren T. Wollman, "Encouraging the transition from concrete to formal cognitive functioning – an experiment", *J. Res. Sci. Teach.*, **2003**, *40(S1)*, 33-50.

This study addresses the problem of stimulating students to develop formal thought (Piaget's formal operational development) through instructional methods and activities, in part through capitalizing on students' intuitive understanding of formal ideas such as the control of variables. 5th and 7th grade students were tested to determine their Piagetian development levels and placed in study and control groups. Individual sessions between students and instructors used a series of instructional activities designed to encourage students to transition from an intuitive to an explicit model for experimentation that was transferrable. Some success was obtained with the 5th grade students, and greater success with the 7th grade students, demonstrating that the intervention was indeed feasible. It is not clear to what extent this approach can be adapted to a whole class rather than individual students, however.

27. Melissa C. O'Connor and Sampo V. Paunonen, "Big five personality predictors of post-secondary academic performance." *Personality & Individual Differences*, **2007**, *43*, 971-990. This review summarizes the theoretical background to and research findings from the use of the "Big 5" personality predictors, covering original articles published between 1991 and 2006. The first part summarizes findings relating academic "success" (variously, exam, essay, or course grades, or GPA) to the traits of neuroticism, extraversion, openness, agreeableness, and conscientiousness, with the last being the most positive predictor. Sub-scales ("personality facets") within these traits are then reviewed. Finally, there is a broad discussion of the predictive utility of the 'Big 5', current state of the literature, and future directions.

28. J. Dudley Herron, "Advice to my intellectual grandchildren." *J. Chem. Ed.*, **2008**, *85(1)*, 24-32. This is an adapted version of the author's ACS Award for Achievement in Research for the Teaching and Learning of Chemistry address (2007). In it, the author reflects on over 30 years of chemical education research, and particularly on the use of constructivism in both research and teaching practice. He balances the importance of theory with a call to develop a database of "pedagogical content knowledge": knowledge about content, sequencing, examples and analogies that work, *etc*. Herron concludes with a plea for chemical education researchers to present their findings clearly and plainly to their chemistry colleagues who may well not be as familiar with the language of sociology, psychology, and education.

29. Michael Shayer, "Intelligence for education: As described by Piaget and measured by psychometrics." *British Journal of Educational Psychology*, **2008**, *78*, 1-29. This extensive review provides an account of the different phases of Piaget's life work, contrasting the "Geneva research" criterion-referenced approach with the alternative of norm-referenced approach of psychometrics developed over the same period, both as concepts of intelligence. The author argues that these two approaches must be viewed as complementary in order to make progress in educational development and reform. New insights from neuroscience are introduced briefly, and the 'Flynn effect' - referring to apparent gains on intelligence test scores over several decades of use - is also discussed.

30. Adrian Furnham, Jeremy Monsen and Gorkan Ahmetoglu, "Typical intellectual engagement, big five personality traits, approaches to learning and cognitive ability predictors of academic performance." *Brit. J. Educ. Psychol.*, **2009**, *79*, 769-782. This study of high school students employed a variety of psychometric tests to examine the contributions of fluid and crystallizable intelligence, the 'big 5' personality traits,

engagement, and study habits (using Biggs' SPQ) to academic success. For these students, the intelligence tests accounted for the largest proportion of the variance accounted for by linear regression models having English and Math grades as the outcome variables. Of the personality traits, openness (rather than conscientiousness as found for university students) was indicated to contribute, while a deep learning approach seemed to be negatively correlated (perhaps because of the style of exam, although the authors seem unaware of this aspect of learning styles?) The main finding, though, was that the Typical Intellectual Engagement (TIE) instrument was more effective in predicting academic performance at this level.

31. Marc S. Schwartz, Philip M. Sadler, Gerhard Sonnert and Robert H. Tai, "Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework." *Science Education*, **2009**, *93(5)*, 798-826. This paper uses "time on topic" as a surrogate for "depth" and "topics covered" as a surrogate for "breadth" in reviewing the FICSS survey data. Breadth and depth were found to unrelated to each other. Depth was positively correlated to college chemistry grades, while breadth was negatively correlated, across students in chemistry, physics and biology. The paper provides considerable background to this topic, as well as a fairly detailed analysis of the potential problems associated with the surrogates and definitions employed in the analysis. More work is needed, but high school teachers should aim for depth rather than breadth.

Assessment Tools and Learning Taxonomies:

1. Michael Shayer and David Wharry, "Piaget in the classroom. Part I: Testing a whole class at the same time." *School Science Review*, **1974**, *55*, 447-458. The authors describe the development of a set of group assessment tasks that can be employed by teachers to evaluate the Piagetian developmental level of students in a school science class within specific curriculum contexts. The tasks involve a teacher demonstration of the task, with questions being asked; students record their observations and responses in an answer booklet, which is subsequently graded on a scale of 1-10 where 9 & 10 correspond to formal operations, 5-6 correspond to concrete operations, and intermediate values are treated as 'transitional'. Results for one class over the course of a year of instruction are provided.

2. M. Shayer, D. E. Küchemann and H. Wylam, "The distribution of Piagetian stages of thinking in British middle and secondary school children." *Brit. J. Educational Psychology*, **1976**, *46*, 164-173. A survey of 10,000 UK school children between the ages of 9-14 was examined to determine the distribution of Piagetian concrete and formal operational thinkers. This was done using tasks that could be administered to whole classes at a time, and that were counterparts of the original interview tasks described by Piaget & Inhelder. Small samples of children were also tested using Piaget & Inhelder's individual interview tasks for comparison. The tasks are demonstrated to a class of students, with oral questions and individual written responses. The results show that very few of the students where formal operational thinkers, even at age 14, while most students are undergoing a transition from early to late-stage concrete thinking over the age range of the study. Those in the top 20% show a greater proportion transitioning into

early formal thinking at ages 12-14 but, even here, less than 20% are late-stage formal thinkers. This has profound implications for curriculum design and implementation.

3. Anton E. Lawson, “The development and validation of a classroom test of formal reasoning.” *J. Research Sci. Teaching*, **1978**, *15(1)*, 11-24. This paper describes an attempt to produce a test instrument that can assess numbers of students in terms of their Piagetian level (concrete through formal operational development) in a less resource-intensive manner than the individual assessment exercises originally employed by *e.g.* Inhelder & Piaget. In this case, a teacher demonstrates one or more experiments whilst asking students questions; students record their answers in individual booklets. The test was evaluated using 8th-10th grade students from a number of schools. The instrument was found to have face, convergent, and factorial validity. A contingency table is provided to convert test scores into Piagetian levels. Implications of the test instrument for classroom teaching are discussed.

4. Herbert G. Cohen, “Dilemma of the objective Piagetian paper-and-pencil assessment within the Piagetian framework” *Science Education*, **1980**, *64(5)*, 741-745. This paper examines several group assessment tools for assessing the Piagetian development (concrete and formal) of adolescent students. The point is raised that such tests lose the context of the thought processes and so may misrepresent the level of actual intellectual development demonstrated by a student. Supporting evidence comes from a study involving 109 students, 20 of whom were subsequently given actual Piagetian tasks; while these students generally demonstrated consistent rating between the two phases, certain tasks highlighted a discrepancy between the evaluations.

5. Michael Shayer, Philip Adey and Hugh Wylam, “Group tests of cognitive development: Ideals and a realization.” *J. Res. Sci. Teaching*, **1981**, *18(2)*, 157-168. This paper builds on the earlier work of Shayer, as well as Shayer & Wharry, and describes the validation of group assessment tasks for evaluating concrete vs. transitional vs. formal development in school children. These tasks are proposed as diagnostic tools for teachers to see where their students are, and how effective teaching of particular units has been in terms of intellectual development. After the tasks were evaluated and refined with small groups, they were tested for validity and reliability against a group of 200 students. Validation included subsequent clinical interviews of selected students, and the results subjected to correlation analysis. Construct validity was tested by factor analysis. The authors further suggest evidence for the suitability of the group tests in cross-cultural studies.

6. Christopher F. Bauer, Beyond ‘‘Student Attitudes’’: chemistry self-concept inventory for assessment of the affective component of student learning, *J. Chem. Ed.*, **2005**, *82(12)*, 1864–1869. This article provides a review of the components related to “attitude” as developed within the psychology, social science, and educational literature. The article continues to describe the development and validation of the Chemistry Self-Concept Inventory (CSCI), a psychometric instrument to evaluate a student’s “perception of self, an evaluation an individual makes and customarily maintains with respect to himself or herself, in general or specific areas of knowledge”. Derived from earlier general or mathematics inventories, the resulting instrument was tested with a cohort of general chemistry students and subjected to factor analysis and examined for validity and reliability. The article concludes by describing the meaning of the subscale scores. (CSCI available as SI)

7. Christopher F. Bauer, Attitude towards Chemistry: A Semantic Differential Instrument for Assessing Curriculum Impacts, *J. Chem. Ed.*, **2008**, *85(10)*, 1440–1445. Whereas the author's CSCI looked at self-concept, this paper describes the development of an attitudinal survey instrument, the Attitude to the Subject of Chemistry Inventory (ASCI). The key differential between self-concept and attitude is that one reflects 'what I am good at' while the other reflects 'this is valuable or worthwhile'. The ASCI consists of multiple items describing the factors: interest/utility, anxiety, intellectual accessibility, fear, and emotional satisfaction. The instrument was field-tested with general chemistry students and subjected to factor analysis as well as an examination of validity and reliability. (ASCI version 1 available as SI)

8. Kariluz Dávila and Vincente Talanquer, "Classifying end-of-chapter questions and problems for selected general chemistry textbooks used in the United States." *J. Chem. Ed.*, **2010**, *87(1)*, 97-101. Bloom's taxonomy was used to classify the types and distribution of chapter questions in typical (top 3) texts for 1st-year general chemistry in US colleges and universities. Each text tended to have more of a certain type of question than others, such as recalling, quantitative calculations, and inferential or predictive questions. For all three, the greatest number of questions fell in the application and analysis categories. A similar pattern was observed for the types of questions on the ACS general chemistry exam.

9. Lillian Bird, "Logical Reasoning Ability and Student Performance in General Chemistry." *J. Chem. Ed.*, **2010**, *87(5)*, 541-546. Students at the University of Puerto Rico at Rio Piedras were tested using a questionnaire based on Piagetian tasks, scoring them as concrete, transitional, or formal operational thinkers. This was compared to their ability in general chemistry based on final grades in a two-semester course. 59% of students enrolled by the mid-point of the course fell below the formal operational thinking category, although 40% were classified as "transitional". Gender differences were observed, particularly for proportional and probabilistic reasoning. The highest proportion of A grades was obtained by those in the formal category, while more B and C grades were obtained by transitional students.

10. K. Christopher Smith, Mary B. Nakhleh and Stacey Lowery Bretz, An expanded framework for analyzing general chemistry exams. *Chem. Ed. Res. Pract.*, **2010**, *11*, 147-153. This paper reviews and compares various different taxonomies for describing different types of assessment questions, within the general framework of the revised Bloom's taxonomy. The authors go on to derive primary categories of definition, algorithmic, and conceptual questions, with each being further divided into secondary categories. Examples of questions that exemplify each category are provided and are then used to classify questions on the ACS general chemistry exams.

11. Xiaoying Xu and Jennifer E. Lewis, Refinement of a chemistry attitude measure for college students, *J. Chem. Ed.*, **2011**, *88(5)*, 561-568. This article describes a review and refinement of Bauer's 2008 Attitude to the Subject of Chemistry Inventory (ASCI). Both versions were administered to a cohort of university students in general chemistry and examined for validity and reliability. This included both exploratory and confirmatory factor analysis, as well as test-retest reliability. Refinement of the instrument was required in order to resolve over-lapping factors found in both EFA and CFA, resulting in a shorter version comprising of two sub-scales, intellectual accessibility and emotional

satisfaction. The authors then tested ASCIv2 as a predictor of success (ACS exam grades), along with SAT-M and ACT-M scores. A moderate correlation was found, which was maintained when only the ASCIv2 sub-scale scores were used ($R^2 = 0.28$). (ASCIv2 and supporting data are available in the SI).

12. Xu, X. Villafane S. M. and Lewis J. E., (2013), *Chem. Ed. Res. Pract.,* **14(2)**, 188-200. ; 10.1039/C3RP20170H)
13. A. A. Flaherty, "A review of affective chemistry education research and its implications for future research" *Chem. Ed. Res. Pract.*, **2020**, *21(3)*, 698-713. A review of chemistry education research on Bloom's Affective domain published in the decade since 2000, covering a total of 91 studies on students' attitudes, self-efficacy, self-concept, expectations, values, interest, motivation, effort beliefs, and achievement emotions. (The review specifically looked at articles published in Chemistry Education Research and Practice (CERP), Journal of Chemistry Education (JCE), Journal of Research for Science Teaching (JRST), International Journal of Science Education (IJSE) and Science Education (SE).) These studies concentrate on five themes: demographics and contexts, learning interventions, exam performance, the development and validation of research instruments, and to deriving theoretical frameworks. These are summarized through the remainder of the review.

Naive or Alternate Conceptions (Misconceptions) in Chemistry:

1. Björn Andersson, "Pupils' conceptions of matter and its transformations (age 12-16)." *Studies Science Education*, **1990**, *18(1)*, 53-85. This review examines numerous studies of alternate conceptions amongst middle and junior high school students concerning matter, chemical and physical change, and atomic/molecular/particle theories. Some difficulties with interpreting student answers in such studies are explored, as well as certain common themes. The review concludes by describing different teaching units designed to address student misconceptions around matter and its transformation. It is clear that conceptual change is achievable, but it is gradual and requires great care in the design and use of classroom materials and activities in order to avoid reinforcing the very conceptions one wants to change. Overall, a constructivist approach appears well suited to this task.
2. 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. The authors describe here a concept inventory, or diagnostic tool, based on the existing literature documenting first-year students' alternate conceptions in chemistry. The article discusses results for specific questions in detail, illustrating both the alternate conceptions and drawing attention to the ways in which these undermine student success and future learning. Complete results are available in supplementary material, while the inventory itself is available through the J. Chem. Ed. question bank. http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/
3. Keith S. Taber, "Mediating mental models of metals: Acknowledging the priority of the learner's prior learning." *Science Education*, **2003**, *87(5)*, 732-758. A group of UK college students were interviewed over a period of time to examine their understanding of metallic bonding. An alternate conception of bonding based on what the author terms

"the octet framework" was uncovered. Misconceptions and confusion over the octet rule undermine students' comprehension of bonding in general, but particularly hinder an understanding of bonding in metals. Specific insights and recommendations are made for teachers to address this.

4. Vincente Talanquer, "Commonsense chemistry: A model for understanding students' alternative conceptions." *J. Chem. Ed.*, **2006**, *83(5)*, 811-816. This intriguing paper attempts to derive a simple framework for understanding how students arrive at their naive or alternative conceptions (misconceptions) in chemistry. Based on a meta-analysis of the literature on chemical misconceptions, this highlights the fact that some misconceptions arise from taking our teaching analogies and models too far. The framework summarizes common empirical (and false) assumptions and simple reasoning heuristics that give rise to student misconceptions.

5. Keith S. Taber and Alejandra G. Franco, "Intuitive thinking and learning chemistry", *Education in Chemistry*, **2009**, *46(2)*, on-line article, https://edu.rsc.org/feature/intuitive-thinking-and-learning-chemistry/2020171.article (Retrieved February 8th 2021). The authors summarize research on the origin of student misconceptions in chemistry, with a particular emphasis on the role of pattern recognition and perception in processing information. Since students relate new information to existing ideas and experiences, the natural tendency is to understand new concepts in light of these by an intuitive process rather than more demanding scientific reasoning. They conclude with a summary of three key principles teachers can follow in order to minimize student misconceptions: focusing on explanation, providing diverse contexts and highlighting similarities and differences, and attending to language in particular where words might have a different understanding attached to them in everyday use.

6. Karrie Gerlach, Jaclyn Trate, Anja Blecking, Peter Geissinger and Kristen Murphy, "Valid and reliable assessments to measure scale literacy of students in introductory college chemistry courses" *J. Chem. Ed.*, **2014**, *91(10)*, 1538-1545. This article describes the development and evaluation of two assessment instruments for assessing students' conceptions of scale in introductory college chemistry. These were the Scale Literacy Skills Test (SLST) and the Scale Concept Inventory (SCI), which were used together to obtain a student's Scale Literacy Score. Students completing these instruments had also taken chemistry and mathematics placement exams at the beginning of the year; this information was combined with ACT scores as predictors for final chemistry exam scores. Both the individual instrument scores and the combined SLS score were strongly correlated with final exam scores.

Success in Post-secondary Chemistry

A. First Year Undergraduate Chemistry:

1. S. R. Powers, "The achievement of high school and freshman college students in chemistry." *School Sci. Math.*, **1921**, *21(4)*, 366-377. The same tests (originating from the University of Minnesota) were given to high school and 1st-year students at the University of Arkansas. The university students consisted of two groups, comprising those with and without a prior year of high school chemistry. One test covered naming, formulas, equations, and stoichiometric calculations. The second covered 100 items of

factual chemical knowledge. Analysis of the data was based on the percentage of students answering each question category correctly, by school or university group. University students with high school chemistry did better than those without; both groups did better than the high school students, for which there was a wide range between scores by school.

2. Harry S. Fry, "Questions relative to the correlation of college and high-school chemistry courses." *J. Chem. Ed.*, **1925**, *2(4)*, 260-269. This commentary reflects on the desirability (or otherwise) of having separate college/university courses in chemistry based on whether or not students took a high school course in the subject. The general argument is that this is not desirable for many reasons. Attention is also drawn to the fact that this would require standardization at the high school level not only of the course content and exams, but the quality of teaching, equipment, and laboratories. Different post-secondary institutions are likewise unequal in their ability to offer separate courses to such students. Data on student attainment shows that although proportionately more students had taken high school chemistry, both groups were equally likely to pass the course. In fact, across 10 years, there was very little difference in the attainment by grade range of the two groups.

3. Jacob Cornog and George D. Stoddard, "Predicting performance in chemistry." *J. Chem. Ed.*, **1925**, *2(8)*, 701-708. This paper describes development of the University of Iowa placement test. Students who do well in chemistry score highly on a general IQ test, but the converse is not always true! This paper describes the development of a chemistry aptitude test (for those without high school chemistry) and a training exam (for those who do). The aptitude test focussed on math skills, reading comprehension, analysis and recall of extended technical arguments, and a "general interest in natural phenomena" - familiarity with general phenomena to do with science and the environment. The training test was more focussed on prior chemistry instruction and problem solving. Reliability scores suggested that the tests could be used for sectioning within courses based on preparation and ability. Outcomes also showed good success at predicting pass/fail criteria, with fairly high correlation coefficients between test and final grades. The predictive power of both tests was better than for general IQ or high school grades.

4. W. A. Everhart and W. C. Ebaugh, "A comparison of grades in general chemistry earned by students who (a) have had, and (b) have not had high-school chemistry." *J. Chem. Ed.*, **1925**, *2(9)*, 770-774. This paper summarizes first-term grades for students at Denison University from 1919 to 1923 using bar charts. The lectures and tutorials were common for all students, but students were split for laboratory sessions on the basis of having had high school chemistry. On average, those without high school chemistry were 1/5th as likely to obtain a grade of 90-100%, but 4.5 times as likely to fail, as those with high school chemistry. Note than only a simple analysis based on bar charts of grade distributions was attempted. It was found that differences between the two groups tended to disappear during the second term - at least as far as average grades and grade distributions were concerned.

5. F. E. Brown, "Separate classes in freshman chemistry for pupils who present high-school credits in chemistry." *J. Chem. Ed.*, **1926**, *3(3)*, 301-306. This article presents a counter-view to Harry Shipley's 1925 JCE article on whether students with high school chemistry should take the same or a different introductory college chemistry course. One

factor is a decreased duration for this course at the author's institution, so students are streamed into separate first year courses. Students who had high school chemistry therefore took a more advanced 1st-year course than those who didn't. The comparison is then made between these students in subsequent courses. This data demonstrates consistent differences by grade range in attainment between the two groups. The author suggests that differentiation should be carried throughout the program in all courses, which seems highly impractical.

6. Jacob Cornog and George D. Stoddard, "Predicting performance in chemistry II." *J. Chem. Ed.*, **1926**, *3(12)*, 1408-1415. This article is a follow-up to the 1925 JCE article by the same authors and describes further results of using the Iowa Chemistry Aptitude and Chemistry Training Tests, as reported from over 50 colleges and universities using these exams as placement tools. Significant variation in mean scores is seen on the test for students lacking a high school chemistry course, which appears to depend on whether the college/university recruitment area was rural or urban. In terms of the actual questions, students who did poorly had very weak mathematical ability, being unable to perform simple stoichiometric calculations.

7. C. S. Slocombe, "A note on the results obtained from Iowa chemistry tests." *J. Chem. Ed.*, **1927**, *4(7)*, 894-896. This commentary disputes some of the findings from Cornog & Stoddard (JCE 3, 1926, 1408-1415). Specifically, it is shown that if relative mean scores on the Iowa Aptitude and Training Test are used for comparison, the difference noted by Cornog and Stoddard between universities and colleges disappear. Further, conclusions regarding student recall are questioned by analysing the placement within the test and student answers to repeated questions. This suggests that students may simply not have been given enough time for all of them to complete the tests without experiencing undue pressure.

8. Maude B. Scofield, "An experiment in predicting performances in general chemistry." *J. Chem. Ed.*, **1927**, *4(9)*, 1168-1175. This study from Syracuse University compared student performance in 1st-year exams with their high school chemistry grades and their scores on an entrance placement exam. It was concluded that the latter was a much better indicator of success (A) or failure than the former, and that streaming of the students would be better based on placement test results. The placement test examined basic mathematical ability – particularly the use of fractions – as well as fundamental chemistry knowledge.

9. Alexander Silverman, "Intensive training in chemistry." *J. Chem. Ed.*, **1928**, *5(3)*, 317-322. Based on a comparison of grade distributions, the author concludes that different courses should be provided for students with and without high school chemistry. These should employ different texts and labs. Intensive summer chemistry courses were compared to regular semester versions of the same courses. It was further concluded that such courses provided superior results when they were the only course a student could take during the summer. Conclusions were based on the relative proportions of A–F grades.

10. P. M. Glasoe, "The deadly parallelism between high-school and college courses in chemistry." *J. Chem. Ed.*, **1929**, *6(3)*, 505-509. In this article, the author argues that we should offer different courses and labs to students who have and have not taken senior

high school chemistry. His argument is that, by repeating much of what a student has already covered, instructors instil in the student a negative attitude towards the subject matter and denigrate the efforts of those high school students and teachers who have invested time and academic effort into the subject. Although the author acknowledges that students retain only a fraction of what was covered in high school, he insists that instructors should assume a core body of knowledge and build on it. No empirical evidence is presented either for or against the proposition that this will be of positive benefit to the students, or that they would attain better outcomes than if "dumped into the common freshman chemistry hopper and ... ground out with the normal curve quota [of grades]".

11. C. A. Buehler, "The one college chemistry course for freshmen." *J. Chem. Ed.*, **1929**, *6(3)*, 510-513. This paper reports a six-year, grade-based study of students at the University of Tennessee, taking the common introductory chemistry course. Students without high school chemistry were 2.5 times less likely to obtain grades of 85-100% in the first half of the course, but seemed to 'catch up' during the second half. Reasons for this are suggested, but there is no further analysis or additional data reported.

12. Ira D. Garard and Thalia B. Gates, "High-school chemistry and the student's record in college chemistry." *J. Chem. Ed.*, **1929**, *6(3)*, 514-515. This study of female students at Rutgers University looked at the average grades of first-year students who had and did not have high school chemistry. The averages for the former are consistently higher than the latter for both exams and labs, although there is no breakdown of the spread in grades for the two categories. The authors conjecture that familiarity with terms and language, together with repetition of core concepts, explains the difference, but no evidence is offered to support this.

13. Murray A. Hines, "Of what value is the high-school course in chemistry to those students continuing the subject in college?" *J. Chem. Ed.*, **1929**, *6(4)*, 697-707. This paper compares student performance over a 12-year period, contrasting the continued performance of students with and without high school chemistry through 3 years of undergraduate courses, both before and after streaming students in 1st year. As the number of students enrolling with high school chemistry increased, the class average in the streamed university course decreased while that for non-high school chemistry students remained more or less constant. In higher courses, those who had high school chemistry scored on average slightly higher than those who did not, but more students with high school chemistry continued in the subject than otherwise.

14. Maude B. Scofield, "Further studies on sectioning in general chemistry." *J. Chem. Ed.*, **1930**, *7(1)*, 116-126. This paper reports findings from a study of students at Syracuse University of first-semester students in two chemistry courses for those with and without high school chemistry. High school math grades were found to be a good indicator of college success for students regardless of whether or not chemistry was taken in high school, and could be used as the basis for sectioning the courses. High school physics and chemistry grades were less reliable. A placement exam was developed and tested through several years of the study; high school math grades were still better indicators for students who had taken high school chemistry, which would suggest that math be part of the placement exam.

15. George A. Herrmann, "An analysis of freshman college chemistry grades with reference to previous study of chemistry." *J. Chem. Ed.*, **1931**, *8(7)*, 1376-1385. This paper describes results from both a qualitative student survey (300 students) and an analysis based on high school and college grades (826 students, 1929-1930). It is clear from the survey that students had encountered a wide range of teaching practices and effectiveness in high school chemistry; of these students, about half considered it had helped them in college. Of those who did not take high school chemistry, 92% felt it would have helped them. The grade data clearly shows more college grades of 85% or above amongst students with high school chemistry, and more grades below 70% (including fails < 60%) amongst those who did not take high school chemistry.

16. Guy A. West, "Influence of high school science on grades in college chemistry." *School Sci. Math.*, **1932**, *32*, 910-913. This study looked at the correlation between college grades and high school science grades, yielding a correlation coefficient of 0.11±0.08. Student data were subsequently divided by grade category, and analysed as to the number and type of high school science courses. "A correlation coefficient of 0.38±0.08 was found between intelligence test scores and grades in college chemistry at the end of the first quarter."

17. L. E. Steiner, "Contribution of high-school chemistry toward success in the college chemistry course." *J. Chem. Ed.*, **1932**, *9(3)*, 530-537. This study looked at students taking 1st-year chemistry at Oberlin College over the period 1926-1930, and considered their 1st-year grades, as well as both attendance and performance in subsequent chemistry courses, in the light of whether or not they had taken high school chemistry. For the average student, high school chemistry results in better grades in 1st-year; such students are also three times more likely to continue to higher courses. Although little factual content and even fewer principles are reported to be retained from high school, the importance of having encountered the vocabulary and concepts before is emphasized, as well as a "way of thinking" that is particular to physical science courses.

18. Paul Maurice Glasoe, "Residue of high-school knowledge utilizable in college chemistry." *J. Chem. Ed.*, **1933**, *10(9)*, 571-574. This paper compares grade distributions for students in separate first-year chemistry courses, one for those with and one for those without high school chemistry. The former assumed core knowledge and prior lab experience, and built on these. Both courses were taught and tested by the author. There was a clear difference in grade distribution and median course grades between the two groups, with those having high school chemistry out-performing those without.

19. Lyle O. Hill, "Results of a short first-year college course for students who have had high-school chemistry." *J. Chem. Ed.*, **1935**, *12(7)*, 323-324. This paper compares grade outcomes between students in a second-year course who had taken different first-year programs: a one-semester course for students with high school chemistry, and two one-semester courses for those without. Very little difference in grade distributions between the two groups was observed, although students with low grades in the second group (D) did not continue with the upper level course in anywhere near the same numbers. Correlation coefficients were calculated for the two groups, but no measure of statistical significance was calculated for these. It was concluded that the current course structure should be continued.

20. Paul E. Clark, "The effect of high-school chemistry on achievement in beginning college chemistry." *J. Chem. Ed.*, **1938**, *15(6)*, 285-289. This study compares students who had and had not taken high school chemistry during their first year course at Muskingum College. The methodology is different from other studies, in that the analysis is based on student marks from a chemistry aptitude test and a training test given both at the beginning and end of the first semester. (These were Iowa Placement Exams.) Predictions of end-test scores were based on a regression analysis of the pre-test scores and a psychological exam. These predictions were then compared to actual student results. Generally, it was found that students with high school chemistry did better than predicted, while students without high school chemistry did not.

21. F. D. Martin, "A diagnostic and remedial study of failures in freshman chemistry." *J. Chem. Ed.*, **1942**, *19*, 274-277. This study looks at entering engineering students taking a required introductory chemistry course at Purdue. A significant proportion of chemistry failures also failed English and math, but chemistry was not seen as harder than these other courses. It was also noted that having high school chemistry did not necessarily result in better performance, and streaming on this basis was dropped. Scores on an entrance math exam seemed to be good predictors of success in chemistry; indeed, math ability acted as an equaliser between students with and without high school chemistry. Students were prevented from repeating chemistry until they had passed remedial English and math courses. Students without high school chemistry were offered additional tutorials.

22. John P. McQuary, Henrietta V. Williams, and John E. Willard, "What factors determine student achievement in first-year college chemistry?" *J. Chem. Ed.*, **1952**, *29(9)*, 460-464. This reports a survey of ~650 University of Wisconsin students, looking at class make-up and background, and comparing two courses: one for students with, and another for students without, high school chemistry. In addition to high school grades, courses, and rank, a number of psychological evaluations were performed; some demographic data was also obtained. In general, High school math, science, and chemistry courses are important to success, along with "intellectual factors"; gender and the size of each student's community was not found to be an influence. Students who had taken high school chemistry tended to be among those who scored more highly on the psychological evaluations, which was taken as indicating greater "intellectual ability".

23. E. H. Hadley, R. A. Scott, and K. A. van Lente, "The relation of high-school preparation to college chemistry grades." *J. Chem. Ed.*, **1953**, *30(6)*, 311-313. This paper reports a survey of ~700 students at Southern Illinois University, enrolling between 1947-1950. This cohort consisted entirely of students who required the course for various programs, rather than as a breadth requirement (different course). Those who had taken high school chemistry, math, and physics, were more likely to obtain higher college grades than those who lacked one or more of these subjects, obtained. A curious comment on the latter group: "*Native intelligence*, interest in science and mathematics, and the willingness to work *probably* are involved" (emphasis added). The final figure demonstrates the large difference in high school versus university grade distributions.

24. John J. Carlin, "Do courses in chemistry and physics at the high-school level contribute to success in beginning college chemistry?" *J. Chem. Ed.*, **1957**, *34(1)*, 25-26. This study of students at post-secondary institutions in the New York area used psychological

test scores, gender, and institution to select pools of students with and without high school chemistry and/or physics as the study subjects. After normalizing 1st-year grades from the different institutions, comparisons were made on the basis of mean grades for each pair of groups, using a form of the t-test of two means. On average, high school chemistry helps, while a combination of high school chemistry and physics is better, however the methodology used only considers mean grades, and offers no predictive power.

25. Robert C. Brasted, "Achievement in first year college chemistry related to high school preparation." *J. Chem. Ed.*, **1957**, *34(11)*, 562-565. Two surveys, with 1400 and 1100 students, respectively, of students within the Minnesota universities and colleges are reported. There were "marked differences in performance" between students with and without high school chemistry, "irrespective of geographic area." Generally, having high school chemistry, math, and physics was found to be important indicators of success in college. Evidence was also seen that students in smaller schools might have a slight advantage over those in larger ones. The author expresses surprise since larger schools should have "better physical facilities"

26. Nelson W. Hovey and Albertine Krohn, "Predicting failures in general chemistry." *J. Chem. Ed.*, **1957**, *35(10)*, 507-509. This University of Toledo study describes a pre-test developed to place freshman chemistry students. Effectively, a streaming process was put in place based upon a diagnostic chemistry test. From 1943-1954, the percentage of A & B grades declined steadily, while the number of fails and drops increased. Rather than "watering down" content or adjusting grades, a pre–test placed students at risk into a chemistry-flavoured "study skills" course. Those who took this pre-course had double the chance of passing first-year chemistry than those at-risk students who chose not to. High school rank and/or grade were not good predictors of first-year success. *See also Hovey & Krohn, J. Chem. Ed. 1963, 40(7), 370ff.*

27. William E. Kunhart, Lionel R. Olsen and Roger S. Gammons, "Predicting success of junior college students in introductory chemistry." *J. Chem. Ed.*, **1958**, *35(8)*, 391-391. This paper describes the results of a correlation analysis on the 1st-year college chemistry grades of students in California with high school chemistry, algebra, and American Council of Education psychological exam scores (chemistry, total, and linquistic) - i.e.scholastic aptitude test scores. The strongest single correlation was with high school chemistry (0.263), but even a multilinear correlation only resulted in a coefficient of 0.397. The time lapse between high school and 1st-year for many college students is cited as a possible factor in these results, as is variability in high school grading practices across the nineteen high schools from which the student population is drawn.

28. Herbert A. Meyer, "What value high school chemistry to the freshman college chemistry student?" *School Sci. Math.*, **1962**, *62(6)*, 410-414. The author notes that despite multiple statistically sound research studies indicating otherwise, many college chemistry instructors still believed that high school chemistry was of no value to students entering their first post-secondary chemistry course. He also notes that many schools do not offer separate offerings for students with and without high school chemistry, but teach everyone as though they had no prerequisite high school course. The article then describes a correlation analysis of student data from the University of Nebraska to

evaluate whether or not the selection process used to stream students between such courses. The outcome of multiple linear regression across a range of factors was that the three best predictors of a student achievement score were (in order) a chemistry pre-test score, the ACE psychological test linguistic score, and the student's high school chemistry grade. A follow-up matched-pair covariance analysis the following year showed that student with high school chemistry continued to perform better in their second year post-secondary chemistry course.

29. Virginia M. Schelar, Robert B. Cluff and Bernice Roth, "Placement in general chemistry." *J. Chem. Ed.*, **1963**, *40(7)*, 369-370. This study of students at Northern Illinois University used biserial correlation tests to identify predictors of success in introductory chemistry on a success/failure basis (A/B versus F/D). Available data included math test scores, SAT total and reading comprehension scores. Biserial *r*-values showed the highest correlation to be with the Math score. A trial Chemistry Placement Test was tested, including factual chemistry knowledge, math, and science reading comprehension sections. This had the highest biserial-*r* of all. This was used to place students into classes of "similar ability" within the course.

30. Nelson W. Hovey and Albertine Krohn, "An evaluation of the Toledo chemistry placement examination." *J. Chem. Ed.*, **1963**, *40(7)*, 370-372. This follow-up paper to an earlier study by the same authors, and describes a study of the TCPE as used from 1959-1963 by many other institutions. The TCPE includes multiple-choice questions on arithmetic, algebra, formulas, naming, equations, algebraic formulations, and chemical problems. 100 tests from three academic sessions were used to produce rank/score data and Kuder-Richardson reliability coefficients for the exam; the majority of the questions were found to provide "outstanding" or "very good" discrimination between students. It is noted that the fraction of fails in 1st-year chemistry has been cut to 1/3rd since streaming based on TCPE results was introduced. The predictive ability of the TCPE was also investigated; this was better for high scoring than middle-scoring students. *See also Niedzielski & Walmsley, J. Chem. Ed. 1982, 59(2), 149ff.*

31. B. O'Neal Hendricks, Charles L. Koelsche and Joseph C. Bledsoe, "Selected high school courses as related to first quarter chemistry marks." *J. Res. Sci. Teaching*, **1963**, *1*, 81-84. This study at the University of Georgia compared the first quarter chemistry grades of 200 students with their high school grades in math, physics, and chemistry, as well as aptitude test scores. Various correlation methods were used, as well as ANCOVA, to identify the best predictors of grade (A-F). Factors related to differences in high school (size etc.) were discounted; the best predictors were high school grade average and SAT math score, with *r*-values of 0.245-0.414 (depending on gender). There was an advantage to taking a more advanced math course, but no significant contribution from having taken high school chemistry.

32. D. P. Lamb, W. H. Waggoner and W. G. Findley, "Student achievement in high school chemistry." *School Sci. Math.*, **1967**, *67*, 221-226. This paper describes the development of a test to be administered at both the start and end of 1st-year post-secondary chemistry, in an attempt to ascertain the value (or otherwise) of students' prior chemistry in high school. Test subjects were 1st-year students at the University of Georgia in 1964/5. These were given a 50-item, 1-hour multiple-choice test covering background chemistry knowledge and operations (stoichiometric calculations, etc.), the

question subject areas being listed in the article. The greatest difficulty (i.e. percentage answering incorrectly) was found for mathematical calculation problems. ANOVA was applied to the test scores along with variables including high school average and SAT math and verbal scores. Math scores and age were found to be most important in predicting test scores.

33. Richard W. Haffner, "Placement of freshmen in the chemistry program." *J. Chem. Ed.*, **1969**, *46(3)*, 160-162. Students at the USAF academy may be placed in an accelerated chemistry program based on their scores on the ACS general chemistry exam, a math validation exam, and their composite score on the college board entrance exams. A predicted chemistry grade is calculated using an equation derived from multiple linear regression analysis of prior data and final course scores. The predicted grade shows a higher correlation with final course grades than any individual component, with the ACS exam score showing the best correlation amongst the latter. Interestingly, of the four years for which data is provided, the first shows the highest correlation coefficients, with a noticeable decline subsequently, although the author does not comment on this.

34. Neil R. Coley, "Prediction of success in general chemistry in a community college." *J. Chem. Ed.*, **1973**, *50(9)*, 613-615. This study from Chabot College (CA) looked at students in college on the basis of the Toledo Chemistry Placement Exam, using multi-linear correlation analysis to determine the best means of predicting grades in order to direct students to an appropriate chemistry course. Other factors included ACT scores and high school chemistry and math (algebra) grades. Success measures were taken as college chemistry and ACS General Chemistry Exam grades. The first college chemistry grade was the best single predictor of subsequent college chemistry grade, followed by the TCPE score. For students who had not taken this introductory college course, only the TCPE score was found to be predictive. The paper concludes, "Based on the total variance ... there is something else that contributes to success in chemistry. It may or may not be academic in nature, however, it is very significant!"

35. L. G. Pedersen, "The correlation of partial and total scores of the scholastic aptitude test of the college entrance examination board with grades in freshman chemistry." *Educational & Psychological Measurement*, **1975**, *35(2)*, 509-511. As part of efforts to provide a preparatory chemistry course for under-prepared students, this study from the University of North Carolina looked for predictors that could be used as means of identifying which students should take this course. The factors studied included the SAT verbal and math scores, as well as a combined total score. Although average grade increased with average SAT scores, the standard deviations were so large – corresponding to ±1 grade – that it was impossible to make predictions for individual students.

36. Miles Pickering, "Helping the high risk freshman chemist." *J. Chem. Ed.*, **1975**, *52(8)*, 512-514. This Columbia University study looked at minimum, average, and maximum SAT math scores by grade division in first year chemistry. The discussion around the observed correlation is based on this plot, ignoring the tremendous overlap between ranges for each grade category. It does note a higher SAT math average amongst C grade students, attributed to students coasting rather than working to their ability. Students with low SAT scores were selected for a special chemistry course teaching strategies and algorithms for solving particular types of problem. A t-test comparison of

grades was made with regular course students with the same SAT scores. There was a small but significant lowering of minimum SAT scores within grade categories. It was noted that the main difficulty encountered by students was “an inability to do chemical problems that were mathematical.”

37. Mark Albanese, David W. Brooks, Victor W. Day, Roger A. Koehler, J. D. Lewis, Robert S. Marianelli, E. P. Rack and Carol Tomlinson-Keasey, “Piagetian criteria as predictors of success in first year courses.” *J. Chem. Ed.*, **1976**, *53(9)*, 571-572. This paper reports on the use at the University of Nebraska-Lincoln of the Toledo Placement Test combined with a set of written Piagetian tasks designed to assess the development level of students entering 1st-year chemistry, offered as a multi-track course. The authors note that this is a challenge, as conventional Piagetian tests require physical experimentation and observation/interview to examine the participant’s thought processes. Contrary to earlier results from Purdue reported by Herron (JCE **1975,** *52(3)*, 146*ff*), these authors did not find a significant correlation between course grades and Piagetian task performance, however this may have been due to a more heterogeneous student sample and/or differences in the specific tasks/tests used, as well as differences in teaching and assessment practices.

38. Miles Pickering, “The high risk freshman chemist revisited.” *J. Chem. Ed.*, **1977**, *54(7)*, 433-434. This paper is a follow-up to an earlier publication (JCE **1975**, *52(8)*, 512*ff*) examining interventions aimed at assisting students at risk of failure in first year chemistry. It was found that while students taking the supplementary course on problem-solving skills did better on average the following year than their counterparts who took general chemistry course only, this advantage did not persist through later years with biology and organic chemistry. This was attributed to a different set of skills being necessary for these courses rather than the more mathematical physical chemistry.

39. C. B. Mamantov and W. W. Wyatt, “A study of factors related to success in nursing chemistry.” *J. Chem. Ed.*, **1978**, *55(8)*, 524-525. This study of nursing students taking a required chemistry course at the University of Tennessee used correlation analysis to determine the best predictors of score on both a nursing chemistry exam and the ACS Exam, using student ACT scores (composite, math, English) and whether a student had a prior chemistry credit. When the exams were written after a quarter of predominately inorganic chemistry, ACT math was the best predictor; however, when a significant amount of organic and biological chemistry was included (after 2 quarters), the ACT science score was better. No effect was observed for taking high school chemistry, while results for the nursing and ACS chemistry exams were comparable.

40. Ardas Ozsogomonyan and Drew Loftus, “Predictors of general chemistry grades.” *J. Chem. Ed.*, **1979**, *56(3)*, 173-175. A UC Berkely study of students in first-year general chemistry, which used a pre-test to identify at-risk students and direct them into an alternate program. The pre-test consisted of both chemistry and algebra components; the students’ high school letter grade and math SAT score were also included. Multivariate analysis was used to determine the best predictors. It was found that math SAT score with either high school or chemistry pre-test grade could account for most of the variance observed amongst students for whom the study authors had full data. (Note that the bulk of the results actually presented employ “binned” data, however, so some variance is masked.)

41. Marjorie H. Andrews and Lester Andrews, "First-year chemistry grades and SAT math scores." *J. Chem. Ed.*, **1979**, *56(4)*, 231-232. This University of Virginia study used a similar approach to that of Pickering (JCE 1975). A correlation is observed between average SAT math scores and student first-semester chemistry grade, but the standard deviations are again very large. It is noted that "It was almost impossible to predict any student's first semester grade when his SAT math score was within 1 standard deviation of the overall group mean SAT." Similarly, "A high math SAT was not a guarantee of a good grade, but a low math SAT was a strong indicator of a low grade." No other variables were considered in this study.

42. Robert J. Niedzielski and Frank Walmsley, "What do incoming freshman remember from high school chemistry?" *J. Chem. Ed.*, **1982**, *59(2)*, 149-151. A follow-up on the use of the Toledo Chemistry Placement Exam (*JCE, Hovey & Krohn, 1958 and 1963*). There was a noted decline in both average mark and the fraction of students scoring a "pass" on the TCPE over the period 1977-1980, so this paper looks at the results for 3227 University of Toledo students over this period. The analysis found that students were "generally weak in writing formulas, naming compounds, and solving chemical problems." Specific misconcepts included that oxidation must involve oxygen, and confusion between hydrogen peroxide and water. Confusing °C and K was also common. Simple arithmetic skills were in evidence, but algebraic manipulation - especially when involving negative numbers - was particularly apparent amongst failing students.

43. Walter J. Deal, "Predictions of course grades: uses and uncertainties." *J. College Sci. Teach.*, **1984**, *13*, 154-156. The practice at the University of California (Riverside) of using high school chemistry grades and SAT math scores to predict 1st-year chemistry grades is described. Typically, a grade almost a full letter below high school grade is predicted. The UCR expectation table is provided, indicating the median and range of grades based on SAT math score range and high school letter grade. 73% of students receive a grade within ±0.33 of a point of their predicted grade. There was no statistically significant difference between actual and predicted grades between groups of students assigned to different teaching assistants. The impact of supplemental assistance for at-risk students was also investigated; although an improvement in grade was seen for 2/3rds of these students, the gain was not significant compared to the class as a whole.

44. C. L. Craney and R. W. Armstrong, "Predictors of grades in general chemistry for allied health students." *J. Chem. Ed.*, **1985**, *62(2)*, 127-129. This study looks at the performance on the Toledo Chemistry Placement Test of health students at Russell Sage College, and includes a multivariate correlation analysis to identify first-semester college chemistry grade predictors based on this, Math SAT, and high school average and chemistry grade. The math SAT score was a significant predictor, whilst high school chemistry grades were the worst. It was noted, however, that the spread of individual results was very broad. The best use of the predictive relation appeared to be identifying at-risk students, who were then recommended to take additional problem-solving/tutorial sessions. Insufficient data were available to assess the efficacy of this intervention program.

45. J. W. Carmichael Jr., Sr. Joanne Bauer, John P. Sevenair, Jacqueline T. Hunter and Richard L. Gambrell, "Predictors of first-year chemistry grades for black Americans." *J.*

Chem. Ed., **1986**, *63(4)*, 333-336. This study looks at grade prediction for students at the predominately black Xavier University. The methodology is essentially the same as that of the UC Berkeley study (JCE 1979, Ozsogomonyan and Loftus), using multiple linear regression analysis to predict college chemistry grades from ACT scores, high school GPA and chemistry grade, and gender. Additionally, the Fall semester grade was included as a predictor variable for the following course. ACT Math or composite scores where still the best predictors for the first college chemistry course grade. Correlation coefficients were very similar to the UC Berkeley study; it was also noted that even the best equation only predicted grade to ±1 grade division. In comparing the two studies, it was noted that black students did poorly in majority white institutions. The authors propose that a "noncognitive factor, possibly a cultural one" is at play in such cases.

46. Robert E. Yager, Bill Snider and Joseph Krajcik, "Relative success in college chemistry for students who experienced a high-school course in chemistry and those who had not." *J. Res. Sci. Teach.*, **1988**, *25(5)*, 387-369. This paper compares 53 'high-ability' students attending summer session at the University of Iowa, with half having not taken high school chemistry. Junior HS students were recruited to a residential summer school so all students were motivated with above-average grades. Based on recurring testing and observations, no difference in academic achievement was found between students by the end of the course, but those who did not have high school chemistry made greater use of study time and access to tutors.

47. Brian H. Nordstrom, "Predicting performance in freshman chemistry." paper presented at the National Meeting of the ACS, Boston MA, April **1990**. ERIC document no. ED347065. This paper reports a study of engineering students at Embry-Riddle Aeronautical University (Prescott AZ) with data collected during the 1980s. Discriminant analysis was applied to student data including high school grades, aptitude and performance tests, and demographic data in order to divide the students into pass/fail categories at the end of their first semester of university chemistry. The final model identified the following as good predictors, in terms of decreasing standardized coefficients: SAT/ACT maths score, high school GPA, high school chemistry, high school maths GPA, and high school English grade.

48. Diane N. Bunce and Kira D. Hutchinson, "The use of the GALT (Group Assessment of Logical Thinking) as a predictor of academic success in college chemistry." *J. Chem. Ed.*, **1993**, *70(3)*, 183-187. The authors used a written test designed to measure logical reasoning abilities as a potential predictor of success in first-year chemistry. GALT scores were evaluated along with math and verbal SAT scores using stepwise multiple linear regression analysis to determine correlation with first year grades amongst various populations of students taking chemistry. Interestingly, math SAT scores were better predictors amongst science majors, while GALT scores were better predictors amongst non-science majors. Both the math SAT and GALT scores appear to be measuring the same (or similar or overlapping) abilities, so the latter can be used by an instructor if the former is not available.

49. Arlene A. Russell, "A rationally designed general chemistry diagnostic test." *J. Chem. Ed.*, **1994**, *71(4)*, 314-317. This describes the development of a diagnostic test by the California universities and colleges, the test aims to provide a diagnostic for success in first-year general chemistry. The test can be used to provide feedback directly to

students; with appropriate norms established, it can also be used as a placement exam. The exam has since been included in the ACS exams institute web site catalogue.

50. Harry E. Spencer, "Mathematical SAT test scores and college chemistry grades." *J. Chem. Ed.*, **1996**, *73(12)*, 1150-1153. This paper looks specifically at math SAT scores in relation to final first-year chemistry grades. Students were subdivided variously by gender, self-declared ethnicity, and program (chemistry major vs. non-majors). The relationship between SAT-M scores and grades was investigated using the chi-squared test to see if subgroups had different grade distributions from the whole. The analysis essentially looked at grade distributions for students in various SAT-M "bands". No gender difference was observed, while any ethnic differences were attributable to differences in mathematical skills represented by SAT-M scores (i.e. differences reflect the opportunity to acquire and develop such skills rather than any intrinsic difference). Chemistry and biochemistry majors were characterized as "overachievers" relative to non-majors, but the reasons for this were not studied.

51. Craig McFate and John Olmsted III, "Assessing student preparation through placement tests." *J. Chem. Ed.*, **1999**, *76(4)*, 562-565. The authors were concerned with the ability of diagnostic placement tests to accurately predict which students would pass (C or better) or fail a first-year chemistry course. The correlation between placement test scores for three different tests and the fraction of students succeeding was very good (R^2 of 0.82–0.98). Cut-off scores of 50% or higher successfully placed more than two-thirds of the students, but ~ 20% were incorrectly placed. Analysis of the questions on the tests suggested several that contributed most strongly to the predictive power of the instrument. The most effective questions "required multi-step mathematical operations and formal reasoning". The authors recommend using placement tests to provide advice rather than force placement, and that other factors such as motivation and maturity need to be taken into account.

52. Margaret J. Legg, Jason C. Legg and Thomas J. Greenbowe, "Analysis of Success in General Chemistry Based on Diagnostic Testing Using Logistic Regression." *J. Chem. Ed.*, **2001**, *78(8)*, 1117-1121. The California chemistry diagnostic test (CCDT) is used as a means of advising students about their first-year chemistry program. The authors wanted a tool to simplify this process by predicting "success" (defined as a grade of C or higher) or "failure" based on the CCDT score. This requires a different regression technique since the outcomes are binomially distributed when considered this way (rather than as a predicted course grade on a continuous scale). Logistic refers to an inverse logit function, which results in a probability expressed as a ratio of exponentials. This provides a much better "fit" to the binomial pass/fail data than a regular straight-line regression, and still allows a multivariate approach. I suspect, however, that students would be more interested in predicting their actual grade than a simple pass/fail, especially if the course is a pre-requisite for a competitive program!

53. Gale J. Clark and Wayne D. Riley, "The connection between success in a freshman chemistry class and a student's Jungian personality type." *J. Chem. Ed.*, **2001**, *78(10)*, 1406-1411. Myers-Briggs personality inventory categories were determined for 407 students in first-year chemistry. The distribution of personality types was compared with that for all 1085 first-year students, and with the chemistry faculty members. ANOVA was used to compare normalized average grades for each category with the class average.

It was found that the best-performing students were INTJ individuals, while the lowest scoring students were in the exact opposite category (EFSP). It was also noted that the distribution of faculty personality types was quite dissimilar from both the "background" and the chemistry students, but quite similar to the distribution of high-performing students. The reasons for this remain to be explored, as they could not be ascertained from the data obtained during the study. The authors seem unaware of prior work looking at different personality indicators, such as the Eysenck personality inventory.

54. C. A. R. Berg, "Factors related to observed attitude change toward learning chemistry among university students." *Chem. Ed. Res. Pract.*, **2005**, *6*, 1-18. (http://www.rsc.org/Education/CERP/) Used questionnaire data to derive a measure of student attitude towards learning chemistry in first year (general chemistry with a cross-section of chem. and non–chem. students.) Coherent student views on "good teachers". Factors influencing attitude shifts had to do with individual student motivation and perception of the goal/reward of work, as well as the time required to attain success in these tasks.

55. R. H. Tai, P. M. Sadler, J. F. Loehr, "Factors influencing success in introductory college chemistry." *J. Research Sci. Teaching*, **2005**, *42(9)*, 987-1012. Introduction to a 5-year US study across 12 institutions on the relationship between high school and 1st-year college or university performance; this paper describes the chemistry component of the study. A student's final high school math grade is a better predictor of their 1st-year chemistry grade than their mark in chemistry!

56. R. H. Tai, R. B. Ward, and P. M. Sadler, "High school chemistry content background of introductory college chemistry students and its association with college chemistry grades." *J. Chem. Ed.*, **2006**, *83(11)*, 1703-1711. A follow-up to their 2005 paper (*J. Res. Sci. Teach. 2005, 42(9), 987ff.*), this paper looks more closely at the high school curriculum content covered, and the time spent on different topics. In keeping with earlier findings, the amount of time spend on stoichiometry is important to success in university.

57. R. H. Tai and P. M. Sadler, "High School Chemistry Instructional Practices and their Association with College Chemistry Grades." *J. Chem. Ed.*, **2007**, *84(6)*, 1040-1046. In this instalment of the series on high school preparation for university chemistry, the impact of different instructional practices is examined. This includes the survey instrument questions given to high school students about their teachers' classroom methodology. One finding is that teacher demonstrations appear to have a negative impact, although this may be due to a lack of follow-up class discussion; the finding on labs is a little controversial (it seems to indicate that labs also have a negative impact) largely because no information is available about the nature, design, or implementation of those labs by the teachers. The two most effective teaching strategies appear to be peer teaching and the use of everyday examples.

58. Michael K. Seery, "The Role of Prior Knowledge and student aptitude in undergraduate performance in chemistry: a correlation–prediction study." *Chem. Educ. Res. Pract.*, **2009**, *10*, 227-232. This study of students in Dublin considered a cohort for which ~40% of students had little or no high school chemistry prior to first-year undergraduate studies. Multivariate linear regression was performed using a "top 6" high school

average, high school chemistry grade (if available), and scores based on attitude, interest, and attendance, as well as commuting distance. Term test and lab marks were also included in the study. Prior knowledge was strongly correlated ($r > 0.5$) with final course grade, although term test grades were more strongly correlated ($r > 0.6$). In the final multivariable regression model, however, prior knowledge contributed weakly (based on standard beta coefficient values) compared to high school "top 6" average and commuting distance. The R^2 for this final model was 0.618.

59. David C. Stone, "High to low tide: The high school–university transition." *Collected Essays on Learning and Teaching*, **2010**, *3*, 133-139. (http://apps.medialab.uwindsor.ca/ctl/CELT/celtvol-3.html) This paper presents initial data from a recent study on the high school–university transition in chemistry, emphasizing the extreme disparities in performance and grades between students despite their high school grades. This article discusses some of the reasons for this, and steps instructors can take to provide help and more valid assessments of factual knowledge and conceptual understanding early in the first semester of post-secondary education.

60. Dietmar Kennepohl, Matthew Guay, and Vanessa Thomas, "Using an Online, Self-Diagnostic Test for Introductory General Chemistry at an Open University", *J. Chem. Ed.*, **2010**, *87(11)*, 1273-1277. Students attending a remote on-line institution generally score poorer in their first chemistry course than other subjects. A need was identified for a test to better identify at-risk students and advise them accordingly. The test is fully described and both its validity and reliability assessed. Since students are generally older and further removed from high school, "a more recent measurement of performance is a better predictor" than high school grades.

61. Bo Jiang, Xiaoying Xu, Alicia Garcia and Jennifer E. Lewis, "Comparing two tests of formal reasoning in a college chemistry context", *J. Chem. Ed.*, **2010**, *87(12)*, 1430-1437.

62. Julia Y. K. Chan and Christopher F. Bauer, "Identifying at-risk students in general chemistry via cluster analysis of affective characteristics" *J. Chem. Ed.*, **2014**, *91(9)*, 1417-1425. This study used cluster analysis in conjunction with various affective domain instruments to identify differences between high and low achieving students that might be used to identify those at-risk of failure. These included: the Chemistry Self Concept Inventory (CSCI), the Attitude to the Subject of Chemistry Inventory (ASCI) versions 1 and 2, and the Motivated Strategies for Learning Questionnaire (MSLQ). Student performance was assessed using both the first term test and final exam for students in a general college chemistry course; these were converted to z-scores for statistical analysis. The authors found moderate to strong positive correlations between chemistry self-concept, math self-concept, emotional satisfaction, intellectual accessibility, and self-efficacy throughout. Students were classified into low, medium, and high affective groups based on the cluster analysis. This was based on item scores related to self-efficacy, test anxiety, emotional satisfaction, intellectual accessibility, and math and chemistry self-concepts. The groupings succeeded in identifying at-risk students amongst low-affective students but missed some among the high-affective group. Recommendations for interventions focused on training in study and metacognitive skills.

63. Mark S. Cracolice and Brittany D. Busby, "Preparation for college general chemistry: More than just a matter of content knowledge acquisition" *J. Chem. Ed.*, **2015**, *92(11)*, 1790-1797. This study of 157 students in a large general chemistry course used a variety of instruments to investigate factors affecting student success in a chemistry course for non-chemists. This included the Chemical Concepts Inventory (misconceptions), a measure of intelligence, the Classroom Test of Scientific Reasoning (Anton Lawson - Piagetian Formal operational thinking), a proportional reasoning assessment task, and an attitudinal survey. Students were assessed using ACS-EI general chemistry exam. The resulting data was examined using correlation and ANOVA methods. A medium correlation was found between the final exam and the CCI and CTSR scores. Teaching methods (such as Lawson's learning cycles) that promote the development of scientific (formal) reasoning are therefore strongly recommended.

B. Undergraduate Chemistry *After* First Year:

1. Gayle Nicoll and Joseph S. Francisco, "An investigation of the factors influencing student performance in physical chemistry." *J. Chem. Ed.*, **2001**, *78(1)*, 99-102. Two groups of students were extensively surveyed about their attitudes to a physical chemistry course, then tested regarding their math skills and logical thinking ability (using the Group Assessment of Logical Thinking test). Surprisingly, it was not the mechanical math skills that were found to correlate with course performance, but the ability to do word problems and reason logically. (This actually makes a lot of sense retrospectively!) This is different from the perceptions of physical chemistry professors as to what it takes to do well in physical chemistry, which were identified as math skills and persistence. Note, however, that effective math skills do require that logical thinking component! (The referencing in this paper is off: neither ref. 1 nor ref. 8 is to the work indicated in the text.)

2. Jodi L. Wesemann, "Undergraduate transitions: enhancing student success." *J. Chem. Ed.*, **2005**, *82(2)*, 196-198. This report summarises discussion from the 18th BCCE conference on student transitions. Primarily, this was concerned with the increasing diversity of post-secondary paths taken by students, including an increasing number transitioning from community college to university after 1st-year. The report summarizes the main points from the keynote speakers, as well as key recommendations resulting from the sessions. This includes improved communication and cooperation between colleges and universities to enhance student success in moving from one to the other.

3. David P. Pursell, "Predicted versus actual performance in undergraduate organic chemistry and implications for student advising." *J. Chem. Ed.*, **2007**, *84(9)*, 1448-1452. The author notes that high school grades (and other scores) are used in the admissions process, but that "the usefulness of predictive measures typically is superseded by actual academic performance" in undergraduate courses. At the authors' institution, a student score is calculated as the weighted average of SAT-math, SAT-verbal, and high school rank. This was combined with a validation exam in general chemistry, as well as general chemistry grade and cumulative GPA in first year, then subjected to correlation analysis. Actual first-year organic grades were found to be the best predictors of 2nd-year course grades, as might be expected.

4. Doreen Geller Leopold and Barbara Edgar, "Degree of mathematics fluency and success in second-semester introductory chemistry." *J. Chem. Ed.*, **2008**, *85(5)*, 724-731. Results from a mathematics assessment test for second-year chemistry students were analysed by gender, question subject matter, and correlation with average course grade in the second semester introductory chemistry course. The correlation for the latter is not as high as the graph might suggest, since the data is binned prior to the analysis and plotted against course average for students in each bin. Pedagogical misconceptions regarding students' mathematical ability were discussed in detail, along with suggestions for improving math fluency.
5. David C. Easter, "Factors Influencing Student Prerequisite Preparation for and Subsequent Performance in College Chemistry Two: A Statistical Investigation." *J. Chem. Ed.*, **2010**, *87(5)*, 535-540. This study looked at both demographic factors and content mastery from the prerequisite first-year chemistry course (as assessed by the ACS general chemistry exam) using ANOVA and multivariate linear regression analysis. Demographic factors included first-year GPA, where and when the course was taken, and firs-year instructor student evaluation average. The most significant variables were first-year GPA and chemistry course grade, although the individual correlation coefficients were fairly low (i.e. not much utility on their own). Students taking the prerequisite at 2-year institutions and transferring did more poorly than those taking first-year at the institution, which was attributed to the higher GPA required of the latter for entry.

Teaching and Learning Styles and Approaches:

A. Conceptions of Deep and Surface Learning

1. N. J. Entwistle and Dorothy Entwistle, "The relationships between personality, study methods and academic performance." *British Journal of Educational Psychology,* **1970**, *40*, 132-141. This study of first-year university and college students in the UK used the Eysenck Personality Inventory (EPI), study habits, and end-of-year grades to look at the influence of personality type and study habits on student success. This resulted in four scales: motivation, study methods, extroversion, and neuroticism. A-level grades were used to assess prior academic achievement. Correlation analysis was used to identify relationships between scales and outcomes, by both institution type and gender. Discriminant analysis was also performed on the items and scales. Overall, students attaining high marks tended to have high scores on study methods and motivation, while good study methods linked strongly with introversion and stability.
2. N. J. Entwistle, Jennifer Thompson and J. D. Wilson, "Motivation and study habits." *Higher Education*, **1974**, *3*, 379-395. Starting with a review of the prior literature on motivation and study habits, the authors develop certain profiles of different types of learners, who experience different learning outcomes. Organized study habits are emphasized as being consistently valuable for academic success. There are differences between students in terms of their motivation (intrinsic or extrinsic) for being at university, the degree to which they are convergent or divergent thinkers, and whether they are conscientious or obsessive about their studying. The second part concerns semi-structured interviews with final year students who had participated in an earlier study. These were identified as overachievers and underachievers (both high and low) based on a comparison of high school and university grades. This emphasized a strong difference

in university experience between those motivated by a "fear of failure" and "hope for success", even though both groups were capable of academic success.

3. F. Marton and R. Säljö, "On qualitative differences in learning: I – Outcome and process." *British Journal of Educational Psychology,* **1976**, *46(1)*, 4-11. This study looked at qualitative differences between students on their grasp (comprehension) of ideas through various learning tasks. Students read a passage on a specific topic, were interviewed about it, given a set of open questions on it, and finally asked about how they had studied it. Students generally exhibited either deep or surface levels of processing the information, with corresponding differences in learning outcome.

4. G. Pask, "Conversational techniques in the study and practice of education", *British Journal of Educational Psychology*, **1976**, *46(1)*, 12-25.

5. P. Tamir, "The relationship between achievement in biology and cognitive preference styles in high school students." *British Journal of Educational Psychology*, **1976**, *46(1)*, 57-67. This study of Israeli high school biology students looked at the relationship between achievement and a student's cognitive preference - simply stated, whether the student prefers to interact with material in terms of simple recall, understanding fundamental principles, critical questioning, or application. Students took a biological cognitive preference test, then were assessed using a biological achievement test. A correlation was found between achievement and cognitive preference, although students showed different preferences in different subject areas. Curiously, cognitive preference did not correlate with achievement on questions of the corresponding type as classified using Bloom's taxonomy; this was interpreted as a difference between preference and ability. A strong influence on cognitive preference was found to be the teacher's attitude towards inquiry-based learning.

6. J. B. Biggs, "Dimensions of study behaviour: Another look at ATI." *British Journal of Educational Psychology*, **1976**, *46(1)*, 68-80. This paper describes an attempt to study factors involved in student academic success that might not be amenable to study by a traditional one-dimensional pre-/post-test methodology. The author employed a study behaviour questionnaire (SBQ), which provides scores representing various student aptitudes or behaviours around learning. Combined with high school grades, GPA, gender, and faculty (Arts or Science) these were subjected to various statistical analyses. While different study strategies were evident amongst the students and between faculties, there appeared to be no single approach to academic success (as defined in terms of GPA); different students could employ different strategies to the same end.

7. F. Marton and R. Säljö, "On qualitative differences in learning: II – Outcome as a function of the learner's conception of the task." *British Journal of Educational Psychology*, **1976**, *46(2)*, 114-127. Following on from part I, students were split into two groups, both studying the same material. One was repeatedly tested using questions designed to provoke deep (what is the author's *intent*?) and the other surface-level (factual content) learning. Learning outcomes and recall were subsequently evaluated and the two groups compared. This demonstrated that a student's approach to learning was influenced by the perceived nature of the task, such as reproducing lists of items rather than identifying arguments and principles.

8. G. Pask, “Styles and strategies of learning”, *British Journal of Educational Psychology*, **1976**, *46(1)*, 128-148.

9. Frank Fazio and Geno Zambotti, “Some cognitive style variables and their relationships to chemistry achievement.” *J. College Sci. Teach.*, **1977**, *6*, 154-155. The authors used their Cognitive Preference Survey (CPS) tool to examine differences between chemistry and nonsicence majors in their respective introductory chemistry courses. This instrument provides scores on preferences for Memory (rote learning, factual), Principle (conceptual understanding), and Questioning (higher order processing). They also administered the Survey of Personal Values (SPV). A preference for Memory over Principles was characteristic of the nonscience majors, in contrast to the chemistry majors. Scores from both instruments were tested as potential predictors of final course grade. Key differences were again noted between chemistry and nonscience majors; differences between genders were also noted. It was concluded that science majors functioned at a higher cognitive level than their nonscience counterparts.

10. J. B. Biggs, “Individual and group differences in study processes.” *British Journal of Educational Psychology*, **1978**, *48(3)*, 266-279. This paper provides greater detail and analysis of student learning in terms of the Study Process Questionnaire (SPQ). This combines cognitive and affective factors relating to motivation, personality, ways of thinking, and specific study skills or strategies. These were found to interact in complex ways, along with institutional factors such as choice of faculty (arts versus science) and assessment practices. Data from three separate cohorts (one Canadian and two Australian) were analysed in a variety of ways, resulting in three distinct processes: reproducing, internalising, and organizing. These appear very similar to the surface, deep, and strategic styles identified by Entwistle et al using the ASI/ASSIST instrument.

11. Noel Enwistle, Maureen Hanley, and Dai Hounsell, “Identifying distinctive approaches to studying.” *Higher Education*, **1979**, *8*, 365-380. Part of the groundwork for the ASSIST instrument/questionnaire, this paper looks at developing a scale to measure aspects of study methods and motivation. Earlier scales suffered from “an over-simple description of study methods, though a failure to take [into] account ... different approaches to studying.” Here, earlier work by the authors is combined with that of Biggs, Marton, and Pask, to develop a broader depiction of student learning (See Fig.1 on page 376), along with a corresponding measurement instrument (the “Lancaster Inventory of Approaches to Learning”) In this context, the authors distinguish between a student’s learning style (preferred way of learning) and strategy (method of study for a specific learning task). Instrument validity was examined by factor analysis, and both discriminant analysis and correlation studies performed. These strongly related success in university to organized studying and low scores on surface approach items.

12. John Biggs, “Individual differences in study processes and the quality of learning outcomes.” *Higher Education*, **1979**, *8*, 381-394. This article looks at student learning in terms of both the processes students employ in order to learn, and the quality of their learning outcomes. This is done in terms of a survey instrument - the Study Process Questionnaire (SPQ) - and evaluation of the quality of student learning outcomes using the Structure of the Observed Learning Outcome (SOLO) taxonomy. The SPQ distinguishes study processes in terms of utilising, internalising, and achieving, with each having an affective (motivational) and cognitive (strategy) component. The SOLO

taxonomy is described as being functionally close to Bloom's taxonomy rather than Piaget's developmental hierarchy. Predictions about the quantity (recall) and quality (SOLO) of learning based on SPQ dimensions and specific instructions were largely confirmed by experiment.

13. Diana Laurillard, "The processes of student learning." *Higher Education*, **1979**, *8(4)*, 395-409. This small-scale study of undergraduate science students is interesting in that student interviews were conducted specifically with reference to actual learning tasks the students were engaged in as part of their respective courses. This avoided assuming that students exhibit stable learning styles to every task. Interviews required students to present what they were working on; they were then asked about how and why they approached the task. Transcripts were analysed in the terms introduced by Pask and Marton & Säljö (holist/serialist, operation/comprehension, deep/surface). Chemistry students were interviewed on tasks concerning phase equilibrium diagrams (cooling curves), reaction kinetics, and stereographic projections. Interestingly, the latter resulted in the highest use of operational learning procedures, even though students were also capable of using comprehension procedures. Interactions were found not just with the way students perceived the tasks, but how the material was taught in lectures.

14. Paul Ramsden, "Student learning and perceptions of the academic environment." *Higher Education*, **1979**, *8*, 411-427. This paper uses the Course Perceptions Questionnaire (CPQ) and semi-structured interviews to examine whether the academic environment created by a particular academic unit (including issues such as curricula, teaching, and assessment) affects student learning and approaches to learning. The study took place in a UK university, where students are predominantly located within a single department during their degree program. Different departments were found to require different learning approaches, although it was not clear if these were a consequence of departmental, or discipline-specific, differences.

15. Roger Säljö, "Learning about learning." *Higher Education*, **1979**, *8*, 443-451. Semi-structured interviews around a learning task were employed to look at conceptions of learning and the learning process for a very broad range of students (from 15-73 years in age). There is a progression from a very operational view of learning as the memorization of facts apart from any relevance or life context, to what the author terms a more 'thematic' view of learning, where the ability to truly understand and apply knowledge becomes valued over simply assembling an array of facts. To quote: "Real learning or understanding is, in this case, contrasted with rote learning and its main feature is that it in some way involves the abstraction of *meaning* from learning materials rather than a mere *reproduction* of them" (p.449, emphasis added).

16. Dai Hounsell, "Learning to learn: Research and development in student learning." *Higher Education*, **1979**, *8*, 453-469. This paper provides a good overall review of the literature on "learning to learn" in higher education as it emerged through the late 1960s into the 1970s. The author highlights both the different approaches to teaching students how to learn, and the difficulties associated with assessing the effectiveness of such programs. Links are made between the literature on student learning and individual development (*ie*. Perry's scheme), as well as the academic environment in which students find themselves. There is a particular emphasis on encouraging students to

develop deeper views of what constitutes learning, and of finding appropriate strategies for adapting to the learning requirements imposed by their respective courses.

17. Ference Marton and Lennart Svensson, "Conceptions of research in student learning." *Higher Education*, **1979**, *8*, 471-486. This thoughtful and thought-provoking review looks at the ways in which research into student learning has been conducted, and how this influences the way we think about student learning. The authors raise various distinctions throughout, such as: the differences between the context, content, and consciousness (awareness or self-reflection) or learning; the difference between how a learner is (traits) and how they function (processes); between a learner's orientation, intention, and process for learning; and between general and contextual descriptions of student learning. These considerations are used to illuminate six dichotomies in research on student learning, such as experiential–observational and quantitative–qualitative. These are not seen as mutually exclusive, although it can be difficult to maintain both in simultaneous perspective. As the authors conclude, "We cannot arrive at a procedure of observation which makes all the various aspects visible simultaneously."

18. P. Ramsden and N. J. Entwistle, "Effects of academic departments on students' approaches to studying." *British Journal of Educational Psychology*, **1981**, *51(3)*, 368-383. This paper uses both the approaches to study inventory (ASI) and course perceptions questionnaire (CPQ) to look at the influence on the academic environment (department, subject matter, teaching and evaluation style, social environment) on the ways in which students learn. Factor analysis of the ASI data confirms earlier work on distinct learning styles amongst students. Amongst the findings are that departments/courses with a high perceived workload and lack of freedom in learning are more likely to have students employing reproducing (surface/memorisation) strategies. These included physics and engineering and, to a lesser extent, economics.

19. D. Watkins and J. Hattie, "The learning processes of Australian university students: investigations of contextual and personological factors." *British Journal of Educational Psychology*, **1981**, *51(3)*, 384-393. This Australian study examined factors influencing student study behaviour using both the study behaviours questionnaire (SBQ) and its successor, the study processes questionnaire (SPQ), across different science-based faculties. Results from the questionnaires, combined with grades, faculty, and gender, were subjected to various statistical methods including MANOVA and discriminant analysis. The first study confirmed Biggs' earlier finding that science students adopted a more surface approach and scored higher on a neuroticism scale (anxiety). Students in higher years were also more likely to adopt a deep approach over a surface approach, with the second study indicating that this was more a matter of age rather than course level. The second study found some significant differences between arts and science students by gender, although the gender ratio of students in each area was not stated. Multiple linear correlation analysis suggested that the study skills scales could be used as predictors of GPA, although faculty differences were observed.

20. Graham Gibbs, Alistair Morgan and Elizabeth Taylor, "A review of the research of Ference Marton and the Gotegborg group: A phenomenological research perspective on learning." *Higher Education*, **1982**, *11(2)*, 123-145.

21. Patrick R. Thomas and John D. Bain, "Consistency in learning strategies." *Higher Education*, **1982**, *11(3)*, 249-259. The authors employ a similar approach to others (Biggs, Entwistle, etc) in using a questionnaire to identify students' approaches to learning as either surface or deep. A significant difference is that a much shorter questionnaire is used (seven items), tailored to a specific task that the students have just completed, and this is repeated for the same students across tasks in different courses. The study cohort consisted of first-year undergraduates in a teacher preparation program. In agreement with earlier studies, high achieving students made greater use of deep, rather than surface, study strategies in preparing for tests and essays. Students in this study appeared to adopt consistent strategies across courses (English and psychology) and tasks (test and essay).

22. Noel J. Entwistle and Paul Ramsden, *Understanding Student Learning*, Croom Helm (London/Canberra) and Nichols Publishing Company (New York), **1983**. This book summarizes a 5-year research program on student learning based at Lancaster University that began in 1976, out of which came the *Approaches to Study Inventory* (ASI) survey instrument. This was subsequently developed into the ASSIST instrument (Tait & Entwistle, 1996).

23. Noel Entwistle and Hilary Tait, "Approaches to learning, evaluations of teaching, and preferences for contrasting academic environments". *Higher Education*, **1990**, *19*, 169-194. The starting point for this study was a modified version of the ASI and elements of the CPQ, along with additional items, provided to 431 1st-year BEng students at Scottish universities and polytechnics. Factor analysis was used to confirm the structure of the ASI from previous studies, and to derive representative factors from the course evaluation items; the latter resulted in a five-factor solution. Following this, a five-factor analysis was performed for both sets of items in order to identify item overlap. "Good teaching" remained a separate factor with no overlap to studying. A shortened questionnaire was then given to 123 engineering and 148 psychology 1st-year students. In both studies, a high perceived workload was associated with surface (reproducing) learning, with students scoring high on a non-academic scale tended to be more negative in scoring teaching. Weaker relationships between factors and outcomes were found amongst the psychology students compared to those in engineering.

24. Paul Ramsden, "A performance indicator of teaching quality in higher education: The course experience questionnaire." *Studies Higher Ed.*, **1991**, *16(2)*, 129-150. This article describes the development of a performance indicator to collect information at the academic unit/program of study level, rather than the individual instructor. The literature on student evaluations of individual instructors is reviewed briefly, including a short discussion of the practices identified by both students and teachers of what constitutes "good teaching". This research builds on Ramsden & Entwistle's CPQ, in order to develop an instrument to measure "differences between academic organisational units". The reliability and validity of the CEQ were determined by various means. Following validation of the CPQ, it was used to examine differences in perceived teaching quality between different types of institution, between different fields of study (medicine, engineering, etc.), and between different institutions within the same field. It is proposed that the CEQ be used as a diagnostic tool within institutions in comparing academic units.

25. Keith Trigwell and Michael Prosser, "Improving the quality of student learning: The influence of learning context and student approaches to learning on learning outcomes." *Higher Education*, **1991**, *22(3)*, 251-266. The authors set out to study the validity of Ramsden's Course Perceptions Questionnaire (CPQ, subsequently CEQ). To obtain a clearer picture of the interaction between teaching, learning, and quality of outcome, they employed both a short form of the ASI (subsequently ASSIST) and Bigg's SOLO taxonomy. The study cohort consisted of 143 1st-year nursing students at an Australian university. The results validated the structure of the CEQ and support the view that teaching environments perceived as encouraging a deep approach to learning "are more likely to facilitate higher quality learning" than simply trying to discourage surface learning. That is, instructors should actively promote a deep approach rather than simply discouraging a surface one. Importantly, the authors point out that attempts to make material more interesting and relevant will not work if only the instructor – and not the students – perceives that to be the case!

26. Hilary Tait and Noel Entwistle, "Identifying students at risk through ineffective study strategies." *Higher Education*, **1996**, *31(1)*, 97-116. This paper describes the development of the ASSIST survey instrument from the previous "Approaches to Studying Inventory" (ASI), and its use in identifying at-risk students early in their undergraduate program. It also provides a brief review of other study inventories available at that time.

27. Keithia L. Wilson, Alf Lizzio and Paul Ramsden, "The development, validation and application of the course experience questionnaire." *Studies Higher Education*, **1997**, *23(1)*, 33-53. A short-form version of the CEQ has been used for annual student surveys at Australian universities from 1993. Over that time, various questions and concerns regarding the instrument have been raised. This paper reports a large-scale validity and reliability study of both long and short form variants, including a new "General Skills" scale to reflect evolving national graduation requirements. Construct reliability was evaluated using Cronbach's alpha. Validity was investigated using both exploratory FA (principal components analysis with oblique rotation) and confirmatory FA combined with structural equation modelling. Additional correlation analyses with ASI results established criterion validity. The findings duplicate and extend those of earlier research, confirming the link between good teaching and deep learning. The paper concludes with a discussion of practical uses of the CEQ in higher education.

28. Keith Trigwell, Michael Prosser and Fiona Waterhouse, "Relations between teachers' approaches to teaching and students' approaches to learning." *Higher Education*, **1999**, *37*, 57-70. These authors looked at both teaching approach and learning approach, to examine the interplay of both on learning outcomes. They note the importance of both conception of teaching AND perception of teaching context to the approach adopted by university instructors. The study used the Approaches to Teaching Inventory - Information transmission/teacher-focussed versus conceptual change/student-focussed approaches – and the Study Process Questionnaire to look at student approaches to learning. There was definite evidence of connections between the teaching and learning approaches combining to promote either deep or surface learning.

29. Noel Entwistle, "Promoting deep learning through teaching and assessment: Conceptual frameworks and educational contexts." *Teaching and Learning Research Program*

(TLRP) Conference paper, **2000**. This paper presents a review of the underlying framework for the ASSIST instrument within the larger context of learning outcomes, conceptions of teaching, and the complex interplay of factors that influence student learning. This is particularly useful as it highlights many areas beyond the scope of the ASSIST instrument that nonetheless make important contributions to the intrinsic variation in success between students.

30. Noel Entwistle, Hilary Tait and Velda McCune, "Patterns of response to an Approaches to Studying Inventory across contrasting groups and contexts." *European Journal of Psychology of Education*, **2000**, *15(1)*, 33-48. This paper compares results from the ASSIST instrument between students at a number of British universities, a Scottish technical university, and a South African university. A particular focus was placed on the occurrence of dissonance - conflicting scores on different item scales, reflecting for example a discrepancy between study approach and perceived learning environment or assessment demands. Cluster analysis (using k-means joining) was used to further explore groups of students within each data set, with the aim of identifying differences between successful and unsuccessful students.

31. Noel Entwistle and Velda McCune, "The conceptual bases of study strategy inventories." *Educ. Pysch. Rev.*, **2004**, *16(4)*, 325-345. This review describes the "historical origins and development of a series of well-known study strategy inventories and seeks to identify their conceptual bases." It is useful in being both a source of historical references and providing a side-by-side comparison of seven such inventories. This provides a handy "rosetta stone", showing the similarities and differences in both items and terminology between the inventories.

32. Carolin Kreber, "The relationship between students' course perception and their approaches to studying in undergraduate science courses: A Canadian experience." *Higher Education Research & Development*, **2003**, *22(1)*, 57-75. This study looks at study approaches and the learning environment, contrasting deep, surface, and strategic approaches to learning. The ASSIST and CEQ survey instruments were administered to students at several Canadian universities *during the last week of term*. Factor analysis was performed on the ASSIST data, and Cronbach α internal reliability scores for the various main and secondary item scales. A similar analysis was performed on the CEQ data, along with principal component analysis. Finally, stepwise correlation coefficients were calculated between the ASSIST and CEQ data. The author notes that mature students were more likely to adopt a deep approach, while a heavy workload contributed strongly to a surface approach. Gender was only a noticeable predictor for a strategic approach.

33. Maryann Byrne, Barbara Flood and Pauline Willis, "Validation of the approaches and study skills inventory for students (ASSIST) using accounting students in the USA and Ireland: A research note." *Accounting Education*, **2004**, *13(4)*, 449-459. The ASSIST instrument was administered to students taking their first accounting course at both US and Irish institutions. Validation was undertaken by factor analysis and calculation of Cronbach α internal reliability scores for the different scale and subscale items in the inventory. A cross–loading was noted for the monitoring effectiveness item between both deep and strategic factors, as has been noted in other validation studies. One difference was the alertness to assessment item, which loaded on the deep factor for US

students and did not load significantly on any factor for the Irish students. Similar problems have been found for this item in other studies with first-year students.

34. Charles A. Buckley, Edd Pitt, Bill Norton and Tessa Owens, "Students' approaches to study, conceptions of learning and judgements about the value of networked technologies". *Active Learning Higher Ed.*, **2010**, *11(1)*, 55-65. This study seeks to examine the role of technology in a blended education environment in terms of its impacts on student approaches and strategies for learning and subsequent learning outcomes. The study cohort consisted of 144 1st-year undergraduate sports studies students in the UK. Correlation analysis was performed between the ASSIST main scales and the Judgements about Networked Learning (JNL) scale. In keeping with a number of earlier studies, positive correlations were observed between deep and strategic scales and students' perceptions of their learning environment while surface learners showed a negative correlation. Essentially, deep and strategic learners engage more with an online environment and are more independent learners. It is interesting to note that the cohort in this study had, as part of their course, been exposed to several learning styles inventories, as well as critical self-reflection on their learning experience.

35. Sandra Cristina A. T. S. Valadas, Fernando R. Gonçalves and Luís M. Faísca, "Approaches to studying in higher education Portuguese students: A Portuguese version of the approaches and study skills inventory for students". *Higher Education*, **2010**, *59*, 259-275. The validity and reliability of a Portuguese version of the ASSIST survey instrument were investigated for 566 students in one institution, comprising students in a variety of faculties, and from both first and final years of study. The authors performed exploratory analysis using "principal components axis method ... as well as a non-orthogonal rotation procedure", as well as calculating Cronbach α values for the main scales and sub-scales. Only the main scale structure was subject to factor analysis. The authors also looked at the mean, std. deviation, skewness, and kurtosis of the scores on each scale and sub-scale. The data was compared to other international validation studies. The authors noted a positive correlation between the deep and strategic scales, and negative correlations between these and the surface scale. Overall, validity and reliability were confirmed, but questions remained about specific sub-scales and items.

36. Julia Y. K. Chan and Christopher F. Bauer, "Learning and studying strategies used by general chemistry students with different affective characteristics", *Chem. Ed. Res. Pract.*, **2016**, *17(4)*, 675-684. The authors described the validation and use of a new instrument, the Study Strategies Survey, as part of a research study looking at how and why different students approach learning. The study cohort was the same as in Chan & Bauer JCE 2014 91 1417. These were used to examine how characteristics such as emotional satisfaction, intellectual accessibility, chemistry self-concept, math self-concept, self-efficacy, and test anxiety related to a student's learning and studying strategies. Students completed a series of survey instruments (earlier paper) and were then invited to discuss their approach to doing practice exams, use of lecture learning strategies, and exam preparation strategies. The results were subjected to PCA, correlation analysis, and MANOVA. The most effective study methods observed are consistent with other studies, but the items and student comments provide useful context. The authors conclude, "The results suggest that learning and studying behaviors are different for students who exhibit higher vs. lower sets of affective characteristics, and

that those behaviors are linked to better exam performance. These results regarding attitude, motivation, and self-concept complement the work of others, reported in the introduction, which primarily considered student achievement measures. The study strategies survey seems to have provided some insight regarding student learning approaches, but its psychometric characteristics should be more strongly developed and established in future work".

37. Diane M. Bunce, Regis Komperda, Maria J. Schroeder, Debra K. Dillner, Shirley Lin, Melonie A. Teichert and JudithAnn R. Hartman, "Differential use of study approaches by students of different achievement levels" *J. Chem. Ed.*, **2017**, *94(10)*, 1415-1424. This study used a modified version of the ASSIST questionnaire to look at approaches to studying amongst first year chemistry students in the US Naval Academy. Validity and reliability of the M-ASSIST instrument were investigated, showing that it could be used to categorize study approaches within the cohort investigated. Note that this was only on the Deep and Surface scales - the M-ASSIST does not include the Strategic scale. The study then looked for differential study approaches between high and low achieving students, as well as looking to see how intermediate students approached studying. There was a strong inverse correlation between surface score and outcome, with a small positive correlation between deep score and outcome. Both structured means modelling (SMM) and ANOVA were employed to look for differences between the various outcome groups. These results confirmed that the surface and deep scales are not mutually exclusive – students may use strategies characteristic of both – but that more consistent use of deep strategies resulted in better learning outcomes.
38. Emily L. Atieh, Darrin M. York and Marc N. Muñiz, "Beneath the surface: An investigation of general chemistry students' study skill to predict course outcomes", *J. Chem. Ed.*, **2021**, *98(2)*, 281-292. This study uses the short form Modified-ASSIST instrument to score students on their deep and surface approaches to learning (the strategic scale is not included.) One goal of the study was to improve student placement efforts to ensure that students in remedial programs weren't just given an opportunity to cover missed material or learn at a slower pace, but to help them adopt successful study approaches. The study cohort consisted of undergraduate students in multiple sections of introductory general chemistry. The results show a pronounced inverse correlation between surface scale score and course outcome, with a slight positive correlation between deep scale score and course outcome. Logistic regression was carried out to examine which factors (study approach and EDI indicators) contributed to success or failure. Students specific ideas and approaches to exam preparation were also investigated, confirming the value of known successful study habits.

B. Other Learning Style Schemes:

1. John G. Sharp, Rob Bowker and Jenny Byrne, "VAK or VAK-uous? Towards the trivialisation of learning and the death of scholarship." *Research Papers in Education*, **2008**, *23(3)*, 293-314. This critical review looks not so much at the research on VAK (or VARK or VAKT), but at the way in which it has been adopted and implemented in elementary/middle schools throughout England and Wales. Discrepancies between actual research studies and various misrepresentations or misinterpretations of that research are highlighted.

2. Harold Pashler, Mark McDaniel, Doug Rohrer and Robert Bjork, "Learning styles: Concepts and evidence." *Psychological Science in the Public Interest*, **2008**, *9(3)*, 105-119. This review examines the research literature on learning styles in education. In particular, it examines whether there is any evidence to support the idea that individuals learn best when taught in a way that meshes with their preference for style of presentation (VAK) or preferred mental processing (analysis, listening). The authors found "ample evidence" that learners will express a preference on learning style questionnaires, and that such instruments have "at least some psychometric reliability. They found, however, "virtually no evidence" from properly designed and implemented studies that learners had better outcomes when instructional style matched learning preference (i.e. a learning style–treatment interaction study). The authors conclude that learning style assessments should not be introduced into educational systems unless/until such evidence is produced. The particular learning styles schemes reviewed were those of Dunn & Dunn, Kolb, and Honey & Mumford. The authors also discussed aptitude-treatment and personality-treatment interaction studies.

Chemistry Curriculum:

1. Laurence E. Strong, "Facts, Students, Ideas" *J. Chem. Ed.*, **1962**, *39(3*), 126-129. This article formally introduces the Chemical Bond Approach (CBA) high school curriculum project, which had first been described in 1958. The article goes on to describe the approach adopted to specific topics within the curriculum, including the experiments chosen to illustrate the concepts under study. While the CBA curriculum was not fully developed at this point, the article does give a good idea of progress to date.
2. Carl W. Clader, "Chem Study – a progress report" *School Sci. Math.*, **1963**, *63(5)*, 377-378. This short report describes the origins and development of the CHEM Study program, and was published in the same year as the first text (edited by George Pimentel) for the new course. This started under the auspices of the American Chemical Society with a committee drawn from university chemistry instructors lead by A. B. Garrett and Glenn Seaborg, which subsequently drew in a number of high school chemistry teachers, writers, and consultants. Progress was made through a series of summer institutes and field testing by collaborating schools, resulting in the completion of a curriculum, course text, laboratory text, and instructor materials.
3. Robert W. Heath and David W. Stickell, "CHEM and CBA effects on achievement in chemistry" *The Science Teacher*, **1963**, *30(5)*, 45-46. This study compared students in traditional curriculum high school programs with those in (a) CHEM Study and (b) CBA based courses. All students wrote the SCAT and performed comparably, with no significant difference in average scores. Students also wrote the Cooperative Chemistry Test (CCT) at the end of the course, as well as either the CHEM Study or CBA final exam. The CCT was considered to be a common test covering the content of the traditional high school chemistry curriculum. Students in 'traditional' courses attained significantly higher average scores on the CCT than CHEM Study/CBA students. Similarly, CHEM Study/CBA attained significantly higher average scores on their tests than students in traditional courses. In short, students did better on the test based most closely on the curriculum they had studied.

4. Robert G. Rainey, "A comparison of the CHEM Study curriculum and a conventional approach in teaching high school chemistry" *School Sci. Math.*, **1964**, *64(6)*, 539-544. Four groups of students attending high school in Minneapolis MN were split between CHEM Study and traditional high school chemistry classes. Both groups took the ACS-NSTA Cooperative Chemistry Exam and the CHEM Study final exam at the end of the year. Both programs included laboratory experiments, with the CHEM Study materials based around the experiments while the traditional course experiments were follow-up to class content. A matched–pair analysis was performed using the t-test on both pre-test and final exam scores. No significant difference was found between the two groups on either count.
5. Robert D. Sherwood. "Student attitude and achievement in IAC and CHEM Study" *J. Chem. Edu.*, **1978**, *55(11)*, 733-734. This article compares the use of CHEM Study materials with the Interdisciplinary Approach to Chemistry (IAC) curriculum for high school chemistry. The study cohort consisted of students in grades 9-12 at a small Indiana high school over a two year period. Students were assessed on content using the ACS-NTSA cooperative exam, while attitudes to chemistry were assessed using the Student Opinion Survey in Chemistry (SOSC; Heikkinen, 1974). The results are difficult to interpret due to limited scope and lack of proper control group in the research design. The general conclusion is that students are unlikely to be disadvantaged by using the IAC curriculum, and may retain a better attitude towards chemistry as a subject.
6. Tony Mitchell, "What do instructors expect from beginning chemistry students? Part 1" *J. Chem. Edu.*, **1989**, *66(7)*, 562-564. High school and college/university instructors were surveyed as to what content knowledge, skills, and attributes they felt students should have in order to be successful in post-secondary education. Topics and skills were based on the ACS high school chemistry exam. There was a considerable difference between the two groups, which was much more pronounced for topics than skills. Post-secondary instructors were far less concerned overall with specific content knowledge than general abilities related to science and chemistry. The author also raised concerns that most students forget what they learned in high school anyway, so offering a pseudo-first year chemistry course in high school was deemed of less value than teaching study and problem-solving skills.
7. Tony Mitchell, "What do instructors expect from beginning chemistry students? Part 2" *J. Chem. Edu.*, **1991**, *68(2)*, 116-118. A follow-up to part 1, focusing on the skills and abilities that high school and college/university instructors feel are most likely to contribute to success in chemistry. This paper focusses on academic skills and personal attributes such as note taking, facility with algebra, and perseverance. There are striking differences in perceived importance between the various groups of instructors, and particularly between high school teachers, science education faculty, and college/university instructors. The paper raises valid questions and concerns over who sets the high school chemistry curriculum and what it should emphasize. This touches on the different needs between students who will not pursue post-secondary chemistry and those who will, as well as the potential impact of having only a 'college/university prep' version of the course in terms of student interest.
8. A. Truman Schwartz, "Contextualized chemistry education: The American experience" *Int. J. Sci. Edu.*, **2006**, *28(9)*, 977-998. This paper describes the development and testing

of the 'Chemistry in Context' text book and associate curriculum for use in introductory post-secondary chemistry primarily for non-science majors. It builds on the approach previously adopted for the development of 'Chemistry in the Community', pioneered by the American Chemical Society and the National Science Foundation. There is a short discussion of earlier developments in the high school/college chemistry curriculum and texts, including the CHEM Study and CBA revisions. Evolution and implementation of both the text and associated materials is described, with discussion of various research studies that have been undertaken to evaluate effectiveness.

9. Alex H. Johnstone, "You Can't Get There from Here." *J. Chem. Ed.*, **2010**, *87(1)*, 22-29. This article is based on Alex Johnstone's address on receiving the 2009 ACS award for achievement in research for the teaching and learning of chemistry, delivered March 24th 2009. In it, he provides a critique of the "modern" approach to teaching chemistry implemented in the "Sputnik" era, particularly as it relates to the intellectual development demanded of students. An alternative approach is suggested which aims to connect with students' prior knowledge before moving into the more abstract concepts and topics, allowing time to develop logical/abstract reasoning ability. The article also includes a summary of cognitive models for information processing and their implications for learning chemistry, along with survey results of what skills/abilities chemists actually report using in the workplace.

Lectures and Presentations:

1. Uri Zoller, "Are lecture and learning compatible? Maybe for LOCS: unlikely for HOCS" *J. Chem. Ed.*, **1993**, *70(3)*, 195-197. This paper examines how instructors might improve students use of higher level cognitive skills (HOCS) over lower order ones (LOCS). The principle conclusion is that the traditional lecture with an emphasis on equations, facts, and algorithms (with corresponding assessments) is antithetical to such aims. Realizing high level learning goals (such as the development of critical thinking and problem solving skills) therefore requires a different approach to the teaching of chemistry, as well as new ways of assessing student learning. Examples are given in the article and associated references.
2. A. H. Johnstone and W. Y. Su, "Lectures - a learning experience?" *Educ. Chem.*, **1994**, *81*, 75-79. A study of student attention, note–taking, *etc.* in lectures; lessons for instructors! Lectures were recorded, and all blackboard/overhead material copied. Student notes from the same lectures were also obtained, and analysed. The analysis took into account individual students' working memory and ability to isolate essential information from background "noise".
3. David K. Smith, "Use of the mid-lecture break in chemistry teaching: a survey and some suggestions." *J. Chem. Ed.*, **2006**, *83(11)*, 1621-1624. Comparison of student opinions regarding the interest, educational value, and overall value of different types of mid-lecture break: Simple pause; Voting (clickers *etc*.); "Fascinating Facts"; Problem solving; and Demonstration. Demos were rated highest overall; problem solving was seen as having the highest educational value (as it involves working with content); "fascinating facts" seen as more interesting. Students were not aware of value of "mental break" in terms of attention/engagement.

4. Dudley E. Shallcross and Timothy G. Harrison, “Lectures: electronic presentations versus chalk and talk – a chemist’s view.” *Chem. Ed. Res. Pract.*, **2007**, *8(1)*, 73-79. (http://www.rsc.org/Education/CERP/) An attempt to research what makes for good lecture presentation - chalkboard, overheads, or PowerPoint™. Examines some of the potential pitfalls to be avoided; essentially, any good tool can be undermined by poor implementation and execution on the part of the instructor!

Multimedia Teaching and Learning:

1. Guy B. Homman and Kenneth E. Anderson, “A study of several factors and their relationship to achievement in high school chemistry by use of factorial design and covariance” *Science Education*, **1962**, *46(3)*, 269/-282. This study looks at student outcomes from high school chemistry courses which made extensive use of films as teaching aids to teach chemistry. The study cohort consisted of 590 students in 33 classes across 5 high schools in Wichita Kansas (1959-60 school year). The classes were split between those that did (7) and did not (23) make use of the films. Students were given a pre- and post-test using the Anderson Chemistry Test, the ACS-NSTA Cooperative Exam for High School chemistry, and the SCAT form 2A (for grade 11 & 12 students). Results were subjected to ANOVA and ANCOVA to look at any differences between the film and non-film groups based on gender, career goals, or science and mathematics preparation (prior courses). It was found that the non-film groups generally scored better than the film groups on understanding chemical facts and concepts, in keeping with prior studies. This was taken as highlighting the need for research in to the effective use of media, and particularly the quality of the materials offered (which was not described or evaluated in this paper)
2. Michelle P. Cook, “Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles.” *Science Education*, **2006**, *90(6)*, 1073-1091. This article provides a good introduction to the research on the impact of prior knowledge and cognitive load theory as it relates primarily to multimedia presentations. This is translated into several instructional design recommendations that, if implemented, can increase the effectiveness of visual materials for student learning. See the table on P.1086 for a quick overview of the main principles.
3. Derek A. Muller, Manjula D. Sharma, and Peter Reimann, “Raising cognitive load with linear multimedia to promote conceptual change.” *Science Education*, **2008**, *92(2)*, 278-296. This paper describes a convergence of constructivism and cognitive load approaches to instructional multimedia design. The main premise is that using multimedia to present alternate (confounded) conceptions will provide a means by which the students’ own misconceptions can be challenged and modified, resulting in a more accurate understanding. This requires more mental effort. One finding that illustrates this is that students viewing multimedia without misconceptions presented, tended not to invest as much attention, and often felt that the presentation actually supported their own misconceptions. In other words, the material was not recalled accurately. Students confronted with misconceptions tended to have more accurate recall of the material, and perform better on post-test questions.

Calculations and Problem-Solving:

1. Susan C. Nurrenbern and Miles Pickering, "Concept learning versus problem solving: Is there a difference?", *J. Chem. Ed.*, **1987**, *64(6)*, 508-510. The authors note that (since earlier curriculum reforms) there has been a strong emphasis on the quantitative approach to teaching general chemistry; that is, students perform lots of calculations. The research – involving questions on gas laws and stoichiometry – looked to see whether students were simply applying a rote algorithmic approach to the calculations ("plug-and-chug") or whether they were actually making use of conceptual understanding. The main conclusion is that the former is the case for most students. In concluding, the authors note that "Massive amounts of research in education have tried to identify the reasons why students cannot solve problems, but few researchers have questioned the assumed equivalence between problem-solving educational objectives and conceptual educational objectives." This last point is a significant issue for chemistry teaching.
2. David V. Frank, Claire A. Baker, and J. Dudley Herron, "Should students always use algorithms to solve problems?", *J. Chem. Ed.*, **1987**, *64(6)*, 514-515. The article differentiates between exercises (where it is clear what equation or process must be applied) and problems (where it is not clear how to get from the question to the solution). Algorithmic problem-solving only works well for exercises, since these are well defined. It can be used for problem-solving if the student realizes the need to modify the algorithm for the problem at hand, but not all students are successful in this. Instructors should emphasize the concepts behind algorithms and encourage students to see the connections between similar situations.
3. Diane M. Bunce, Dorothy L. Gabel, and John V. Samuel, "Enhancing chemistry problem-solving achievement using problem categorization" *J. Reseach Sci. Teaching*, **1991**, *28(6)*, 505-521. This study looks at the use of the Explicit Method of Problem Solving (EMPS) as a tool to enhance students' problem solving skills in chemistry. In this case, the step of categorizing the type of problem being addressed was emphasized with explicit instruction. Specifically, students are taught to assign "a description to a chemistry problem according to the major concept(s) involved". Students were administered the Logical Mathematical Reasoning Test, as well as a pre- and post-test either side of instruction that required them to categorize problems. A control group was simply shown a worked solution to problems, while the study group were engaged in discussion to identify the underlying concepts involved in the same problems. In addition to various tests, students were interviewed to describe their thinking while solving the problems. While differences in achievement scores were noted between the groups, these were not statistically significant; note however, that the sample size was small. Recommendations for best practice when setting problems are made.
4. Sebastian G. Canagaratna, "Is dimensional analysis the best we have to offer?". *J. Chem. Ed.*, **1993**, *70(1)*, 40-43. A comparison of two approaches to calculations common in chemistry texts: dimensional analysis (DA, aka factor label and unit analysis) and the method of equations (ME). The main criticism against DA seems to be that it focuses exclusively on balancing out units without identifying the relationships first; that is, students can get by simply by rote memorization the units of different parameters. A

secondary criticism is that it bypasses symbols and needlessly complicates calculations involving units with prefixes (since these can be addressed by simply substitution). However, there is very little research on the relative merits of the two approaches at time of publication. There are unfortunately some misconceptions evident in this paper that detract from the most relevant points raised.

5. Mary B. Nakhleh, "Are our students conceptual thinkers or algorithmic problem solvers?" *J. Chem. Ed.*, **1993**, *70(1)*, 52-55. The author constructed a simple test using paired conceptual and algorithmic multiple choice questions on five common areas of introductory general/physical chemistry. The aim was to identify conceptual thinkers amongst "second tier" students who might choose not to pursue chemistry based on teaching that was more algorithmic than conceptual focused. A simple four-quadrant classification system was employed based on which types of question (conceptual or algorithmic) students answered correctly. The data was analysed to look for differences among remedial, science/engineering, majors, and honours students. Average scores for each student group were higher on algorithmic over conceptual questions, and there were significant differences in performance on the paired problems. 31% of students fell in the low conceptual/high algorithmic category, meaning they had completed the course without gaining understanding of what they had been taught.

6. Mary B. Nakhleh and Richard C. Mitchell, "Concept learning versus problem solving: There is a difference" *J. Chem. Ed.*, **1993**, *70(3)*, 190-192. This mixed-mode research study used a combination of paired algorithmic and conceptual problems to categorize students as high or low functioning conceptual and algorithmic problem solvers, followed up with interviews to explore their thought processes, approach, and conceptual understanding. The results for a cohort of chemistry majors showed an even split between high and low conceptual ability thinkers, with a strong bias (85% overall) towards high algorithmic ability. This does not seem to translate into actual conceptual understanding, however, and so may be of limited utility. The authors conclude that teaching should take on a much more concept-based framework to promote higher level understanding and problem-solving abilities.

7. Amy J. Phelps, "Teaching to enhance problem solving: It's more than just the numbers" *J. Chem. Ed.*, **1996**, 73(4), 301-304. This study looked at the impact of taking a more conceptual approach to teaching introductory chemistry to classes of science and non-science majors. Both classes (~150-200 students each) were taught the same way by the same instructor, while an observer took field notes on the class interactions during discussion of the problems presented. These revealed striking differences in to "the ways in which the two groups of students have been socialized with regard to science". That is, the science majors were conditioned to expect calculations, and would refrain from engaging in discussion or tackling the open-ended conceptual problems while waiting for the "right answer", whereas the nonscience majors were more likely to engage in discussion and questioning. The main findings were that nonscience majors were much more engaged in the course, learned more chemistry, and were more enthusiastic about the subject as a result.

8. Diana S. Mason, Duane F. Shell and Frank E. Crawley, "Differences in problem solving by nonscience majors in introductory chemistry on paired algorithmic-conceptual problems" *J. Res. Sci. Teach.*, **1997**, *34(9)*, 905-923. This study of 180 students in an

introductory course for nonscience majors at the University of Texas sought to find similarities and differences in the approaches used by students and faculty to solving algorithmic and conceptual questions. Many of the paired questions used in the study were taken from earlier work for consistency; these would be similar problems were the first instance could be solved by calculation while the second required reasoning from first principles by identifying the key concept. Students were categorized as high and low algorithmic and conceptual problem solvers based on the test scores; students and faculty were also interviewed to understand the processes by which they addressed the problems. Time required and the number of steps involved increased with decreasing proficiency, as might be expected. The general conclusion was that students should spend more time developing students' conceptual understanding in order to boost problem solving abilities.

9. Susan C. Nurrenbern and William R. Robinson, "Conceptual questions and challenge problems", *J. Chem. Ed.*, **1998**, *75(11)*, 1502-1503. This short article introduces the Conceptual Questions and Challenge Problems web site originally hosted as a resource of JCE Internet (no longer accessible following the transfer of JCE to the ACS journals web site). The authors note that students can be assessed under three broad categories of questions: recall, algorithmic, and higher order (which includes conceptual questions). Conceptual questions "ask the student to: justify a choice, predict what happens next, explain why something happens, link two or more areas or topics, recognize questions phrased in a novel way, or extract useful data from an excess of information". These require students to operate at the higher cognitive levels within Bloom's taxonomy.
10. George M. Bodner, "Problem solving: the difference between what we do and what we tell students to do." *U. Chem. Ed.*, **2003**, *7*, 37-45. This article tackles the questions: how do you solve problems? and, how do you teach people to solve problems? It starts by differentiating between exercises and actual problems, and describes some of the strategies employed by different groups for problem solving. In particular, it demonstrates that one key differentiation between a question being an exercise and a problem is novelty for the person confronted by the question. The bulk of the article explores different strategies for problem solving, including the work of Polya and Wheatley. A number of useful examples and strategies are included.
11. Dimitrios Stamovlasis, Georgios Tsaparlis, Charalambos Kamilatos, Dimitrios Papsoikonomou and Erifyli Zarotiadou, "Conceptual understanding versus algorithmic problem solving: further evidence from a national chemistry examination". *Chem. Ed. Res. Pract.*, **2005**, *6(2)*, 104-118.

Assessment:

1. Karen M. Scouller and Michael Prosser, "Students' experiences in studying for multiple choice question examinations". *Studies Higher Ed.*, **1994**, *19(3)*, 267-279. This study used Bigg's SPQ along with a custom questionnaire and interviews to examine the relationship between the ways students prepared for assessments, the style of assessment (multiple choice exam or essay), and their perceptions of the level of learning required by that assessment (recall, analysis, etc.) Students (121) were drawn from 1st and 2nd-year courses in (a) life science and (b) nursing programs at an Australian institution.

Correlation and factor analysis was performed on the data, both with and without assessment results, for both the entire cohort and at the course level. Surface learners were found to be "confused" about what MC exams assess and had no clear strategies for preparing for them; this was in contrast to deep and strategic learners. Further, students who perceived MC exams as assessing high order learning were more likely to employ deep strategies than those who considered them to assess only recall.

2. Karen Scouller, "The influence of assessment method on students' learning approaches: Multiple choice question examination versus assignment essay". *Higher Education*, **1998**, *35*, 453-472. This study examines students' preferences and approaches to study for two types of exams: multiple choice and essay. A group of 206 2nd-year Australian education students completed a questionnaire based in part on Biggs SPQ, after having written a MC exam. MC exam, essay, and course grades were also recorded. The resulting data was analysed using t-tests, factor analysis, and multiple linear regression. Students were "more likely to employ surface strategies" on MC exams and perceived such testing to operate at a recall level of learning rather than involving higher order thinking; the converse was true for the essay assignment. Unfortunately, there is no discussion of the nature of the MC questions, and whether these had been validated against taxonomic criteria; this may explain inconsistent results from the factor analysis. Poor essay scores were associated with a surface approach and perception of a low-level assessment; deep students anticipating higher-level assessment scored higher.

3. David DiBattista, John O. Mitterer, and Leanne Gosse, "Acceptance by undergraduates of the immediate feedback assessment technique for multiple-choice testing." *Teaching Higher Ed.*, **2004**, *9(1)*, 17-28. The IFAT is an example of using multiple-choice as a formative assessment technique. The article describes the use of a special "scratch'n'see" multiple-choice form, where the correct answer is marked with a * on the form. Student response to the IFAT was extremely positive, with broad appeal.

4. Gregory Schraw, David W. Brooks, and Kent J. Crippen, "The Interactive, Compensatory Model of Learning". *J. Chem. Ed.* **2005**, *82*, 637-640. This article describes approaches to instruction, and the effect on student learning and motivation.

5. David W. Brooks, Gregory Shaw, and Kent J. Crippen, "Performance-related Feedback: The hallmark of efficient instruction". *J. Chem. Ed.* **2005**, *82*, 641-644. A continuation of (*12*), including examples of different styles of learning activity and feedback.

6. David DiBattista, "The immediate feedback assessment technique: A learner-centered multiple-choice response form." *Can. J. Higher Ed.*, **2005**, *35(4)*, 111-131. The IFAT is an example of using multiple-choice as a formative assessment technique. The article describes the use of a special "scratch'n'see" multiple-choice form, where the correct answer is marked with a * on the form. A student scratches away the coating for their selected answer. If the answer is incorrect, they can try again until the get the correct answer, but they get progressively fewer points the more attempts they make. I believe that this could readily be implemented (including automatic scoring for multiple attempts) using the BlackBoard Test tool.

7. David DiBattista, "Making the most of multiple-choice questions: getting beyond remembering." *Collected Essays in Learning & Teaching*, **2008**, *1*, 119-122. This paper discusses levels of assessment that can be implemented on MC questions by careful

attention to wording of the stem and items. Terminology uses a modified Bloom's taxonomy to categorize questions in terms of understanding, application, analysis, and evaluation of information. Some examples are given to illustrate how wording can be used to test higher levels of learning.

Laboratory Work

A. Lab Reviews:

1. Avi Hofstein and Vincent N. Lunetta, "The role of the laboratory in science teaching: Neglected aspects of research". *Review of Educational Research* **1982**, *52(2)*, 201-217. Describes the role of labs in science education from the early 1900s, through the 'new' science curriculum initiatives of the 1960s and 1970s. Provides a critical analysis of the strengths and weaknesses of various studies, and makes recommendations for future research areas.

2. Daniel S. Domin, "A review of laboratory instruction styles". *J. Chem. Ed.* **1999**, *76*, 543-547. Defines a framework for describing different styles of laboratory instruction, and provides a short introduction to available research on instructional methods. Presents the pros and cons, with descriptions, of expository, inquiry, discover and problem-based laboratory styles. Each defined with descriptors in terms of outcome (predetermined or undetermined), approach (deductive or inductive) and procedure (given or student generated).

3. Derek Hodson, "Laboratory work as scientific method: Three decades of confusion and distortion". *J. Curriculum Studies* **1996**, *28(2)*, 115-135. A critical review of the history of "discovery" lab experiments introduced to UK and US schools from the 1960s onwards, including the Nuffield Science programs. Note that this type of "discovery" is not what has the same label today! Highlights the role of false assumptions about how science is done in how these programs were designed and implemented. The intention was to teach science by "doing science", but most teachers ended up using "guided discovery" instead...

4. Precharn Dechsri, Loretta L. Jones, and Henry W. Heikkinen, "Effect of a laboratory manual design incorporating visual information-processing aids on student learning and attitudes." *J. Res. Sci. Teach.,* 1997, *34(9)*, 891-904. Considers neo-Piagetian cognitive theory, as modified by Pascual-Leone, to describe working memory in terms of the "maximum number of different bits of information or schemes that can be coordinated at one time" (M-space). Looks at cognitive, affective, and psychomotor aspects of the laboratory experience, and specifically the outcomes of the lab manual on student attitude, understanding, and practical skills. Some discussion of the merits of photographs *vs.* diagrams.

5. Avi Hofstein and Vincent N. Lunetta, "The laboratory in science education: Foundations for the twenty-first century". *Sci. Ed.* **2004**, *88(1)*, 28-54. A follow-up to the earlier 1982 review, with more recent information. There remains much to be done!

B. Lab Environment–Attitude Associations:

These papers describe the use of a survey tool, the Science Laboratory Environment Inventory (SLEI), to examine the role of the lab environment on student attitudes and outcomes in learning science.

1. Barry J. Fraser, Campbell J. McRobbie, and Geoffrey J. Giddings, "Development and cross-national validation of a laboratory classroom environment instrument for senior high school science". *Sci. Ed.* **1993**, *77(1)*, 1-24. This paper describes the initial development, validation, and refining of the Science Laboratory Environment Inventory (SLEI). This looks at: student cohesiveness (*i.e.* peer interactions); open-endedness; integration with regular class content; rule clarity (procedures, expectations); and material environment (adequate instrumentation, materials, *etc.*) There are two versions: the actual and "preferred" environments, both of which are included in appendices at the end of the paper.

2. Angela F. L. Wong and Barry J. Fraser, "Environment–attitude associations in the chemistry laboratory classroom". *Res. Sci. & Tech. Ed.* **1996**, *14(1)*, 91-102. This paper describes the use of the SLEI (modified to use the word 'chemistry' instead of the more general 'science') to study student attitudes to learning chemistry in senior high school classes in Singapore. Correlational analysis was performed against student chemistry-related attitudes. Perhaps unsurprisingly, it was found that students felt more threatened by open-ended activities (*i.e.* no one 'right' answer to be obtained). A key finding is that "it appears that chemistry laboratory classes which integrate knowledge from regular chemistry lessons, and provide clear rules for students to follow, have a positive effect on the students' chemistry-related attitudes", including overall enjoyment of chemistry.

3. Avi Hofstein, Tami Levy Nahum, and Kelly Shore, "Assessment of the learning environment of inquiry-type laboratories in high school chemistry". *Learning Environments Research* **2001**, *4*, 193-207. This paper describes the use of the SLEI as a tool to investigate differences between regular lab classes and those using inquiry-based laboratory experiments as part of the chemistry high school curriculum. Overall, it appears that the inquiry lab format leads to closer agreement between students actual and preferred lab experience. Selected comments from student and teacher interviews are included, which suggest distinct advantages to the inquiry approach (*i.e.* it was positive experience for both.) Careful integration of lab experiments with classroom material is critical, however. "The introduction of inquiry-type experiments ... was a 'breath of fresh air' in the way in which chemistry is being taught and learned."

C. Lab Styles:

1. David J. McGarvey, "Experimenting with undergraduate practicals". *U. Chem. Ed.* **2004**, *8*, 58-65. (http://www.rsc.org/Education/CERP/) Describes the introduction of problem–based experiments to an intermediate-level undergraduate physical chemistry lab.

2. Alison M. Mackenzie, Alex H. Johnstone, and R. Iain F. Brown, "Learning from problem based learning". *U. Chem. Ed.* **2003**, *7*, 13-26. (http://www.rsc.org/Education/CERP/) This paper described lessons learnt from the implementation of a problem-based learning approach across a professional medical school program, and offers many valuable insights on PBL.

3. J. Henderleiter and D. L. Pringle, "Effects of context-based laboratory experiments on attitudes of analytical chemistry students". *J. Chem. Ed.* **1999**, *76(1)*, 100-106. This article describes a comparison of conventional expository lab experiments with what can best be described as discovery-based labs, and the effect of establishing a contextual framework on student attitudes towards both the labs and the subject matter.

4. C. Anders R. Berg, V. Christina B. Bergendahl, and Bruno K. S. Lundberg, "Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment". *Int. J. Science Educ.* **2003**, *25(3)*, 351-372. Looks at the development, and revision of, an inquiry-based experiment at the undergraduate level. The importance of interim review to prevent students from being 'stuck' pursuing a wrong strategy or protocol is emphasized.

5. Melanie M. Cooper and Timothy S. Kerns, "Changing the laboratory: Effects of a laboratory course on students' attitudes and perceptions". *J. Chem. Ed.* **2006**, *83(9)*, 1356-1361. Describes an entire lab course built around problem-based group projects. This intermediate lab was designed and evaluated following the introduction of similar experiments in the first-year program. The importance of group dynamics and workload is addressed in particular.

D. Lab Preparation:

1. Lea Pogacnik and Blaz Cigic, "How to motivate students to study before they enter the lab", *J. Chem. Ed.*, **2006**, *83*, 1094-1098.

2. Andrzej Burewicz and Nikodem Mrianowicz, "Effectiveness of multimedia laboratory instruction", *Chem. Ed. Research & Practice* **2006**, *7(1)*, 1-12. (http://www.rsc.org/Education/CERP/) Students had to prepare for labs in scheduled study room hours, so the instructors could try different approaches: text only; PowerPoint presentation; interactive on-line tool with simulation of the

actual experiment. Unsurprisingly, students who spent more time in preparation – especially with the simulation – spent less time doing the experiment, made fewer errors, and analysed the results much faster.

Miscellaneous:

1. Kenneth D. George, "A comparison of the critical-thinking abilities of science and non-science majors" *Science Education*, **1967**, *51(1)*, 11-18. This study looks at the correlation between teaching methods employed in the high school class room and the development of critical thinking skills by students. After defining and describing what critical thinking skills are, the focus switches to assessing both the teachers' and the students' critical thinking skills. The cohort in this study included education students graduating in 1964-65 at the University of Kansas and made use of the Watson-Glaser Critical Thinking Appraisal tool. Students were grouped according to subject area (science, languages, English, etc.) and their scores subjected to ANOVA and various statistical tests. This suggested that science education majors were overall better critical thinkers than the others. The next step in this research is to test the critical thinking of students taught by these different categories of teachers.
2. Babu George, V. P. Wystrach, and Ronald I. Perkins, "Why do high school students choose chemistry?" *J. Chem. Ed.*, **1987**, *64(5)*, 431-432. Results from a survey of 321 US high school students across 25 states on their motivations for pursuing a degree in chemistry or a related field on entering post-secondary education. 14.7% indicated they would pursue a program in chemistry. The authors used a weighting scheme to rank the importance of different factors based on students' 1st-3rd choices from a list. In terms of career motivation, this was notably towards a future career in medicine or medical field.
3. Michael R. Abraham and John W. Renner, "The sequence of learning cycle activities in high school chemistry", *J. Res. Sci. Teach.*, **1986**, *23(2)*, 121-144. Learning cycles were developed partially out of Piagetian theory from earlier work by Karplus. They are a pedagogical format in which students learn concepts by more closing mimicking a scientific research model. They consist of three phases: exploration (data gathering - ideally from experiment or demonstration), conceptual invention, and conceptual expansion. They therefore differ from standard laboratory practice (inform-verify-practice). This study investigated whether the sequence of phases in each cycle mattered; it was found that it did, but this depended on whether the concept being studied was new or whether the unit was a review of earlier material. The critical factor seems to be the placement of the invention phase.
4. Gabriela C. Weaver, "Strategies in K-12 science instruction to promote conceptual change." *Science Education*, **1998**, *82(4)*, 455-472. This interview-based study examines

the effectiveness of instructional techniques for addressing misconceptions in science among students primarily in middle and high school. Student and teacher perceptions of classroom and lab activities (affective domain) were compared, along with teacher background and confidence to teach the science subjects on the curriculum. Recommendations for promoting student engagement (which is posited to lead to conceptual change) include more lab work and hands-on activities, and the use of real-life/relevant examples and contexts. Recipe-driven labs are discouraged in favour of an emphasis on evaluation of data, hypothesis creation, and testing of ideas.

5. Katherine L. McNeill and Joseph Krajcik, “Scientific explanations: characterizing and evaluating the effects of teachers’ instructional practices on student learning” *J. Res. Sci. Teach.*, **2008**, *45(1)*, 53-78. This study looked at teacher instruction and student performance on a middle-school chemistry module involving chemical and physical change (“How can I make new stuff from old stuff?”) The goal was to identify best instructional practice for teaching scientific inquiry and reasoning skills, such as reasoning from evidence and developing scientific explanations. Students were given identical pre- and post-test evaluations of their topical understanding. Classes were also videotaped and encoded for instructional practices. Students struggled most with the reasoning component of the unit, although this showed the largest effect size for improvement. There was also a significant teacher interaction on both learning gains and pre-test scores. Interestingly, it was noted that while all teachers discussed use of evidence in the introductory lessons, there was very little discussion of appropriateness or sufficiency (!) The key teacher practices having a positive outcome were: defining scientific explanation, making the rationale of scientific explanation explicit, and connecting scientific explanation to everyday explanation.