An Annotated Bibliography
of
Research Into The Teaching and Learning
of
The Physical Sciences
at
The Higher Education Level.

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Return to the LTSN Physical Sciences web site.

Notes:

This resource has been commissioned by LTSN Physical Sciences and created by David Palmer and Norman Reid at the Centre for Science Education, University of Glasgow. The resource is located on the web site of the LTSN Physical Sciences Centre but for the most part retains the original formatting and is essentially a separate web. To return to the original web site navigate back to this page and click the link above. (October 2002)

This annotated bibliography is aimed at those teaching the physical sciences at the tertiary level who;

- wish to become more informed about teaching related research evidence.
- wish to undertake science education research.

With this in mind, the bibliography seeks to offer:

- An overview of teaching and learning in the physical sciences;
- Key references to research which is orientated toward the teaching and learning of the physical sciences.

Research papers, relevant to tertiary level teaching and learning of the physical sciences, tend to be scattered across many journals. Some are to be found in journals directly relevant to the physics and chemistry communities. However, many are to be found in educational and psychological journals which are not widely read by professional educators in the physical sciences. Where possible, journals which are widely available have, in the hope that they will be readily available in university libraries, been selected. A list of all the journals cited within the bibliography, and (where appropriate) links to online versions, can found here.

In compiling this bibliography, it was noted that, often, those involved in physics education research appear to be unaware of education related research papers in chemistry journals, and vice versa. In general, science education research issues are common to both subject areas and, indeed, other sciences at university, or school level.

The bibliography can be viewed, or downloaded in a variety of formats. A list of these can be found here. There are numerous cross links, brief explanations of ideas and, where appropriate, a glossary of terms.

The intention is that the bibliography should be easily updated, or extended. This will permit, as and when available, the inclusion of both new articles and links to appropriate web resources. LTSN appreciates constructive feedback and/or information regarding key papers which may prove useful for future editing.

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Contents

List of Tables

List of Figures

Topic 1

Journals

Get a .pdf version of this Topic here
Return to beginning of main document

Here is a list of cited journals. Those available online have been highlighted and by following the appropriate link you will be taken to that journal's online home page. (Note: All of the URL's, of all web resources cited in the bibliography, can be viewed in Appendix D) Note that most journals permit the browsing of their online versions. However this is, in general, restricted to the viewing of abstracts and the contents pages of individual issues. To download articles it is necessary to subscribe to the relevant journal, which your institution's library may have already done.

The American Biology Teacher Currently not available online

American Educational research Journal The online version of this quarterly journal has abstracts to published articles from 1997–1999.

American Journal of Physics Published by the American Association of Physics Teachers, this journal regularly has physics education related articles. In addition they have, since July 1999, published a physics education research supplement which is usually published with the July issue. Volumes 67 (1999) onward are available online.

Chemistry Education: Research and Practice in Europe This is a peer-reviewed electronic journal available, *free of charge*, online.

Education in chemistry This journal, published by the Royal Society of Chemistry, has contents pages from November 2000 onward are available online.

European Journal of Physics This journal, published by the Institute of Physics (UK), has occasional articles relating to physics/science education research/practice. All volumes are available online: articles can be downloaded for free until 2003.

Educational and Psychological Measurement Articles from February 1999 (Volume 59) are available online.

European Journal of Science Education Renamed to the International Journal of Science Education

Educational Psychology Journals from March 2000 onward are available online.

Harvard Educational Review Journals from winter 1993 onward are available online.

International Journal of Science Education Journals from January 1999 onward are available online

Journal of Applied Psychology Contents pages from June 2001 (Volume 86) onward available online.

Journal of Chemistry Education Published by the American Chemical Society with Journals from 1995 onward available online.

Journal of College Science Teaching To gain access to almost everything at this site you must sign up for membership.

Journal of Research in Science Teaching Journals from January 1996 (volume 33) onward are available online.

Journal of Experimental Education Articles from January 1994 onward are available online.

Journal of Experimental Measurement Contents pages from Winter 1999 onward are available online.

Psychological Bulletin Past table of contents from July 2000 onward are available online.

Physics Education An Institute of Physics publication that has journals from 1991 (volume 26) onward available on line. The Institute of Physics is currently converting all their journals to electronic format. They expect to have this process completed by 2003. Currently articles can be downloaded for free, however from 2003 a subscription fee will be charged.

Psychological Reports Currently not available online (2002)

Psychology Review Past table of contents, from July 2001 onward, are available online.

Physics Today Published by the American Institute of Physics. Contents pages from January 1995, and articles from July 2000, onward are available online.

Quarterly Journal of Educational Psychology Table of contents information available online from volume 49 (February 1996) onward.

Perceptual and Motor Skills This journal is not available online (2002).

Review of Educational Research Abstracts from 1996 onward are available online.

Research in Science and Technological Education This journal is published bi-annually and Journals from May 2000 onward are available online.

Science Education Abstracts from 1996 (volume 80), and articles (in pdf format) from January 1997, onward are available for download online.

Studies in Higher Education Table of contents from volume 21 (March 1996) and abstracts from volume 25 available online.

School Science Review A journal primarily orientated toward science teachers of 11–19 education. Contents pages from 1998 onward and sample articles are available online.

Studies in Science Education This homepage provides information regarding this journal. Currently (as of 6/2002) journals are not yet available online.

Theory Into Practice Only ordering information available at present.

The Physics Teacher This journal is primarily aimed at those teaching introductory physics at any level. Table of contents are, from October 1987 onward, available online.

University Chemistry Education This journal, published by the Royal Society of Chemistry, is dedicated to publishing articles relating to chemistry education at the higher education level. Online there is free access to all published issues.

Topic 2

General Papers

Get a .pdf version of this Topic here
Return to beginning of main document

Here you will find some general papers on science education.

[Roberts and Brown 2001] Roberts, A. and Brown, L. M., *Evaluation of Physics Examining 1940–2000 at Cambridge*. European Journal of Physics, **22**(4), 413 – 420, 2001.

For those interested in the maintenance of university standards the study presented in this paper maybe of interest.

[McDermott and Redish 1999] McDermott, L. C. and Redish, E. F., *Resource Letter: PER-1: Physics Education Research*. American Journal of Physics, **67**(9), 755 – 767, 1999.

This resource letter provides an overview of research into the learning and teaching of physics. There are some 224 references, almost half of which are related to conceptual understanding.

[Ward and Bodner 1993] Ward, R. J. and Bodner, G. M., *How Lecture Can Undermine The Motivation of Our Students*. Journal of Chemistry Education, **70**(3), 198 – 199, 1993.

In this paper the authors summarise four theories of motivation: Drive, Field, Achievement and attribution. The authors advocate a shifting of students learning motivation from ego-orientated (only interested in how their performance compares with others) to task-orientated (interested in learning a subject for the sake of it). To achieve this:

1. grade on an absolute scale rather than normative.
2. stress participation, self–improvement.
3. instruction and testing should go beyond rote memorisation.

2.1 Flexible Learning Approach to Physics (FLAP)

FLAP, funded by the four UK Higher Education Funding Councils, is a supported self–study resource covering first year and foundation year physics and its associated mathematics. More information can be found at the official FLAP Web Site.

[Tinker et. al.] Tinker, M. H., Lambourne, R. J. A. and Windsor, S. A., *The Flexible Learning Approach to Physics (FLAP): A Review After The First Two Years*. International Journal of Science Education, **21**(2), 213 – 230, 1999.

In this article Flap resources are detailed and a report of its implementation and evaluation, at the University of Reading, is presented.

2.2 Putting It All Together

[Ramster 2001] Ramster, R. D., *A Hybrid Approach to Active Learning*. Physics Education, **36**(2), 124 – 128, 2001.

Describes the design of a calculus based introductory physics course which incorporates cooperative and peer–based methods. Initial experiences and lessons learnt are detailed. Group

[Gabel 1999] Gabel, D., *Improving Teaching and Learning Through Chemistry Education Research: A Look to the Future*. Journal of Chemistry Education, **76**(4), 548 – 553, 1999.

This paper provides a general overview of chemistry education. The complexity of chemistry concepts and the identification of instructional barriers, in terms of current learning theories, are discussed. In addition, teaching recommendations, so as to improve students' conceptual understanding, are presented. Gabel also discusses future chemistry education research.

2.3 Group Work

Note that group/collaborative work has been utilised in many areas of science education. Entries in the bibliography which relate to this pedagogy have been included within individual topics and are identified by a Group sign in the margin. The following paper contains 112 references relating to small–group learning.

[Springer et. al.] Springer, L., Stanne, M. E. and Donovan, S. S., *Effects of Small–Group Learning on Undergraduates in Science, Mathematics, Engineering. and Technology: A Meta–Analysis*. Review of Educational Research, **69**(1), 21 – 51, 1999.

In this meta-analysis the authors conclude that there is evidence that "various forms of small–group learning are effective in promoting greater academic achievement and a more favourable attitudes toward learning". Group

Also, the follow resource, “Small Group Instruction: An Annotated Bibliography of Science, Mathematics, engineering and Technology Resources in Higher Education, 1997”, is available online and can be found here

Group

Topic 3

Lecturing

Get a .pdf version of this Topic here
Return to beginning of main document

In universities lecturing is the primary method of student tuition, and no doubt will remain so for the foreseeable future. Therefore, to maximise their effectiveness, it is important to understand the dynamics of the lecturing process. The follow papers address such issues as: attention span in lectures, effectiveness of note taking styles and pre–lecture material.

3.1 General papers on Lecturing

[Johnstone and Parcival 1976] Johnstone, A. H. and Parcival, F., *Attention Breaks in Lectures*. Education in chemistry, **13**(2), 48 – 50, 1976.

In a study of first year chemistry students it was found that a lapse in attention occurred some 10 – 18 minutes after the lecture had started: with the period between subsequent lapses decreasing. The important factors effecting the rate of decline were attributed to: difficulty of subject, delivery rate, legibility of blackboard work and lecturer personality. By introducing variation and/or deliberate breaks it was found that the lapses in attention could be postponed or even eliminated.

[Johnstone and Su 1994] Johnstone, A. H and Su, W. Y., *Lectures – A Learning Experience*. Education in chemistry, **31**(5), 75 – 79, 1994.

During a lecture approximately 5000 words are delivered by the lecturer but, only some 500 are recorded by the students!. How students select these words and determine which information is important, worthy of a note, is investigated in this paper. The authors identify four note taking styles and the main characteristics of a poor lecturer, concluding that “at best, lectures are overviews or outlines of what has to be learnt rather than learning experiences in themselves”.

[Holme 1998] Holme, T., *Using Interactive Anonymous Quizzes in Large General Chemistry Lecture Courses*. Journal of Chemistry Education, **75**(5), 574 – 576, 1998.

In this paper Holme discusses the use of short (five minutes) multiple choice quizzes administered at the start of a lecture. These are designed to test students' understanding of the key concepts presented in earlier lectures. The format of the quizzes permit student – student interaction and rapid feedback of weaknesses in student understanding.

3.2 Peer Instruction

[Mazur 1997] Mazur, E., *Peer Instruction: A User's Manual*. Prentice Hall, Upper Saddle River, NJ, 1997.

In this book Mazur details the Peer Instruction (PI) pedagogy. Here lectures are interspersed with short concept tests designed to reveal common misunderstandings and actively engage students in lecture courses. A web site providing further information on PI can be found here.

[Crouch and Mazur 2001] Crouch, C. H. and Mazur, E., *Peer Instruction: Ten Years of Experience and Results*. American Journal of Physics, **69**(9), 970 – 977, 2001.

In this article the authors report on data relating to ten years of peer instruction and discuss changes they have made so as to improve PI instruction.

[Fagen et. al. 2002] Fagen, A. P., Crouch, C. H. and Mazur, E., *Peer Instruction: Results From a Range of Classrooms*. The Physics Teacher, **40**(4), 206 – 207, 2002.

This paper presents a survey of Peer Instruction implementation, instructor evaluation, course assessment and effectiveness.

[Meltzer and Manivannan 2002] Meltzer, D. E. and Manivannan, K., *Transforming the Lecture Hall Environment: The Fully Interactive Physics Lecture*. American Journal of Physics, **70**(6), 639 – 654, 1996.

In this article the authors describe how they have attempted to convert the large formal lecture into a more interactive seminar come tutorial format. The methodology that they present here is a variant of Muzar's Peer Instruction [Mazur 1997].

3.3 Pre–lectures

[Sirhan et. al. 1999] Sirhan, G., Gray, C., Johnstone, A. H. and Reid, N., *Preparing the Mind of the Learner*. University Chemistry Education, **3**(2), 43 – 46, 1999.

Before the start of their first year chemistry lecture course students were given a multiple-choice test to identify gaps in background knowledge. After self assessing their performance those students who felt they understood a given concept taught, using a series of short exercises, those that didn't. The authors report that this process improved the performance, in subsequent course examinations, of those students with lower entry qualifications.

[Sirhan and Reid 2001] Sirhan, G. and Reid, N., *Preparing the Mind of Learner – Part 2*. University Chemistry Education, **5**(1), 52 – 58, 2001.

In this paper pre–lecture "Chemorganisers" are presented. These are self contained units, each presented on a single side of A4 paper, covering concepts in chemistry and mathematics. The broad aims of the chemorganisers are:

1. To enhance the preparation of the mind for new learning.
2. To ease the load on working memory
3. To change attitudes towards learning.

For two consecutive years pre–lecture chemorganisers were given to first year chemistry students, were then withdrawn for one year and finally re-administered for a further year. The authors found that, when chemorganisers were used, students, who had entered the course with lower qualifications, showed an improvement in exam performance over those years when chemorganisers were not provided. An example of a chemorganiser, "The Mole and Solutions", can be viewed here, and a large collection of chemorganisers can be found here

[Sirhan and Reid 2002] Sirhan, G. and Reid, N, *An Approach in Supporting University Chemistry Teaching*. Chemistry Education: Research and Practice in Europe, **3**(1), 65 – 75, 2002.

A paper which discusses the use of "Chemorganisers", is available online here

[Kristine 1985] Kristine, F. J., *Developing Study Skills In The Context Of The General Chemistry Course: The Prelecture Assignment*. Journal of Chemistry Education, **82**(6), 509 – 510, 1985.

In this paper the author discuses his use of prelecture assignments, designed to introduce students to studying strategies. These assignments review prerequisite material and preview the upcoming lecture material (including parts of mathematical calculations). Examples of review and preview questions are presented and positive outcomes are discussed.

[Allen 1981] Allen, P. S., *Some Development in the Promotion of Individual Study in Physics*. European Journal of Physics, **2**(1), 58 – 62, 1981.

In this paper the author discusses his eight year study into various ways in which to promote individual student study. He reports that the most effective strategy appears to be one in which students are encouraged to learn from study units *before* the lecture, coupled with tests and discussions in lectures.

[Van Heuvelen 1991] Van Heuvelen, A, *Learning to Think Like a Physicist: A Review of Research–Based Instructional Strategies*. American Journal of Physics, **59**(10), 891 – 896, 1991.

To help students with the acquisition, and long-term retention, of concepts and skills they should be exposed to a technique or concept over an extended time interval, in a variety of contexts, and instruction should provide opportunities for students,

- whilst in lectures, to actively participate in the construction of concepts, reason qualitatively and solve problems,

- to evaluate their own and fellow students thinking,
- to make, whilst getting immediate lecturer feedback, unpenalised mistakes.

3.4 Courses Without Lectures

For an example of an introductory physics course without lectures see [Laws 1991].

3.5 Field Dependency and Lectures

A paper exploring the role of field dependence/independence and learning from lectures can be found in Topic 9, (Field Dependency, [Frank 1984]).

Topic 4

Assessment

Get a .pdf version of this Topic here
Return to beginning of main document

Assessment is generally used:

1. to provide information, to both teacher and student, about a student's subject understanding so as to guide future study.
2. to certificate students for possible entry into further courses or employment selection.
3. to elicit weaknesses in instruction.

Research into assessment is dominated by multiple choice objective testing, other common forms of testing include communication grids, branched true/false tests and "mind maps".

You will find the definitions of some words that are commonly used in the field of assessment (and the following text) here.

4.1 Multiple Choice Scoring Schemes

[Friel and Johnstone 1978a] Friel, S. and Johnstone, A. H., *Scoring Systems Which Allow For Partial Knowledge*. Journal of Chemistry Education, **55**(11), 717 – 719, 1978.

Provides a short introduction to differential weighting and confidence testing. Then presents a comparison of 4 scoring systems; 1 consistent with, and 2 variants of [Willey 1960] and the standard form. The authors conclude that a scoring system which gives credit for partial knowledge may not alter students' rank ordering and may be less discriminatory but, a students' overall mark may more accurately represent their subject understanding.

[Bao and Redish 2001] Bao, L. and Redish, E. F., *Concentration Analysis: A Qualitative Assessment of Student States*. American Journal of Physics, **69**(7), S45 – S55, 2001.

In this paper the authors present a measure to discern how students' multiple choice test responses are distributed. They suggest that concentration analysis can be used in the design and development of a research based multiple choice test.

[Johnstone 1987] Johnstone, A. H., *Can the Slipper Fit?–Grade–Related Criteria for School Science*. School Science Review, **68**(245), 737 – 744, 1987.

Presents a discussion of norm referenced and criterion referenced modes of assessment.

[Dressel and Schmid 1953] Dressel, P. L. and Schmid, J., *Some Modification of Multiple Choice Items*. Educational and Psychological Measurement, **13**, 574 – 595, 1953.

In this study the authors trialled four variants of the standard multiple choice tests. These were the

Free-Choice Test Here the students were required to mark as many choices, as they thought necessary, so as to ensure that they had not omitted the correct answer.

Degree of Certainty Test Here the student had to indicate, on a scale of 1-4, how certain he was that his one choice was correct.

Multiple–Answer Test Here any item might have more than one correct answer. The student had to mark the choices he thought were correct. He would get credit for correct answers and be penalised for any incorrectly marked answers.

Two-Answer Test Here two of the five responses were correct. A students' total score consisted of all their correct responses.

The authors report that there was some evidence that a students were required to examine more critically the test item when one of the modified versions was used.

[Willey 1960] Willey, C. f., *The Three–Decision Multiple–Choice Test: A Method of Increasing the Sensitivity of the Multiple–Choice Item*. Psychology Review, **7**, 475 – 477, 1960.

In this paper the author presents a special five–option multiple choice question where 3 items must be selected: the option which is thought to be definitely correct and the two options which are thought to be definitely incorrect. The marking system is as follows:

- 3 marks if the correct answer is correctly designated as definitely correct.
- 2 marks if the correct answer is **not** designated as definitely correct or definitely incorrect.
- 0 marks if the correct answer is designated as definitely incorrect.

The author suggests that this method discriminates between the conscientious and the superficial, or impulsive, examinee.

[Arnold and Arnold 1970] Arnold, J. C. and Arnold, P. L., *On Scoring Multiple Choice Exams Allowing for Partial Knowledge*. Journal of Experimental Education, **39**(1), 8 – 13, 1970.

Using elementary game theory the authors present a multiple choice examination scoring procedure which gives credit for partial knowledge and controls the expected gain/penalty due to guessing. The authors present a comparison of their scoring system with four alternative procedures. In general, each scoring system had little effect on the higher and lower scoring students. However the relative positions of the middle grades differed considerably from one test to the next. This was attributed to the greater influence of guessing factors on the "middle" scores.

[Aitkin 1967] Aitkin, L. R., *Effect on Test Score Variance of Differential Weighting of Item Responses*. Psychological Reports, **21**(10), 585 – 590, 1967.

Presents, mathematically, the effects of differential response weightings on total test variance of multiple choice objective tests.

[Rippey 1970] Rippey, R. M., *Rationale for Confidence–Scored Multiple–Choice Tests*. Psychological Reports, **27**(5), 91 – 98, 1970.

Presents a scoring scheme which requires an examinee to indicate their confidence when answering multiple choice questions. Also advocates the inclusion of intrinsic items in multiple choice tests, because these items suggest that "not all questions worth asking have single, impeccably defined answers". (Intrinsic items require a distribution of belief over the options on a multiple choice test and do not have a unique answer).

[Hasan et. al. 1999] Hasan, S., Bagayoko, D. and Kelley, E. L., *Misconceptions and the Certainty of Response Index (CRI)*. Physics Education, **34**(5), 294 – 299, 1999.

The Certainty of Response Index (CRI) provides a measure of the degree of certainty with which a student answers a multiple choice question. Here the student indicates, on a scale of 0 – 5, how certain he is that his answer is correct: using well established knowledge, concepts or laws. The authors recommend, and have used, this method to differentiate between students' misconceptions and lack of knowledge.

[Friel and Johnstone 1988] Friel, S. and Johnstone A. H., *Making Test Scores Yield More Information*. Education in chemistry, **28**(3), 46 – 49, 1998.

In this paper the authors recommend the use of caution indices [Sato 1975], in particular the use of the modified caution index [Harnish and Linn 1981], rather than simply using facility and discrimination values to assess student and question performance. That is by employing caution indices it is possible to identify anomalous response patterns to a particular question, and of a particular student.

[Handy and Johnstone 1973a] Handy, J. and Johnstone, A. H, *Reproducibility in Objective Testing*. Education in chemistry, **10**(2), 47 – 48, 1973.

Provides evidence that using common questions, rather than pre-tests, provides a more accurate indicator of performance. That is, common questions can be used as internal standards to compare the respective difficulty levels of two exams, or the respective abilities of two groups of students. Also presents a simple generalised

formula to penalise a student's score for guessing.

$$S = C - \frac{W}{n-1} \tag{4.1}$$

Where S is the corrected score, C is the number of correct responses chosen, W is the number of incorrect responses chosen, and n is the number of possible responses in each question. If all questions have been answered by all students there is *no* difference between the ranking of corrected and uncorrected scores.

4.2 Factors Effecting Test Outcomes

[Handy and Johnstone 1973b] Handy, J. and Johnstone, A. H, *How Students Reason in Objective Tests*. Education in chemistry, **10**(3), 99 – 100, 1973.

Here the authors conclude that answers to multiple choice questions are mostly selected validly, with minimal blind guessing and that failure to answer comprehension questions chiefly arises through deficiencies in knowledge.

[Friel and Johnstone 1978b] Friel, S. and Johnstone, A. H., *A Review of the Theory of Objective Testing*. School Science Review, **59**(209), 733 – 738, 1978.

In this general review of multiple choice testing the following points are discussed:

1. The effects of guessing.
2. The effects of changing the initial response.
3. The effect of item (question) order alteration.
4. The optimum number of choices.
5. The position response set: the number and order of a set of choices.
6. The assessment of partial knowledge.
    - Differential weighting
    - Confidence testing

[Friel and Johnstone 1979] Friel, S. and Johnstone, A. H., *Does Position Matter?*. Education in chemistry, **56**(6), 175 – 175, 1976.

In this investigation the authors conclude that the position of the most plausible distractor, relative to the correct answer, significantly alters the difficulty of a multiple choice question. In particular the difficulty is decreased when the distractor is placed immediately before the correct answer.

[Johnstone et. al. 1983] Johnstone, A. H., Macguire, P. R. P., Friel, S. and Morrison, E. W., *Criterion-Reference Testing in Science – Thoughts Worries and Suggestions*. ssr, (6), 628 – 633, 1983.

In this paper the authors discuss problems associated with multiple choice tests as instruments for criterion–reference testing. The following criterion–referenced tests:

- batteries of true–false items,
- structural communication grids,

- concept linkages and,
- multiple choice tests which test for partial knowledge

are then presented, with advantages and disadvantages, as alternatives to the standard multiple choice exam.

[Cassels and Johnstone 1984] Cassels, J. R. T. and Johnstone A. H., *The Effect of Language on Student Performance on Multiple Choice Tests in Chemistry*. Journal of Chemistry Education, **61**(7), 613 – 615, 1978.

In this study, matched questions (the same questions, used in alternative tests) were used to assess the influence of language on multiple choice outcomes. The following results were reported:

key words : substitution of simpler words brought about improved performance (e.g. choking for pungent)

Terms of quantity : pairings of words such as “most abundant” appear easier to understand than “least abundant”.

Negative forms : In general, the removal of negative questioning (e.g. “Which statement is true”, rather than, “Which statement is not true”) appears to improve performance.

Large numbers of words and arrangement of clauses : Long complex sentences proved to be more difficult than short questions written in short sentences.

Minor changes in parts of speech : the choice of active or passive voice has little effect.

The authors then present, with references, theoretical and experimental research which may explain why the above results were obtained: in particular the thinking processes necessary to solve a question (i.e. number of thinking stages, “chunking” ability and capacity of working memory, see Topic 8).

[Tamir 1990] Tamir, P., *Justifying the Selection of Answers in Multiple Choice Items*. International Journal of Science Education, **12**(5), 563 – 573, 1990.

Notes that, for a given multiple choice question, one third of all students choosing the correct option did so for the wrong reason. Advocates the use of “best answer” multiple choice items, in conjunction with a requirement that students provide a written justification as to why they chose a particular option. This enables the identification of “misconceptions, missing links and inadequate reasoning among students who correctly answered the best answer”

[Johnstone 1981] Johnstone, A. H., *Diagnostic Testing in Science*. In Lewy, A. and Nevo, D. (Eds.), *Evaluation Roles in Education*, London: Gordan and Breach, 1981.

Here Johnstone discusses the role of objective testing as a diagnostic tool for the identification of problems/weaknesses in teaching and learning of science concepts. The advantages, distorting factors and strategies for the effective use of diagnostic testing (in this instance multiple choice and communication grids) are covered.

[Marcus 1963] Marcus, A., *The Effect of Correct Response Location on the Difficulty Level of Multiple–Choice Questions*. Journal of Applied Psychology, **47**(1), 48 – 51, 1963.

In this study the authors agree with [Cronbach 1950] that the position of the correct item, in a multiple choice question, **does not** effect the difficulty level. They do suggest that the unequal attractiveness of distractors and, the sequential effects from item to item, may adversely influence the response to an individual question.

[Cronbach 1950] Cronbach, W. J., *Further Evidence on Response Sets and Test Design*. Educational and Psychological Measurement, **10**(), 3 – 31, 1950.

In this paper, and in his earlier paper [Cronbach 1946], Cronbach discusses the effects of "response sets" (personal ways of responding to test items). The nature of response sets, methods to control their influence on test validity and the design of better tests are all discussed in this paper. Also presents evidence that supports the hypothesis that multiple choice tests are "nearly free" from response sets.

[Jessel and Sullins 1975] Jessel, J, C, and Sullins, W. L., *The Effects of Keyed Response Sequencing of Multiple–Choice Items on Performance and Reliability*. Journal of Experimental Measurement, **12**(1), 45 – 48, 1975.

In this paper the authors report that their study **does not** support the notion that, in a multiple choice test, the correct answer has to be randomly sequenced and appear in each position an equal number of times.

[Harnish and Linn 1981] Harnish, D. L. and Linn, R. L, *Analysis of item response patterns: questionable test data and dissimilar practices*. Journal of Experimental Measurement, **18**(3), 133 – 146, 1981.

In this paper the authors present a comparative study of Response Pattern Indices (indices that measure the degree to which the response pattern for an individual is unusual). These indices can be used to identify students for whom the test is inappropriate, need more study, make careless mistakes, or posses sporadic study habits.

4.3 Alternatives to Multiple Choice Tests

4.3.1 Assessment Using Communication Grids

[Johnstone 1988] Johnstone, A.H, *Methods of Assessment Using Grids*. Lab Talk, (10), 4 – 6, 1988.

Here an array of information is presented in the form of a grid: a set of numbered boxes. In response to a question the pupils are asked to consider the content of each box and decide which box (or combination of boxes) constitutes the most appropriate answer to the question. In some circumstances, the **order** in which boxes are chosen is important. A box may contain pictures, words, ideas, equations, formulae, structures, definitions, numbers and operators. In addition, a series of questions can be set using the same grid. A possible scoring scheme is also presented, see Figure 4.1:

[Mackenzie 1997] Mackenzie, D., *TRIAD: A computer based assessment software*. University of Derby, UK: Centre for Interactive Assessment Development, 1997.

$$\text{Score} = \frac{\text{Number of correct responses chosen}}{\text{Total number of correct responses}} - \frac{\text{Number of incorrect responses chosen}}{\text{Total number of incorrect responses}}$$

Figure 4.1: *Grid Scoring Scheme*

This Commercial software is similar to communication grids. More information can be found here

[Egan 1972] Egan, K., *Structural Communication – A New Contribution to Pedagogy*. Programmed Learning and Educational Technology, **9**(2), 63 – 78, 1972.

Egan's communication grids are presented in this paper.

4.3.2 Assessment Using Branched True False Tests

[Johnstone et. al. 1981] Johnstone, A. H. McAlpine, E. and MacGuire, P. R. P., *Branching Trees and Diagnostic Testing*. Journal for Further and Higher Education in Scotland, **2**(1), 4 – 7, 1981.

In this paper the authors present a computerised branched true false test. They suggest that with this form of testing it is possible to test for wrong and mis–linked knowledge, wrong strategies and, assess the effectiveness of teaching/learning processes. Through the use of this form of test the authors report that they were able to identify a student with a misconception which persisted from 'O' Grade through to final honours level.

Here are the definitions of some words used in the field of assessment.

Key Option : The correct choice (option) in a multiple choice test item.

Item An individual question or exercise in a test.

Criterion–Referenced Test : Here the performance of an individual is measured against a standard or criteria rather than against the performance of others who take the same test.

Norm–Referenced Tests : Here the performance of an individual is measured against other students. Results from norm-referenced tests provide information that compares a student's achievement with that of a representative sample.

Distractor : An incorrect choice in a multiple-choice item (also called a foil)

Faculty Index (or Value) : the proportion of a class answering a given question correctly; measured on a scale of $0 \to 1$

Discrimination Index (or Value) : The extent to which an item differentiates between high-scoring and low-scoring examinees; measured on a scale of $0 \to 1$

Intrinsic Item require a distribution of belief over the options on a multiple choice test and do not have a unique answer.

Certainty of Response Index (CRI) : provides a measure of the degree of degree of certainty with which a student answers each question.

Topic 5

Practical Work – The Laboratory

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Return to beginning of main document

Most would agree that students, in order to learn new skills, reinforce concept understanding and to experience the scientific method, should undertake practical work. The references, presented here, reflect a desire to improve the effectiveness of the laboratory experience.

5.1 General Papers

[Johnstone and Al-Shuaili 2001] Johnstone, A. H. and Al-Shuaili, A, *Learning in the Laboratory: Some Thoughts From the Literature*. University Chemistry Education, **5**, 42 – 51, 2001.

This paper presets a brief overview of the literature relating to laboratory work, including, the purposes of laboratory work, teaching strategies (including how they relate to the purposes) and laboratory assessment.

[Yang and Aitkinson 1998] Yang, M. J. and Aitkinson, G. F, *Designing New Undergraduate Experiments*. Journal of Chemistry Education, **75**(7), 863 – 865, 1998.

This paper offers general questions and checklists, based on experience and observation, to aid new instructors in the development of new undergraduate experiments.

[Laws 1991] Laws, P. W., *Calculus–Based Physics Without Lectures*. Physics Today, **44**(11), 24 – 31, 1991.

This article describes "Workshop Physics": a laboratory based introductory physics course. Although not suitable for large classes the author reports that elements of the course have been adapted for use in universities. Sample exercises from a Workshop unit are presented.

[Browne and Blackburn 1999] Browne, L. M. and Blackburn, E. V., *Teaching Introductory Chemistry: A problem–Solving and Collaborative–Learning approach*. Journal of Chemistry Education, **76**(8), 1104 – 1107, 1999.

This paper describes the development of a problem based introductory university organic chemistry course, centred in the laboratory. Group

5.2 Practical Work: Problems Experienced by Students

[Johnstone and Letton 1990] Johnstone, A, H, and Letton, K. M, *Investigating Undergraduate Laboratory Work*. Education in chemistry, **27**(1), 9 – 11, 1990.

In this investigation, 24 students were given a diary to record their experiences in a second year University chemistry laboratory. Analysis of these diaries identified problematic experiments. Experiments found to be difficult contained a disproportionately high content of theory thus creating a possible information overload: resulting in recipe following. The authors suggest that "most of the learning (if any) takes place at the reporting stage when the student reviews what has been done and tries to interpret the results".

[Johnstone and Letton 1991] Johnstone, A. H. and Letton, K. M., *Practical Measures for Practical Work*. Education in chemistry, **28**(3), 81 – 83, 1991.

Reports that the experimental instruction and observational load, encountered by students in the laboratory, results in recipe–following or observation recording with very little interpretation or understanding. To remedy this the authors advocate the following actions:

- reduce noise in the instruction manual.
- foster confidence in the use of laboratory equipment, by introducing a carefully thought out skills programme.
- use pre-labs.
- use post-labs.

[Johnstone and Wham 1982] Johnstone, A. H. and Wham, A. J. B, *The Demands of Practical Work*. Education in chemistry, **19**(3), 71 – 73, 1982.

In this paper the diagram of Figure 5.1 is presented which is used to represent the experience of laboratory students.

The authors recognise that "during the learning phase, the student is in no position to distinguish between 'signal' and 'noise' ", and as such they present teaching strategies and improvements in experimental design to reduce the 'noise'.

[Johnstone and Wham 1979] Johnstone, A. H. and Wham A. J. B., *A Model for Undergraduate Practical Work*. Education in chemistry, **16**(1), 16 – 17, 1979.

Here the authors suggest that in practical work "there is insufficient emphasis on the mastery of skills to a high level" and that the "student is 'programmed' too much and takes on little responsibility for his own learning, and so thinks little for himself". To overcome these weaknesses they propose the inclusion of experimental units which are composed of two sections:

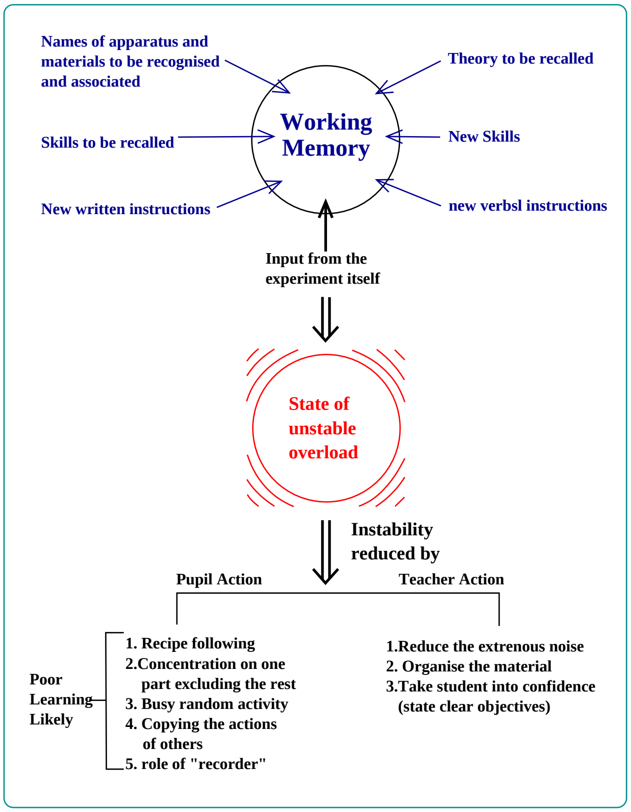

Figure 5.1: *Unstable overload in practical work*

- firstly a taught period in laboratory skills
- secondly a period in which students use their newly learnt skills to investigate a practical problem with the minimum of help or instruction.

This philosophy is illustrated and evaluated with a real example, and the students' attitude to this form of practical work is reported.

[Johnstone et. al. 1994] Johnstone, A. H., Sleet, R. J. and Vianna, J. F., *An Information Processing Model of Learning: Its Application to an Undergraduate Laboratory Course in Chemistry*. Studies in Higher Education, **91**(1), 77 – 87, 1994.

This paper details and evaluates changes to a first year undergraduate chemistry laboratory. Changes were based upon hypothesis derived from an analysis of the information processing model of learning, Figure 5.2. Changes included, re-writing of instructions manuals, re-organisation of the laboratory, the use of pre-labs, training in laboratory skills and the introduction of mini-projects. The authors state that "[their] study supports the conclusion that the changes were effective in improving students' attitudes about the laboratory course". Moreover, "the changes in student attitude and outlook, brought about during this study, are entirely in accord with the predictions inherent in the [information processing] model", See section 13.5

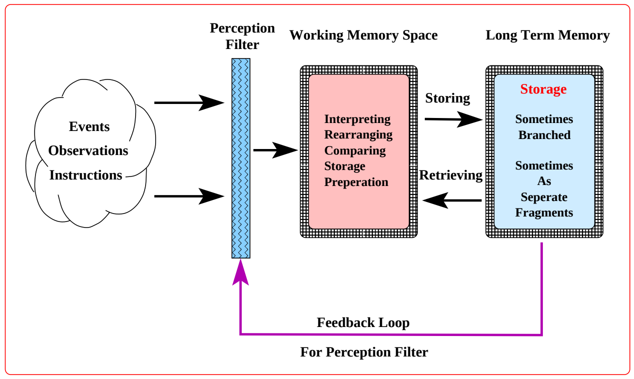

Figure 5.2: *Information Processing Model of Learning*

5.3 Using Pre and/or Post Labs

[Cox and Junkin 2002] Cox, A. J. and Junkin, W. F., *Enhanced Student Learning in the Introductory Physics Laboratory*. Physics Education, **37**(1), 37 – 44, 2002.

In this paper the authors suggest that, where students experience confusion or supply alternative concepts to explain experimental results, laboratory work be augmented by conceptual questions. The effectiveness of this approach was assessed using pre and post labs. The authors conclude that our "results are based on a relatively small data sample, but they do show that embedding questions in the laboratory, asking students to submit these answers real time to the instructor and then occasionally pairing groups across the lab enhances student learning".

[Johnstone et. al. 1998] Johnstone, A. H., Watt, A and Zamen, T. U., *The Students' Attitude and Cognition Change to a Physics Laboratory*. Physics Education, **35**(1), 22 – 28, 1998.

Another study into the use of pre–labs, this time in the physics laboratory. Includes a discussion of cognition, and the role of the short and long term memory on the learning of new material. They found that the use of a "pre-lab fostered a positive attitude in the students toward the changes made in the physics laboratory" and that "understanding of the physics practical work improved". They also report a large improvement in post-lab work by, those students using pre-labs prior to starting an experiment. An example of a Pre-lab, "mechanical oscillator and resonance", is presented in the appendix.

[Meester and Maskill 1995a] Meester, M. A. M. and Maskill, R., *First–Year Chemistry Practicals at universities in England and Wales: Aims and the Scientific Level of the Experiments*. International Journal of Science Education, **17**(5), 575 – 588, 1995.

This survey of 17 university practical classes is concerned with the aims and objectives of practical work, the scientific level of the experiments and the laboratory skills being taught. Differing instructional methods and the relationship between aims and teaching methods are also discussed. In their conclusions they mention that first year undergraduate practical work is heavily based on recipe–following with little attention paid to skills teaching: "students probably learn quite a lot about practical work but probably do not learn too well how to do it, with any skill, speed or efficiency".

[Meester and Maskill 1995b] Meester, M. A. M. and Maskill, R., *First–Year Chemistry Practicals at Universities in England and Wales: Organisational and Teaching Aspects*. International Journal of Science Education, **17**(6), 705 – 719, 1995.

In this follow-up to their earlier paper [Meester and Maskill 1995a], the authors focus on the format of practical classes, the timetable, use of electronic media, the manual and assessment methods. Having cited the literature, which presents possible improvements to laboratory work, the authors "conclude that first-year practical courses in England and Wales have changed vary little over the preceding 15 years."

[Domin 1999] Domin, S., *A Review of Laboratory Instruction Styles*. Journal of Chemistry Education, **76**(4), 543 – 547, 1999.

Identifies four laboratory instruction styles differentiated by three descriptors, see Table 5.1, and provides an overview (with references) of each style

	Description		
Style	**Outcome**	**Approach**	**Procedure**
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student Generated
Discovery	Predetermined	Inductive	Given
Problem–Based	Predetermined	Deductive	Student generated

Table 5.1: Descriptors of the Laboratory Instruction Styles

Expository Traditional - "cookbook" style.

Inquiry Given an assignment the students decide the system to investigate, design their own experiments, and collect and analyse their own data.

Discovery Guided inquiry to aid "discovery" of the desired outcome.

Problem–Based Students are presented with a problem with a clear goal to which they must devise a procedure that will lead them to a solution.

Also reviews the current state of research into the effectiveness of each style. Suggests that additional research is necessary before any conclusions can drawn.

[DeMeo 2001] DeMeo, S., *Teaching Chemical Technique: A Review of the Literature*. Journal of Chemistry Education, **78**(3), 373 – 379, 2001.

This review presents ways in which chemistry laboratory skills can be taught, discusses various types of pre-laboratory exercises and looks at how mental practice can be used to improve the acquisition of motor skills.

[Wright 1996] Wright, J. C., *Authentic Learning Environment in Analytical Chemistry Using Cooperative Methods and Open Ended laboratories in Large Lecture Courses*. Journal of Chemistry Education, **73**(9), 827 – 832, 1996.

Here the author presents the elements of an analytical chemistry course in which the first half is used to provide students with the necessary skills and knowledge base such that, in the second half, they can undertake a collaborative open–ended laboratory project. Naturally the outcomes are all positive. Group

[Vianna et. al. 1999] Vianna, J. F., Sleet, R. J. and Johnstone, A. H., *The Use of Mini-Projects in an Undergraduate Laboratory Course in Chemistry*. Quimica Nova, **22**(1), 138 – 142, 1999.

In this paper the authors report on a three year study into the use of mini-projects. These require students to use knowledge and skills, (supposedly) developed in previously completed set laboratory experiments, to solve a short practical problem. Examples of mini-projects and a number of recommendations related to their use are given.

5.4 Problem Based Learning (PBL)

[Duch et. al. 2001] Duch, B. J., Groh, S. E. and Allen, D. E., *The Power of Problem–Based Learning: A Practical "How To" For Teaching Undergraduate Courses in Any Discipline*. Sterling, Virginia: Stylus Publishing., 2001.

The *Problem–Based Learning* (PBL) pedagogy uses real world problems to motivate students to identify and apply research concepts and information, work collaboratively and communicate effectively. This book, written for college and university faculty, focuses on the practicalities of setting up a PBL course.

[Ram 1999] Ram, P., *Problem–Based Learning in Undergraduate Education*. Journal of Chemistry Education, **76**(8), 1122 – 1126, 1999.

Gives a brief introduction to Problem–Based learning (PBL) and then presents "The Water We Drink" an example of problem based learning successfully incorporated into a Second year university chemistry course. The authors found that when students are presented with "an authentic problem that is challenging and real, they will be motivated to learn and to enjoy the learning process immensely".

Topic 6

Problem Solving

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Return to beginning of main document

Problem solving is a process by which the learner discovers a combination of previously learned rules that he/she can apply to achieve a solution. [Holroyd 1985]

In this section, research papers relating to problem solving are presented. These include papers on problem types, strategies to improve problem solving abilities, and investigations which show that students who can solve a given problem may do so without conceptual understanding.

6.1 General paper

[Fuller 1982] Fuller, R. G, *Solving Physics Problems–How Do We Do It?*. Physics Today, **35**(9), 43 – 47, 1982.

A general discussion on physics problem solving in the light of the information processing (see section 13.5) and constructivist (see section 13.4) theories is presented in this paper. The four stage problem solving strategy of [Reif et. al 1975] is also presented.

[Tsaparlis et. al. 2000] Tsaparlis, G. and Angelopoulos, V., *A Model of Problem Solving: Its Operation, Validity, and Usefulness in the Case of Organic–Synthesis Problems*. Science Education, **84**, 131 – 153, 2000.

In this paper, a problem solving model, based upon working memory theory, (Topic 8) is presented. The authors report that the model was more useful in the case of students without previous training and for those students who were not field–dependent (see Topic 9) for a discussion of field dependency.

[Reid and Yang 2002] Reid, N. and Yang, M., *The Solving of Problems in Chemistry: The More Open–Ended Problems.*. Research in Science and Technological Education, **20**(1), 83 – 98, 2002.

Provides an overview of research into problem solving with some 70 references to the literature.

[Reif et. al 1975] Reif, F., Larkin, J. H. and Brackett, G. C., *Teaching General Learning and Problem Solving Skills*. American Journal of Physics, **44**(3), 212 – 217, 1975.

In this paper the authors present a simple, four stage, problem solving strategy. In addition, there is an exposition of their efforts to teach a general learning skill, designed to help students gain a good working understanding of any new relation.

[Bolton and Ross 1997] Bolton, J. and Ross, S, *Developing Students Physics Problem Solving Skills*. Physics Education, **32**(3), 176 – 185, 1997.

In this paper the authors discuss aspects of problem solving and present an evaluation of the Open University's problem solving booklet and multimedia.

6.2 Problem Types

[Johnstone 1993] Johnstone, A. H., *Introduction*. In Wood, C. and Sleet, R. (Eds.), *Creative Problem Solving Chemistry*, London: The Royal Society of Chemistry, 1993.

In the introduction to this book Johnstone provides a classification of problem types. He suggests that associated with **all** problems are three variables: the data provided, the method to be used and the goal to be reached. By looking at the extremes of these variables (known and unknown) eight problem types can be identified (see, Table 6.1)

6.3 Factors Effecting Success in Problem Solving

[Gabel and Bruce 1994] Gabel, D. L and Bruce, D. M., *Research on Problem solving: Chemistry*. In: D. L. Gabel (Ed.), *Handbook of Research on Science Teaching and Learning: A Project of the National Science Teachers Association*. New York: Macmillan, 1994.

Following 12 years of research, into the chemistry problem solving ability of students, these authors proposed that success in problem solving appears to be influenced by three factors:

1. *The nature of the problem and the underlying concepts upon which the problem is based*: including the problem style and conceptual understanding.
2. *Learning characteristics*: including an individual's cognitive style, developmental level and knowledge base.
3. *Learning environmental factors*: including problem solving strategies / methods, and individual or group activity.

Type	Data	Methods	Goals/ Outcomes	Skills bonus
1	Given	Familiar	Given	Recall of algorithms
2	Given	Unfamiliar	Given	Looking for parallels to known methods
3	Incomplete	Familiar	Given	Analysis of problem to decide what further data are required. Data seeking.
4	Incomplete	Unfamiliar	Given	Weighing up possible methods and then deciding on data required
5	Given	Familiar	Open	Decision making about appropriate goals. Exploration of knowledge networks.
6	Given	Unfamiliar	Open	Decisions about goals and choices of appropriate methods. Exploration of knowledge and technique networks.
7	Incomplete	Familiar	Open	Once goals have been specified by the student these data are seen to be incomplete.
8	Incomplete	Unfamiliar	Open	Suggestion of goals and methods to get there; consequent need for additional data. All of the above skills.

Table 6.1: Problem Types

[Herron and Greenbowe 1986] Herron, J. D. and Greenbowe, T. J., *What Can We Due About Sue: A Case Study of Competence*. Journal of Chemistry Education, **63**(6), 528 – 531, 1986.

In this paper Herron and Greenbowe suggest that successful problem solvers exhibit four characteristics:

1. have a good command of basic facts and principles.
2. can construct appropriate problem representations.
3. can use general reasoning strategies that permit logical connections between problem elements.
4. can apply several verification strategies.

Furthermore, they suggest 4 ways in which problem solving abilities can be fostered in students. However, they do point out that their suggestions are largely untested.

[Bodner and Domin 2000] Bodner, G. M. and Domain, D. S., *Mental Models: The Role of Representations in Problem Solving in Chemistry*. University Chemistry Education, **4**(1), 22 – 28, 2000.

Bodner and Domain suggest that it is often helpful to produce an external representation of a problem in order to solve it. They define:

- The internal representation as "*the way in which the problem solver stores the internal components of a problem in his or her mind*" and,
- The external representation as "*the physical manifestation of this information*": a drawing, an equation or list of information.

They conclude that a characteristic difference between successful and unsuccessful problem solvers is the number and kinds of representations used whilst attempting to solve a problem. They suggest that students, whilst attempting to solve a problem, should be encouraged to move away from only using verbal/linguistic representations, to also using symbolic representations.

6.4 A Network Approach to Problem Solving

[Ashmore et. al. 1979] Ashmore, A. D., Fraser, M. J., and Casey, R. J., *Problem–solving and Problem–Solving Networks in Chemistry*. Journal of Chemistry Education, **56**(6), 377 – 379, 1979.

In this paper a *problem–solving network* approach to solving problems is proposed: a problem is reduced to a network of unitary pieces of information from which interconnections, between pieces of information, can be seen. These pieces of information fall into three categories (1) stated in the problem, (2) retrieved from memory or, (3) via reasoning. A particular problem–solving network can, either be used to solve the problem or, help a teacher perceive student difficulties in solving the problem.

[Fraser and Sleet 1984] Fraser M. J., and Sleet R. J., *A Study of Students' Attempts to Solve Chemical Problems*. European Journal of Science Education, **6**(2), 141 – 152, 1984.

Using the network approach [Ashmore et. al. 1979] Fraser and Sleet attempted to identify and ascertain why some students could solve sub–problems (of the network) but were unable to solve the complete problem. They discovered that students did not have a plan to solve a particular problem. Moreover they lacked confidence, becoming confused when confronted with unfamiliar data or overly long questions. They suggest that problem solving strategies, summarising, drawing diagrams and breaking down a problem into sub–problems, should be taught so as to reduce the load on their working memory (see Topic 8 for a discussion and references on working memory).

6.5 Conceptual Understanding and Problem Solving

[Nakhleh 1993] Nakhleh, M. B., *Are Students Conceptual Thinkers or Algorithmic Problem Solvers? Identifying Conceptual Students in General Chemistry*. Journal of Chemistry Education, **70**(1), 52 – 55, 1993.

In this study, using five paired (algorithmic versus conceptual) general chemistry questions, approximately one thousand students were tested for their competence in solving algorithmic and conceptual problems. It was found that conceptual problem solving ability lagged far behind algorithmic problem solving ability.

[Nurrenbern and Pickering 1987] Nurrenbern, S. C. and Pickering, M., *Concept Learning Versus Problem Solving: Is There a Difference?*. Journal of Chemistry Education, **64**(6), 508 – 510, 1987.

In this study the authors found little connection between a students ability to solve an algorithmic type problem and their understanding of the underlying chemical concepts.

[Nakhleh and Mitchell 1993] Nakhleh, M. B. and Mitchell, R. C., *Concept Learning Verses Problem Solving: There is a Difference*. Journal of Chemistry Education, **70**(3), 190 – 192, 1993.

Following Nakhleh's earlier study [Nakhleh 1993], similar research, using paired exam questions (conceptual and algorithmic), showed that more than 50% of students are poor conceptual problem solvers whilst 85% of students are good algorithmic problem solvers. Furthermore, following interviews with six students, they concluded that most students rely on algorithms to solve problems, even problems specially designed for a conceptual solution.

[Phelps 1996] Phelps, A. J., *Teaching to Enhance Problem Solving; Its More Than Numbers*. Journal of Chemistry Education, **73**(4), 301 – 304, 1996.

In this paper Phelps focuses on conceptual problem solving which rarely had numerical answers. He discovered that non–science students showed more enthusiasm for their chemistry course, whilst the science students became insecure because this approach was not consistent with their expectation of the nature of chemistry. In the later case, students past experience instilled in them the belief that chemistry problems had a right answer and that they should know it. However, after adjusting their expectations, the science students appreciated spending more time developing conceptual understanding.

6.6 Cooperative problem solving

[Qin and Johnson 1995] Qin, Z. and Johnson, D. W., *Cooperative Versus Competitive Efforts and Problem Solving*. Review of Educational Research, **6**(2), 129 – 143, 1995.

Qin and Johnson examined 46 studies published between 1929 and 1993 to ascertain the relative impact of cooperative and competitive efforts on problem solving success. During their investigation six independent variables were considered: Group

- Cooperation versus competition.
- The type of Problem solving tasks, for example linguistic, nonlinguistic, well-defined and ill-defined.
- The age of the participants.
- The year of publication.
- The duration of a particular piece of research.
- The quality of research methodology.

The authors present 63 findings to which clear evidence is shown that cooperation, rather than non linguistic and ill-defined problems. However, this difference is dependent upon age with older students showing the greatest difference.

[Tingle and Good 1990] Tingle, J. B. and Good, R., *Effects of Cooperative Grouping on Stoichiometric Problem Solving in High School Chemistry*. Journal of Research in Science Teaching **27**(7), 671 – 686, 1990.

Here the suggestion is that cooperative groupings are a viable strategy for chemistry problem solving. That is, an active, rather than receptive, learning environment is fostered and as a result students' problem solving abilities are enhanced. Moreover, they provide evidence that students are able to teach group members through modelling, asking questions, and by using analogies during group discussions. Group

6.7 General Books on Problem Solving

There is a whole cornucopia of books relating to the field of problem solving, a small selection of which are presented here. The first three books present a multitude of problems for the students to solve, whilst the remaining two are concerned with problem solving theories and teaching methods.

[Wood and Sleet 1993] Wood C. and Sleet R., *Creative Problem Solving in Chemistry*. London: Royal Society of Chemistry., 1993.

This book is designed to foster good problem solving skills in students working in group situations. The skills that it claims to foster include data seeking and selection, choice of method, balance of criteria, awareness of error, discussion and presentation, and is aimed at 16 to 18 year olds. Group

[Gnädig et. al. 2001] Gnädig, P., Honyek, G. and Riley, K., *200 Puzzling Physics Problems*. Cambridge University Press, 2001.

Presents 200, generally open ended, problems in physics. Ideal for group work, with or without a teacher/lecturer. Group

[Harte 1985] Harte, J., *Consider a Spherical Cow: A course in Environmental Problem Solving*. Los Alto: William Kaufmann, Inc., 1985.

Drawing from the physical and biological sciences this environmental science problem solving book is designed to teach students how to transform a realistic, qualitatively described problem into a quantifiably solvable form and to arrive at an approximate solution. An additional aim is to teach environmental science

[Watts 91] Watts C, *The Science of Problem solving: a practical guide for science teachers*. Cassell Educational, London, 1991.

This book presents the skills, processes and methods of problem solving.

[Randell and Lester 1982] Randell, C. Lester, F., *Teaching Problem Solving: what, why and how*. Palo Alto: Dale Seymour Publications, 1982.

Topic 7

Critical Thinking

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Return to beginning of main document

7.1 What is Critical Thinking?

There are many definitions of critical thinking, a selection of these are presented below.

[Ennis 1987] Ennis, R. H., *A Taxonomy of Critical Thinking Dispositions and Abilities*. In J. Baron & R. Sternberg (Eds). *Teaching Thinking Skills: Theory and Practice (pp 9 – 26) NY: W. H. Freeman*, 1987.

According to Ennis, critical thinking "is reasonable reflective thinking that is focused on deciding what to believe or do".

Moreover, According to Ennis, an able critical thinker will (interdependently):

1. Judge the credibility of sources.
2. Identify conclusions, reasons, and assumptions.
3. Judge the quality of an argument, including the acceptability of its reasons, assumptions, and evidence.
4. Develop and defend a position on an issue
5. Ask appropriate clarifying questions.
6. Plan experiments and judge experimental design
7. Define terms in a way appropriate for the context.
8. Be open–minded.
9. Try to be well informed
10. Draw conclusions when warranted, but with caution

This list of abilities and dispositions is Ennis's own abridgement of work presented in [Ennis 1991] and [Ennis 1993].

.

[McPeck 1981] McPeck, J. H., *Critical Thinking and Education*. New York: St Martins Press, 1981.

McPeck describes critical thinking as "the propensity and skill to engage in an activity with reflective scepticism".

[Zoller 1993] Zoller, U., *Are Lecture an Learning Compatible?: Maybe for LOCS: Unlikely for HOCS*. Journal of Chemistry Education, **70**(3), 195 – 197, 1993.

Zollor uses the following as a working definition of critical thinking: "Rational, logical, and consequential *evaluative thinking* in terms of what to accept (or reject) and what to believe in, followed by a decision (what to do (or not to do) about it), followed by an accordingly responsible action". Critical thinking is one component of Zoller's HOCS (higher order cognitive skills), the others being problem solving and decision making.

7.2 Critical Thinking, Assessment and Improvement Strategies

[Ennis 1993] Ennis, R. H., *Critical Thinking Assessment*. Theory Into Practice, **32**(3), 179 – 186, 1993.

Here the author suggests that assessment of critical thinking is difficult to do well, but is possible. Presents an annotated list of published critical thinking tests. These tests are not subject–specific (the author was unable to identify any subject specific tests). Also gives advice on how to develop "your own test"

This paper also contains the abridgement, of his conception of critical thinking, as detailed above.

[Kogut 1996] Kogut 1996, *Critical Thinking in General Chemistry*. Journal of Chemistry Education, **73**(3), 218 – 221, 1996.

Discusses critical thinking assessment exercises and strategies to improve critical thinking. His strategies to encourage critical thinking skills are: Group

1. Ask questions frequently and direct them to individual students. These questions should be *why* and *how* in nature not simply *yes* or *no* type questions.
2. Use examples and illustrations that challenge dualistic thinking and reinforce the notion that science does not have many absolutely correct answers.
3. Promote discussion among students by using in–class group assignments and encourage out-of-class study groups.
4. Effective use of feedback encourages critical thinking.

The author discusses the advantages and disadvantages of employing these strategies. He concludes that, in addition to improving student critical thinking skills, these strategies improved examination performance, dramatically increased lecture attendance, and encouraged students to became more active learners.

[Moll and Allen 1982] Moll, M. B. and Allen, R. D., *Developing Critical Thinking Skills in Biology*. Journal of College Science Teaching, **12**(2), 95 – 98, 1982.

In this article the authors describe their efforts to teach critical thinking skills to introductory biology students using short video clips, followed by directed discussion, to encourage students to:

- apply concepts as they are learnt,
- derive concepts from observations and data,
- practice scientific processes.

In addition, the authors present data, from pre and post assessment tests, providing evidence of an improvement in students' critical thinking skills and content knowledge.

[Bodner 1988] Bodner, G. M., *Consumer Chemistry: Critical Thinking at the Concrete Level*. Journal of Chemistry Education, **65**(3), 212 – 213, 1988.

Here the author notes that, often, students "cannot apply their knowledge outside the narrow domain in which it was learnt. They "know" without understanding". In this article Bodner advocates the creation of a new, non–mathematical, chemistry course which would enable students to make educated decisions on issues of science and technology, understand how chemistry effects their daily lives and foster the development of critical thinking skills. Here, instead of having to perform the standard chemical calculations found in textbooks, students would be encouraged to ask, and answer, the "how do we know...?" and "why do we believe...?" type questions.

[Adams 1993] Adams, D. L., *Instructional Techniques for Critical Thinking and Life Long Learning in Science Courses*. Journal of College Science Teaching, **23**(4), 100 – 104, 1993.

In this paper the author reports that through the use of the following instructional techniques:

- the mini–research project,
- the scenario–based research project,
- the short essay–examination project and,
- the issues–directed research project

it was possible to enhance valuable developmental objectives, such as critical thinking and the appreciation of the scientific method, and at the same time reinforce subject matter. Examples of each of the four techniques are presented.

[Byrne and Johnstone 1987] Byrne, M. S. and Johnstone, A. H., *Can Critical–Mindedness Be Taught*. Journal of Chemistry Education, **24**(3), 75 – 77, 1987.

In this paper the authors report that, the use of short (1–2 hour), interactive, learning units, designed to compliment existing teaching approaches and largely independent of lecturer involvement, led to a greater and more effective use of critical skills. Moreover, understanding is developed through the consideration of evidence, discussion and collaborative decision making rather than through being "told the answers", and as a consequence material, perceived to be difficult or lacking interest, was more readily assimilated.

7.3 Books

[Garret et. al.] Garret, J., Overton, T. and Threlfall, T., *A Question of Chemistry: Creative Problems for Critical Thinkers*. Longman, 1999.

The exercises in this book are designed to encourage students to think critically and creatively. These exercises are designed to develop a students ability to critically evaluate a chain of reasoning, construct logical arguments, read critically, and gain experience answering questions which have no "right answer". In addition there is a section which is designed to provide students with experience in finding information in primary literature.

Topic 8

Working Memory

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Return to beginning of main document

Working memory, the more contemporary term for short-term memory, is conceptualised as an active system for temporarily storing and manipulating information needed in the execution of complex cognitive tasks [Baddeley 1986] (e.g., learning, reasoning, and comprehension). Experimental evidence has shown that the working memory is of limited size [Miller 1956], and hence, due to the high conceptual demands, complexity of laboratory experiments and potential information overload associated with problems solving, in both chemistry and physics, there are clear instructional implications.

8.1 Definition of working memory

[Miller 1956] Miller, G., *The magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information*. Psychological Review, **63**(2), 81 – 97, 1956.

In this paper Miller presents findings which indicate that short term memory has a capacity of 7 ± 2 “chunks”, where a “chunk” is an arbitrary unit of information.

[Baddeley 1994] Baddeley, A., *The Magic Number Seven: Still Magic After all These Years?*. Psychology Review, **101**(2), 353 – 356, 1994.

This paper provides a review of Miller’s original paper [Miller 1956] on working memory, and presents, with references, related works stemming from his ideas.

[Baddeley 1986] Baddeley, A., *Working memory*. Oxford: Clarendon Press, 1986.

This book presents Baddeley’s theory of working memory.

[Baddeley 1992] Baddeley, A., *Is Working Memory Working? The Fifteenth Bartlett Lecture*. Quarterly Journal of Educational Psychology, **44A**(1), 1 – 31, 1992.

Presents the philosophy underlying the working memory model and then illustrates it by giving a brief review of the model and some of the findings that have resulted from it.

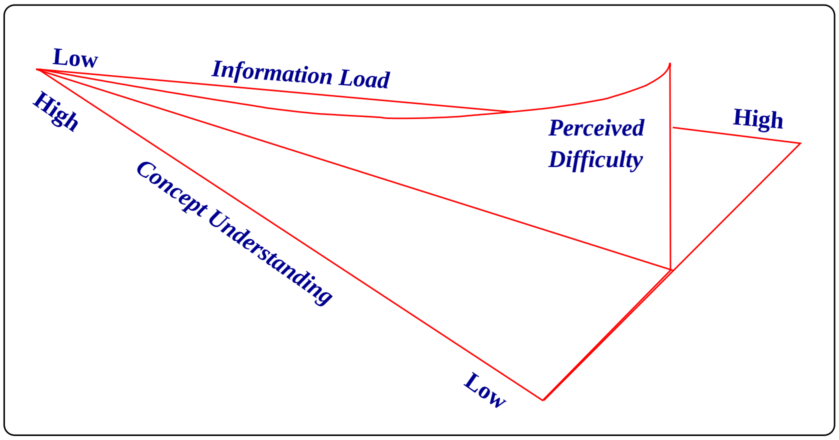

Figure 8.1: *The relationship between concept understanding, information load and perceived difficulty:* At the tip: information load is low, perceived difficulty is low and concept understanding is high. Moving from the tip to the tail: Information load increases, perceived difficulty increases and concept understanding decreases.

[Ashcroft 1994] Ashcroft, M. H., *Human Memory and Cognition*. 2nd Edition. New York: Harper Collins, 1994.

Ashcroft describes the working memory as "the mental workplace for retrieval and use of already known information". He points out that the short term memory implies a static short–lived store which is limited in the amount of work that it can perform. The more information to be held, the less processing can occur and vice versa.

[Kellett 1978] Kellett, N. C., *Studies on the Perception of Organic Chemical Structures*. Ph.D. Thesis University of Glasgow, 1978.

Proposed the I.C.C.U.D hypothesis which relates **I**nformation **C**ontent, **C**onceptual **U**nderstanding and **D**ifficulty. Here pupils who lack conceptual understanding may perform reasonably well when information load is low, but as information load increases their performance decreases, causing complaints of difficulty. This can most easily be appreciated with the "Concorde" representation [Johnstone 1980] (Figure 8.1)

[Johnstone 1980] Johnstone, A. H., *Nyholm Lecture: Chemical Education Research: Facts, Findings, and Consequences*. Chemical Society Reviews, **9**(3), 363 – 380, 1980.

Presents (Figure 8.1) a pictorial representation of the relationship between concept understanding, information load, and perceived difficulty.

[Johnstone and Kellett 1980] Johnstone, A. H. and Kellett, N. C., *Learning Difficulties in School Science – Towards a Working Hypothesis*. European Journal of Science Education, **2**(2), 175 – 181, 1980.

In this paper the authors acknowledge the interaction between conceptual knowledge, "chunking" and perceived subject difficulty. As a students conceptual understanding increases they are able to create larger "chunks" of information and thus

reduce the information load. They also present strategies by which the teacher can reduce information overload and thus facilitate conceptual understanding.

8.2 Laboratory and Working Memory

[Johnstone and Wham 1982] Johnstone, A. H. and Wham A. J. B., *The Demands of Practical Work*. Education in Chemistry, **19**(5), 71 – 73, 1982.

In this paper the authors suggest that the undergraduate laboratory is a poor learning environment. They believe that this is due to an overload of the student's working memory. The reasons for students response to, and suitable strategies that a lecturer can employ to reduce, working memory overload are summarised in Figure 8.2

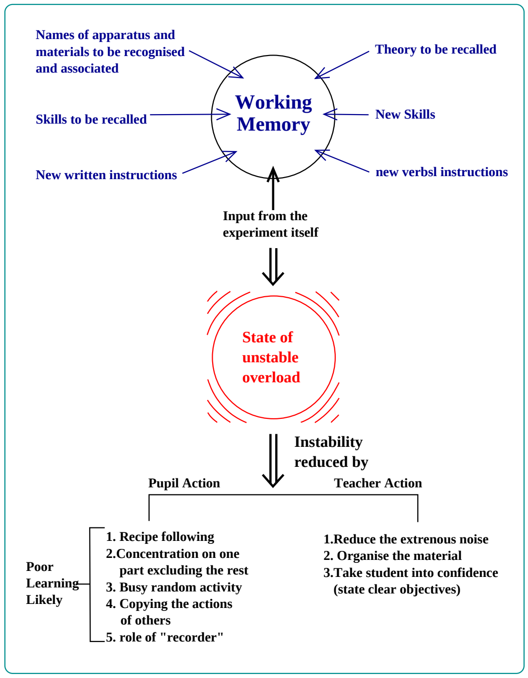

Figure 8.2: *The Effects of Practical Work on the Working Memory*

8.3 Working Memory: Experimental Evidence for Finite Capacity

The following definitions are provided here so as to reduce working memory load during the discussion of subsequent papers.

Z : An integer corresponding to the number of thought steps necessary to solve a problem (i.e. is a measure of a problems complexity or demand). It should be noted that the number of steps varies in accordance with experience/ability. In general, students require more steps than an experienced practitioner. (see "chunking", [Johnstone and Kellett 1980]).

X : An integer corresponding to an individuals working memory capacity (7±2, [Miller 1956]).

Y : Represents, schema, tricks, stored knowledge and techniques that may be brought to bear on a problem to reduce its Z value.

Facility Value (FV) : is the fraction of problem solvers who were able to solve a given problem correctly, and is measured on a scale from $0 \longrightarrow 1$.

Digits Backwards Test (DBT) : In this test a series of numbers are presented to a student to which he or she responds with the same numbers but in the reverse order (i.e $5279 \Longrightarrow 9725$). This can be carried out verbally or as a written test.

Figure Intersection Test (FIT) : In this test, students look at shapes and then shade in, on another diagram, the common area of overlap of all the figures. As the number of figures increases the task becomes more complex.

The following is an introduction to a series of papers, [Johnstone and El–Banna 1986], [Johnstone 1984] and [Johnstone and El–Banna 1989], on working memory overload. The individual papers are then listed with additional comments.

To investigate the overload of working memory a number of chemistry problems were assessed for complexity (Z) and a plot of facility value (FV) against question complexity (Z) produced, Figure 8.3. As can be seen, the plot has two clusters, one with $FV \gtrsim 0.6$ and the other with $FV \lesssim 0.3$ with the break occurring between $Z = 5$ and $Z = 6$. A sample size of $\sim$ 20000 was used and as such contained pupils of differing ability, i.e. working memory capacities (X) of 7 ± 2, and therefore the plot of Figure 8.3 should reflect this. That is, students of a given working memory capacity (X) would successfully answer questions of demand Z until their capacity was exceeded, at which point their performance would fall dramatically (idealised in Figure 8.4). The authors, used the DBT and FIT tests, to assess pupils working capacity (X). Since these tests were new to the students it was assumed that an individuals problem solving strategies (Y) would not be appropriate for these tests and would therefore provide an accurate measure of working memory capacity (X). Students, of varying ability (X), were then presented with questions of varying demand (Z) and plots of facility value (FV) against demand (Z) produced for students with a given capacity X. The authors present data from both secondary and tertiary education and conclude that the results are in general agreement with their hypothesis, but do admit that working memory capacity is not the only factor effecting a students performance.

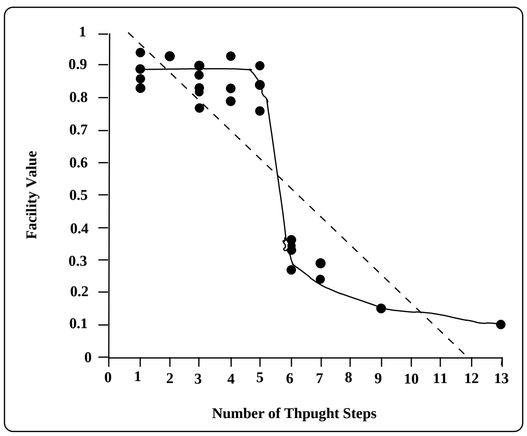

Figure 8.3: *The Correlation Between Facility Value and Question Demand*

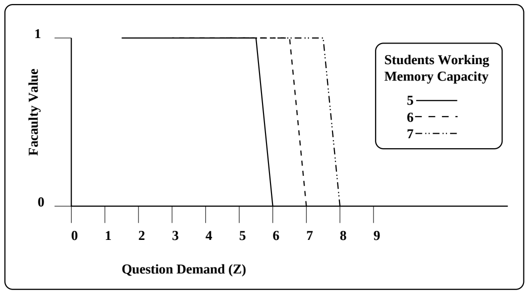

Figure 8.4: *Predicted Performance in Students with Different Working Memory Capacities*

8.4 Investigations into the overload of working memory

[Johnstone 1984] Johnstone, A. H., *New Stars for the Teacher to Steer By*. Journal of Chemical Education, **61**(10), 847 – 849, 1984.

Following an introduction, similar to that given above, this paper discusses overload of working memory and its relevance to both laboratory work and language. Ways in which overload can be reduced in the laboratory, and through appropriate ordering of curriculum content, are presented.

[Johnstone and El–Banna 1986] Johnstone, A. H. and El–Banna, A., *Capacities, demands and processes – a predictive model for science education*. Education in Chemistry, **23**(5), 80 – 84, 1986.

This paper expands on the introduction given earlier and in the light of their evidence offer the following:

- Learning demand (Z) must be kept below the working memory capacity (X) of the learner.
- Strategies (Y) should be taught/developed so that a student can operate beyond their capacity (X).
- Consequences for teaching and testing include:
    1. the re-examining of concepts for Z demand,
    2. the interlinking of concepts to promote Y strategies,
    3. the avoidance of "noise" in the laboratory,
    4. the realisation that high Z questions test both X and Y. The demand (X) may be too great, or strategies (Y) not yet developed, such that the students understanding of the subject is not suitably tested.
    5. the information density of text books and worksheets needs to be scrutinised.

They also note that the two *independent psychological non-science tests* (FIT and DBT) were predictors of student performance in *conventional* school and university chemistry examinations

[Johnstone and El–Banna 1989] Johnstone, A. H. and El–Banna, A., *Understanding Learning Difficulties – A Predictive Research Model*. studies in Higher Education,

14(5), 159 – 168, 1989.

Expands on the introduction given above and presents a discussion of their results.

[Johnstone et. al. 1993] Johnstone, A. H., Hogg, W. R. and Ziane, M., *A working memory model applied to physics problem solving*. International Journal Science Education, **15**(6), 663 – 672, 1993.

In this paper the idea that the same question, presented in different forms, may be testing different skills is explored. In particular, the effects of working memory and *field dependency* on student performance in answering examination and tutorial questions is investigated. Those students who have difficulty in differentiating signal from noise are known as field dependent (see Topic 9, Field Dependency) They found that a physics problem can be presented in such a way as to reduce the noise input and, as a consequence, improve problem solving success for all groups, especially the field–dependent group.

[Opdenacker et. al. 1990] Opdenacker, C., Fierens, H., Van Brabant, H., Sprut, J. and Slootmaekers P. J., Katholieke Universiteit van Leuven, Belgian and Johnstone, A. H., University of Glasgow, Uk, *Academic performance in solving chemistry problems related to student working memory capacity*. International Journal of science Education, **12**(2), 177 – 185, 1990.

In this paper the correlation between working memory capacity and problem solving performance, as hypothesised by [Johnstone and El–Banna 1986], was investigated using two hundred and fifty undergraduate medical students. Again the DBT and FIT were used, with varying degrees of success, to assess the working memory capacity of students. In the discussion of their results they state that "our results does not lead to a straightforward confirmation of [Johnstone and El–Banna 1986]. However, we do find a moderate correlation between the size of working memory and problem–solving ability. This correlation was 0.3 (significance 0.01%)". However they do point out that working memory capacity may only be one factor effecting problem solving ability: "the correlation found is an estimate of the importance or weight of the working memory factor".

[Tsaparlis et. al. 2000] Tsaparlis, G. and Angelopoulos, V., *A model of Problem Solving: Its Operation, Validity, and Usefulness in the Case of Organic–Synthesis Problems.*. Science Education, **84**, 131 – 153, 2000.

In this paper the problem solving model which is based upon working memory theory is discussed. The authors report that the model was more useful in the case of students without previous training and for those students who were field–independent (Topic 9).

Topic 9

Field Dependency

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Return to beginning of main document

Individual learners vary widely in their abilities and psychological characteristics. One such important characteristic is field dependency and as such, papers relating to this subject are presented here. These include references to measuring tools, literature reviews of the field and educational implications. But first, here is a working definition of field dependency:

The more able an individual is at breaking up an organised field so as to separate relevant material from its context, or discern *signal* (the relevant) from *noise* (the incidental and peripheral), the more field independent that individual is.

[Witkin et. al. 1977] Witkin, H. A., Moore, C. A., Goodenough, D. R. and Cox, P. W., *Field–Dependent and Field–Independent Cognitive Styles and their Educational Research*. Review of Educational Research, **47**(1), 1 – 64, 1977.

Provides an excellent review of the theory and state of research as it stood in 1977. Perhaps a good place to start if you are new to the field.

[Witkin et. al. 19971] Witkin, H. A., Oltman, P. T., Raskin, E. and Karp, S. A., *Group Embedded Figures Test Manual*. Palo Alto: Consulting Psychologists Press, 1971.

In this manual the Group Embedded Figures Test (GEFT) is presented. This is a paper and pencil test, where subjects are required to recognise and identify a target figure within a complex pattern. The more figures found, the better the individual is at the process of separation and, is said to be more field independent.

[Goodenough 1976] Goodenough, D. R., *The Role Individual Differences in Field Dependence as a Factor in Learning and Memory*. Psychological Bulletin, **83**(4), 675 – 694, 1976.

This paper presents, and draws conclusions from, a comprehensive review of the literature relating to field dependence as a factor in learning and memory. Contains some 150 references.

[Frank 1984] Frank, B. D., *Effect of Field Independence–Dependence and Study Technique on Learning From Lectures*. American Educational research Journal, **21**(3), 669 – 678, 1984.

Presents evidence that, due to more efficient note taking, field independent students out perform field dependent students. Suggests that field dependent students could be helped to improve their performance through a combination of training in note taking skills and the provision of external organisational aids, such as lecture outlines.

[Frank and Keane 1993] Frank, B. M. and Keane, D., *The Effect of Learner's Field Independence, Cognitive Strategy Instruction, and Inherent Word–List Organisation on free–recall Memory and Strategy Use*. Journal of Experimental Education, **62**(1), 14 – 25, 1993.

In this research the authors provide evidence that, when processing information, field dependent students are as equally likely to employ passive, less effective and inefficient cognitive strategies, such as rehearsal, as they are the more active, categorisation and thematic organisational strategies favoured by better performing field independent students. Suggests that field dependent students may benefit from reorganisation of the learning material to make the organisational structure more explicit. However "this seams to imply that the student's cognitive style is fixed and that we must teach to it . . . [consolidating] an already limited style of incorporating information". Suggestions for further research are also given.

[Dickstein 1968] Dickstein, L. S., *Field Independence in Concept Attainment*. Perceptual and Motor Skills, **27**(), 635 – 642, 1968.

In this study, of 70 female collage and nursing students, the author reports that "concept–attainment performance is more closely related to field–independence than to general intelligence" with field independent out performing field dependent students.

[Johnstone and Al–Naeme 1991] Johnstone, A. H. and Al–Naeme, F. F., *Room for Scientific Thought?*. International Journal of Science Education, **13**(2), 187 – 192, 1991.

In this paper the authors present research findings into the relationship between field dependence/independence, working memory capacity and science examination performance. Findings indicate that students with high working memory capacity, but field dependent, performed like lower working memory capacity, field independent students. Also presents strategies to assist students during the first stages of new learning.

Topic 10

Concept Maps and mind Maps

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Return to beginning of main document

The term “mind map” and “concept map” are used interchangeably. However there are differences:

The difference between concept and mind maps is that a mind map has only one main concept, whilst a concept map may have several. Moreover, the primary role of the mind map is as a note taking technique whereas the concept map is an educational tool used to:

- explore prior knowledge and misconceptions,
- encourage meaningful learning to improve students’ achievement,
- measure concept understanding

Mind Mapping©, developed (and copyrighted) by Tony Buzan, describes mind maps as consisting “ of a central word or concept, around the central word you draw the 5 to 10 main ideas (child words) that relate to that word. You then take each of those child words and again draw the 5 to 10 main ideas that relate to each of those words.”

[Buzan 89] Buzan, T., *Use Your Head*. London: BBC Books, 1989.

This revised edition provides all you need to know about mind maps.

[Novak and Gowin 1984] Novak, J.D and Gowin, D. B., *Learning How to Learn*. Cambridge University Press, 1984.

The concept mapping technique, developed by Prof. Joseph D. Novak, is based on the theories of David Ausubel, who stressed the role of prior knowledge in the learning of new concepts.

Following an introduction on meaningful learning, the authors present a comprehensive description of concept and V maps. The final chapter presents their ideas on improving educational research.

10.1 Articles on Concept maps

[Stuart 1985] Stuart, H. A, *Should Concept Maps Be Scored Numerically?*. European Journal of Science Education, **7**(1), 73 – 81, 1985.

Reviews the use of concept maps in research, instruction and assessment. Presents a variant of [Novak Gowin and Johansen 1983]'s system of scoring concept maps. Acknowledges the deficiencies of current scoring schemes, concluding that a more holistic and qualitative scoring technique needs to be developed.

[Pendley et. al. 1994] Pendley, B. D., Bretz, R. L. and Novak, J. D., *Concept Maps as a Tool to Assess Learning in Chemistry*. Journal of Chemistry Education, **71**(1), 9 – 15, 1994.

In this paper the authors describe their use of concept maps, derived from student interviews, in the investigation of concept understanding pre and post instruction.

[Adamczyk and Wilson 1996] Adamczyk, P and Wilson, M, *Using Concept Maps With Trainee Physics Teachers*. Physics Education, **31**(6), 374 – 381, 1996.

In this paper the authors report their use of concepts maps, to identify knowledge gaps, in the physics understanding of trainee teachers.

[Zieneddine and Abd-El-Khalick 2001] Zieneddine, A. and Abd-El-Khalick, F., *Doing the Right Thing Versus Doing the Right Thing Right: Concept Mapping in Freshman Physics Laboratory*. European Journal of Physics, **22**(5), 501 – 511, 2001.

In this paper the authors report that the use of concept maps serve, "as a crucial step in promoting concept understanding through revealing students' naive conceptions". However, to be useful, they need to be "coupled with teaching strategies that aim at inducing conceptual change". In addition, the authors report that those students who used, pre and post laboratory, concept maps scored higher in concept tests. However the difference, over the control, was not statistically significant.

[Nicoll et. al. 2001] Nicoll, G., Francisco, J. and Nakhleh, M., *A Three-Tier System for Assessing Concept Map Links: A methodological Study*. International Journal of Science Education, **23**(8), 863 – 875, 2001.

This paper presents a novel approach to coding and assessing concept maps. The analysis of a map consists of three levels:

Utility Here links are classified as incorrect, incomplete or useful

Stability This represents students confidence in their information

Complexity is a measure of the predictive ability of a link (not the number of links).

The authors believe that this method, of coding concept maps, yields more information about students' knowledge structures and how they learn information.

[Novak Gowin and Johansen 1983] Novak, J. D., Gowin, D. B. and Johansen, G. T., *The Use of Concept Mapping and Knowledge Vee Mapping with Junior High School Science Students*. Science Education, **67**(5), 625 – 645, 1983.

Discusses and evaluates the use of concept and vee mappings as teaching/learning strategies and as evaluation measures for these strategies.

[Otis 2001] Otis, K. H., *Metacognition: A Valuable Aid To Understanding For Medical Students In Problem Based Learning*. Ph.D Thesis. University of Glasgow, 2001.

In this study, medical students were taught how to develop concept maps as an aid to learning. The work explored and demonstrated the use of concept maps as a tool to aid meaningful learning. The author found that, for a given student, the structure of their concept maps was, in general, constant between subject areas. He also reports that concept maps are **not** appropriate for assessment purposes, because the complexity of a map does not appear to be correlated with concept understanding: Some of the simplest concept maps were produced by the most able students.

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Additional references relating to both concept maps and mind maps can be found here.

Topic 11

Misconceptions

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Return to beginning of main document

The literature relating to the misconception of science concepts is vast, a selection of which is presented here.

11.1 References to Misconceptions

The following three resources were created by Elgin Wolfe and were last updated July 1998.

For an online annotated bibliography, with 89 references, on misconceptions in Chemisty follow this link.

For an online annotated bibliography, with 98 references, on misconceptions in Biology follow this link.

For an online annotated bibliography, with 126 references, on misconceptions in Physics follow this link.

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The resource letter by [McDermott and Redish 1999] contains some 224 references relating to physics misconceptions.

Topic 12

Attitudes

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Return to beginning of main document

Here only attitudes directly relating to science education are considered. These are:

- Attitudes toward science subjects.
- Attitudes toward the learning of these subjects.
- Social attitudes arising through the study of a particular scientific theme.
- The so-called scientific method.

Note that the word **persuasion** is an often used term within the field of attitudes. However, here it has a specific meaning, namely: Persuasion relates to a specific message which may promote attitude change.

12.1 Reasoned Action and Planned Behaviour Theories

The following theories are often quoted in the literature, and so have been included here so as to provide convenient references for those wishing to pursue them further.

[Crawley and Koballa JR.1994] Crawley, F. E. and Koballa JR., T. R., *Attitude Research in Science Education: Contemporary Models and Methods*. Science Education, **78**(1), 35 – 55, 1994.

In this paper the authors provide an overview of the "Planned Behaviour" and "Reasoned Action" theories of attitudes and human behaviour. There is also a discussion of persuasion as a means of changing attitudes, research methods, and application, to determine whether persuasive methods can be utilised to increase the numbers of students enrolling in high school chemistry. The authors report that,"findings from choice–framing research suggest that students are most likely to become risk–takers and decide to enrol in chemistry when they are confronted with information about lost educational, career, and other opportunities when chemistry is avoided".

[Stead 1985] Stead, K., *An Exploration, Using Ajzen and Fishbein's Theory of Reasoned Action, of Students Intention to Study Or Not Study Science*. Research in Science Education, **15**, 76 – 85, 1985.

In this paper Stead suggests that "Ajzen and Fischbein's theory provides, both an instrumental technique for collecting requisite data and an explicit rationale for the analysis, description, prediction and application of generated findings."

[Ajzen and Fischbein 1980] Ajzen, I. and Fischbein, M., *Understanding Attitudes and Predicting Social Behaviour*. New Jersey: Prentice–Hall, 1980.

The Theory of reasoned action is presented in this book.

12.2 Attitude Change

The two extremes processes creating attitude change are:

Internal: attitude change occurs through motivation, desire and control of the individual

External: attitude change arises through outside pressure, forcing a change in attitude and is not always under the control of the individual.

12.2.1 The Internal Mechanism of Attitude Change

[Festinger 1957] Festinger, , *A Theory of Cognitive Dissonance*. Stanford: Stanford University Press, 1957.

This book provides a full discussion of dissonance theory. This influential theory attempts to explain attitude change in terms of an internal dimension. Dissonances is a psychological state arising when new contradictory information disrupts the existing equilibrium amongst elements of the cognitive system: leading to internal inconsistencies. This is an uncomfortable state. That is why, in order to reduce inconsistencies, a new, or change in, attitude may occur. Ways in which dissonance may be reduced are:

- Change the existing elements of knowledge to make the earlier cognitive system, and newly obtained knowledge, consistent. May lead to changes in both attitude and behaviour.
- Find, and accept, the consistent elements from the source of dissonance: does not, in general, lead to attitude change.
- Deny the importance of the new cognition. Attitude is not changed but earlier attitude becomes even stronger.

12.2.2 The External Mechanisms of Attitude Change

Persuasion and its role in attitude change was pioneered by Carl Hovland and his colleagues see the following papers:

[Hovland, et. al. 1957] Hovland, C. I., Luchins,A. S., Mandell, W., Cambell, E. H., Brock, T. C., McGuire, W. J., Feierabend, R. L. and Anderson, N. H. (Eds), *The Order of Presentation in Persuasion*. New Haven: Yale University Press, 1957.

or

[Hovland, et. al. 1953] Hovland, C. I., Janis, I. L. and Kelly, J. J., *Communication and Persuasion*. New Haven: Yale University Press, 1953.

Much of the persuasion research has investigated the role of an external message on attitude change and its influence on behaviour.

[Petty and Cacioppo 1981] Petty, R. E. and Cacioppo, J. T., *Attitudes and Persuasion: Classic and Contemporary Approaches*. Dubuque: William C. Brown, 1981.

12.3 Attitude Measurement

[Osgood et. al. 1957] Osgood, C. E., Suci, C. J. and Tannenbaum, P. H., *The Measurement of Meaning*. Urbana: University of Illinois Press, 1957.

The Semantic–Differential method (or Osgood Method) was not originally developed for attitude measurement but nonetheless has been proven to be a useful measure of attitudes. The method is, most commonly, based on a seven–point rating scale with bipolar word–pairs placed at opposite ends of the scale, for an example see Figure 12.1

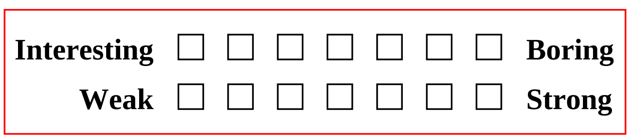

Figure 12.1: *Semantic–Differential Scale*

[Likert, R] Likert, R., *A Technique for the Measurement of Attitudes*. Archives of Psychology, **140**, 5 – 53, 1932.

The Likert method is one of the most popular attitude measuring tools. This method consists of a series of statements, each with an evaluative scale consisting (usually) of five positions running from strongly agree, through neutral, to strongly disagree. A respondent is required to read the given statement and then indicate, on the corresponding scale, the degree to which they agree or disagree with the statement.

[Gardner 1996] Gardner, P. L, *The Dimensionality of Attitude Scales: A Widely Misunderstood Idea*. International Journal of Science Education, **18**(8), 913 – 919, 1996.

Often, researchers have scored and summed individual items in attitude tests. Here the underlying assumption is that the items reflect a common construct. In this paper the author discusses the implications of this assumption and presents case studies of poor and good instrument design.

12.4 Attitudes toward the Study of Science

[Durrani 1998] Durrani, M., *Students Prefer To Mix And Match*. Physics World, 6, p.9., 1998.

"The declining popularity of science is a well–known fact. The number of 18–year–olds taking science and math at A–level [in England and wales] fell from 42 % in 1963 to just 16 % in 1993 . . . "

[Osborne et. al. 1998] Osborne, J., Driver, R. and Simon, S., *Attitudes to Science: Issues and Concerns*. School Science Review, **79**(288), 27 – 33, 1998.

In this article the authors attempt to summarise what is known about young people's attitudes to science, how these impact on subject choice and achievement. The authors "argued that the recent introduction of compulsory science education to 16 in England, Wales and Northern Ireland has not succeeded in changing the level of interest in science and that attention needs to be turned to the content of the curriculum to make it more relevant and engaging."

[Woolnough 1994] Woolnough, B. E., *Why Students Choose Physics, or Reject it.*. Physics Education, **29**(11), 368 – 373, 1994.

In this paper the author reports on some research findings into the interacting factors encouraging or discouraging secondary school students toward or away from higher education and careers in physics.

[Reid and Skryabina 2002] Reid, N and Skryabina, E., *Attitudes Towards Physics*. Research in Science and Technological Education, **20**(1), 67 – 81, 2002.

In this study into attitudes toward physics, it was found that for those students who had experienced an applications led school physics course there was a positive attitude toward physics. Moreover, it was found that university students continued to seek this dimension in their studies. In addition the notion that positive attitudes toward physics need to be fostered early in secondary education was confirmed. Skryabina also notes that the, Scottish Secondary Educations', applications led physics course remains very popular.

[Stokking 2000] Stokking, K. M., *Predicting The Choice of physics in secondary Education*. International Journal of Science Education, **22**(2), 1261 – 1283, 2000.

In this paper the author suggests that the main predictor of choice of physics in secondary education is perceived future relevance. Moreover, Stokking reports that the overall consensus is that curricula which are orientated toward everyday life, with a participative approach, result in well motivated students.

12.5 Reviews and General Papers

[Johnstone and Reid 1981] Johnstone, A. H. and Reid, N., *Towards a Model for Attitude Change*. European Journal of Science Education, **3**(2), 205 – 212, 1981.

In this brief overview of major findings (as of 1981) the authors draw on these finding to produce a model of attitude change.

[Ramsden 1998] Ramsden, J. M., *Missiion Impossible?: Can Anything Be Done About Attitudes To Science?*. International Journal of Science Education, **20**(2), 125 – 137, 1998.

Here the author presents an overview of key terms, methodology and purpose of research into pupils' attitudes to science. Also presents an agenda for future research into attitudes toward science.

[Gardner 1975] Gardner, P., *Attitudes to Science: A Review*. Studies in Science Education, **2**, 1 – 41, 1975.

In this review of the literature Gardner observed that, science lessons became more "masculine" in the course of time which is used as a possible explanation for an observed decline of girls' interests toward lessons at secondary school.

12.6 Gender

[Reid and Skryabina 2002] Reid, N and Skryabina, E., *Gender and physics*. International Journal of Science Education, in press (2002), 2002.

The dominant emphasis of this paper is gender issues as they relate to the study of physics at secondary school. However, references also cover higher education. In addition, unwarranted assumptions concerning the nature of number and scaling methods are discussed.

12.7 Books

[Chaiken and Eagly 1993] Chaiken, S. and Eagly, A. H., *The Psychology of Attitudes*. San Diago: Harcourt Bruce Jovannovich, 1993.

This is a comprehensive theoretical textbook on the psychology of attitudes and related studies on attitude measurement and social cognition

Topic 13

Learning Theories

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Return to beginning of main document

The learning theories presented in this section are based on an accumulation of empirical evidence and, as with any scientific theory, are susceptable to modification or rejection.

Much of the earliest research into learning was undertaken by Piaget (section 13.2) who developed his theory of cognitive development through observation and interviews with young children. His ideas on how new information is assimilated lead to Constructivist theories (section 13.4).

The information processing models (a version based upon Ausubel's [Ausubel 1968] "Meaningful Learning" theory and the ideas of Ashcraft [Ashcraft 1994] is presented below (section 13.5)) has proved a useful model for rationalising the observed difficulties in learning and in predicting ways in which learning may be successfully enhanced.

13.1 Ausubel's Meaningful Learning Theory

[Ausubel 1968] Ausubel, D. P., *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston, Inc, 1963.

Here Ausubel states that "If I had to reduce all of educational psychology to one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly".

[West and Fensham 1974] West, L. T. H. and Fensham, P. J., *Prior Knowledge and The Learning of Science – A Review of Ausubel's theory of the process.*. Studies in Science Education, **1**(1), 61 – 81, 1974.

Suggests that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning occurs when no such interaction takes place.

[Ausubel and Robinson 1969] Ausubel, D. P. and Robinson, F. G., *School Learning: An Introduction to Educational Psychology*. New York: Holt, Rinehart and Winston, 1969.

The following are thought to be the most likely circumstances which result in rote learning:

1. the material to be learned lacks logical meaning,
2. the learner lacks the relevant ideas in his own cognitive structure,
3. the individual lacks a meaningful learning set (a disposition to link new concepts, propositions, and examples, to prior knowledge and experience)

[Ebenezer 1992] Ebenezer, J. V., *Making Chemistry Learning More Meaningful*. Journal of Chemistry Education, **69**(4), 464 – 467, 1992.

In this article Ebenezer presents an overview of Ausubal's meaningful learning theory and then discusses the use of concept maps and V diagrams to elicit and restructure students' prior knowledge.

13.2 Piaget's Theory of Cognitive Development

A short introduction to Piaget and his theory of cognitive development can be found in Appendix B.

[Piaget 63] Piaget J, *The Psychology of Intelligence*. N.J.: Littlefield, Adams, 1963.

Piagian thought in his own words.

[Fuller et. al.] Fuller, R. G., Karpus, R. and Lawson, A. E., *Can Physics Develop Reasoning?*. Physics Today, **30**(2), 23 – 28, 1977.

In this paper the authors present a review of Piaget's cognitive development and then proceed with a discussion of how, through physics instruction, students can be encouraged to develop formal reasoning skills.

13.3 Introductory Books on Piaget's Work

[Wadworth 79] Wadworth B. J., *Piaget's Theory of cognitive development*. N.Y.: Longman, 1979.

This book provides a general over view of Piaget's work. It is aimed at Educationalists and psychologists who are new Piaget.

[Ginsberg 87] Ginsberg, H., *Piaget's Theory of intellectual development*. N.J.: Prentice-Hall, 1987.

Provides a summary of Piaget's theories. Ideal for those looking to ease themselves into Piagetian thought.

13.4 Constructivism

[Herron 1984] Herron, J. D., *Using Research in Chemical Education to Improve My Teaching*. Journal of Chemistry Education, **61**(10), 850 – 854, 1984.

In this paper the author presents a short introduction to constructivism and then discusses how this has influenced his lecture and laboratory instruction and assessment.

[Coll and Taylor 2001] Coll, R. K. and Taylor, T. G. N., *Using Constructivism to Inform Tertiary Chemistry Pedagogy*. Chemistry Education: Research and Practice in Europe, **2**(3), 215 – 226, 2001.

This review (has some 95 references) considers some of the implications and difficulties associated with a constructivist view of learning. The authors conclude that "constructivism offers tertiary chemistry educators some valuable insights into classroom practice, but that appropriate pragmatism with regard to pedagogy is more important than adherence to any particular metaphysical belief system".

13.5 Information Processing Models

"These models focus on learning and the learner and suggests mechanisms in the learning process" [Johnstone 1993].

[Ashcraft 1994] Ashcraft, M. H., *Human Memory and Cognition*. 2nd Edition. New York: Harper Collins, 1994.

Provides a comprehensive treatment of cognitive psychology, including information processing models.

[Johnstone 1993] Johnstone, A. H., *The Development of Chemistry Teaching: A Changing Response to Changing Demand*. Journal of Chemistry Education, **70**(9), 701 – 705, 1993.

Within this paper Johnstone presents a broad perspective on the philosophy of chemistry teaching. In particular, he presents a model of information processing, see Figure 13.1, which draws on the ideas of Ashcraft and Ausubel. In this model the *Perception Filter* receives signals from the outside world and admits some of them to the Working Memory (see Topic 8). Clearly the perception filter is constantly bombarded by stimuli, but an individual is able to select or filter out certain signals for further considerations. This filtering process is influenced by what is already held in the Long Term Memory (LTM): i.e. aids the selection of important from unimportant information. Meanwhile, the Working Memory (WM), see Topic 8, of limited capacity, is the space where information is held for decoding, interaction (with information drawn from the LTM) and encoding (for storage in the LTM). New information is most efficiently stored if it is linked to that already held in the LTM.

13.6 General Works

[Herron and Nurrenbern 1999] Herron, J. D. and Nurrenbern, S. C., *Chemical Education Research: Improving Chemistry Learning*. Journal of Chemistry Education, **76**(10),

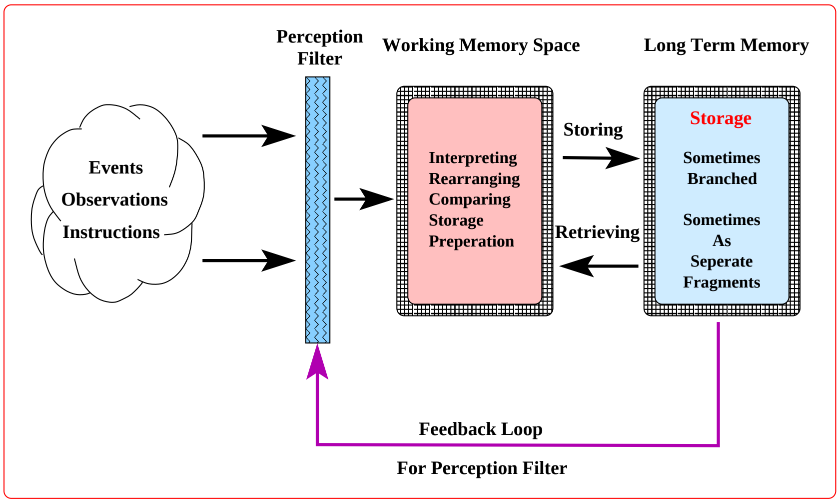

Figure 13.1: *Information Processing Model of Learning*

1354 – 1361, 1999.

This article presents a brief introduction to many aspects of chemistry education research including a brief discussion of behaviourist and constructivist theories.

Topic 14

Perry's Forms of Ethical and Intellectual Development

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Return to beginning of main document

Perry's scheme provides a model of how students view knowledge. It consists of nine positions each of which represents a particular "cognitive filter" through which they interpret their world. The model is hierarchical with higher positions subsuming lower. However progress may be interrupted through temporising, escape and retreat.

A summary of Perry's scheme can be viewed at Scheme of Cognitive and Ethical Development

14.1 Perry

[Perry 1999] Perry, W. G., *Forms of Ethical and Intellectual Development in the College Years: A Scheme.*. San Francisco: Jossey-Bass Inc, 1999.

This book is a reprint of Perry's original work with an introduction by Lee Knefelkamp.

Perry's Scheme was founded upon a longitudinal study of extended interviews with Harvard and Radcliff college students in the 1950's and 60's. Although the model has been criticised for its limited student sample, it has nonetheless generated much research activity, including "alternative" models and assessment methods, for the placement of students within the scheme.

14.1.1 Applied Perry Scheme

[Finster 1989] Finster, D. C., *Developmental Instruction: Part 1. Perry's Model of Intellectual Development.*. Journal of Chemical Education. **66**(8), 659 – 661, 1989.

In this first paper Finster provides a review of the Perry Scheme with a view to increasing the Perry position of a student through instruction. The method by which this can be achieved is presented in part 2 [Finster 1991].

[Finster 1991] Finster, D. C., *Developmental Instruction: Part 2. Application of the Perry Model to General Chemistry.*. Journal of Chemical Education. **68**(9), 752 – 756, 1991.

In this second paper Finster provides specific strategies for advancing general chemistry students along the Perry scheme. Here it is assumed that first year students are at Perry position 2-3 and that it is possible to advance an individual's Perry position by increments of +1. This is set within the context of a general set of strategies for challenging and supporting the dualist, multiplist and relativist Perry positions.

[Harvey 1994] Harvey, J. M., *An Investigation into the ways of Encouraging the Development of Higher Level of Cognitive Skills in Undergraduate Biology Students with Reference to the Perry Scheme of Intellectual Development*. Ph.D. Thesis, Napier University, Edinburgh, 1994.

Reports to have successfully used the Perry scheme, confirming Perry's observations.

14.1.2 Alternative Models

[Belenky 1986] Belenky, M. F., Clenchy, B. M., Goldberger, N. R., and Torule, J. M., *Women's Ways of knowing: The Development of Self, Voice and Mind*. New York: Basic Books Inc, 1986.

Perry's original work was criticised for possible gender bias towards the male college student. Belenky et. al. examine women's ways of knowing and describe five different perspectives from which women view reality and draw conclusions about truth, knowledge and reality. Uses voice rather than views as metaphor.

[Baxter Magolda 1987] Baxter Magolda, M. B., *Knowing and Reasoning in College: Gender-Related Patterns in Students' Intellectual Development*. San Francisco: Jossey Bass Publishers, 1992.

This research explores gender-related patterns of epistemological knowledge. Baxter Magolda's model contains four qualitatively different "ways of knowing", *absolute*, *transitional*, *independent*, and *contextual*. Each of these leads to a "particular expectation of learners, peers, and instructors in learning settings". In addition she found that ways of knowing were not segregated by gender, but rather gender related differences in reasoning patterns occur across the first three ways of knowing.

[Hofer and Pintrich 1997] Hofer, K. H. and Pintrich, P. R., *The Development of Epistemological Theories: Beliefs About Knowledge and Knowing and Their Relation to Learning*. Review of Educational Research, **67**(1), 88 – 140, 1997.

This paper provides an excellent overview of epistemological theories, critically reviewing the models of Perry (*Intellectual and ethical development*), Belenky et. al. (*Women's ways of knowing*), Baxter Magolda (*Epistemological reflections*), King and Kitchener (*Reflective judgement*) and Kuhn (*Argumentative reasoning*). In addition they identify areas of developmental and epistemological theory that warrant future research.

[Wood 1993] Wood, C., *Appendix 2*. In Wood C. and Sleet R. (Eds.), *Creative Problem Solving Chemistry*, London: The Royal Society of Chemistry, 1993.

This appendix presents a simplified adaptation of the Perry scheme. This scheme was used by [Gray 1993]. A summary of this scheme can be seen in Table 14.1. Perhaps

	Student A	**Student B**	**Student C**
Student Role	Passive acceptor of knowledge.	Realises that some responsibility rests with self. But what? and how?.	Sees self as source of knowledge, or is confident of finding it. Debater making own decisions.
Teacher Role	Authority giving facts and know how.	Authority exists. Where there are controversies wants guidance as to which Authority favours.	An Authority amongst other authorities. Values views of peers. Teacher as facilitator.
View of Knowledge	Factual: Black and white; clear objectives. Non controversial, exceptions unwelcome.	Admits no longer black and white. Feels insecure in this.	Wants to explore contexts, seeks connections. Enjoys creativity and scholarly work.
View of exams	Regurgitation of facts. Hard work is rewarded.	Quantity better than quality to demonstrate maximum knowledge.	Quality is better than quantity. wants room for expression.

Table 14.1: Summary of the simplified Perry scheme ([Gray 1993])

say something about Measure of intellectual development (MID) L. Knefelkamp and C. Widick. Also reflective judgement interview - King and Klitchener.

Appendix A

Scheme of Cognitive and Ethical Development

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Return to beginning of main document

The following is a summary of Perry's scheme of cognitive and ethical development.

Position 1 Authorities know, and if we work hard, read every word, and learn right answers, all will be well.

Transition But what about those others I hear about? And different opinions? And uncertainties? Some of our own authorities disagree with each other or don't seem to know, and some give us problems instead of answers.

Position 2 True authorities must be right, the others are frauds. We remain right. Others must be different and wrong. Good authorities give us problems so we can learn to find the right answer by our own independent thought.

Transition But even good authorities admit they don't know all the answers yet!

Position 3 Then some uncertainties and different opinions are real and legitimate temporarily, even for authorities. They're working on them to get to the truth.

Transition But there are so many things they don't know the Answers to! And they won't for a long time.

Position 4a Where Authorities don't know the Right Answers, everyone has a right to his own opinion; no one is wrong!

Transition (and or) But some of my friends ask me to support my opinions with facts and reasons.

Transition Then what right have They to grade us? About what?

Position 4b In certain courses Authorities are not asking for the right Answer; They want us to think about things in a certain way, supporting opinion with data. That's what they grade us on.

Transition But this ”way” seems to work in most courses, and even outside them.

Position 5 Then all thinking must be like this, even for Them. Everything is relative but not equally valid. You have to understand how each context works. Theories are not Truth but metaphors to interpret data with. You have to think about your thinking.

Transition But if everything is relative, am I relative too? How can I know I'm making the Right Choice?

Position 6 I see I'm going to have to make my own decisions in an uncertain world with no one to tell me I'm Right.

Transition I'm lost if I don't. When I decide on my career (or marriage or values) everything will straighten out.

Position 7 Well, I've made my first Commitment!

Transition Why didn't that settle everything?

Position 8 You've made several commitments. I've got to balance them – how many, how deep? How certain, how tentative?

Transition Things are getting contradictory. I can't make logical sense out of life's dilemmas.

Position 9 This is how life will be. I must be wholehearted while tentative, fight for my values yet respect others, believe my deepest values right yet be ready to learn. I see that I shall be retracing this whole journey over and over – but, I hope, more wisely.

Temporising Periods of intense growth are commonly followed by pauses or plateaus. Perry defined temporising as a pause in growth over a full academic year. Temporising is just a rather long plateau and by itself is not bad.

Retreat Retreat is regression to earlier positions. The most dramatic such retreat is movement back to positions 3 or 2 when the complexities of relativism and multiplicity become overwhelming.

Escape In escape the student avoids Commitment by exploiting the detachment afforded by positions 4 and 5. There are two escape paths, both of which start with temporising.

Dissociation In dissociation the student drifts into a passive delegation of responsibility to fate. (position 4)

Encapsulation The alternate path is encapsulation which may be a favourite of engineering students. In encapsulation one avoids relativism by sheer competence in one's field. The student becomes very good at engineering but avoids any questions of deeper meaning or value.

The nine positions may be categorised into four main groups, *Duality*, *Multiplicity Relativism* and *commitment*. [Perry 1999]

Dualism Division of meaning into two realms: Good vs. Bad, Right vs. Wrong, Us vs. Them. Correct answers always exist, and learning them is paramount – the more of this knowledge which is ingested, the better the student.

Multiplicity Diversity of opinion and values is recognised as legitimate in areas where right answers are not yet known. No judgement can be made between opinions "everyone has a right to his own opinion; none can be called wrong."

Relativism Diversity of opinion, values, and judgement derived from coherent sources, logic, analysis, and comparison etc. The individual is now a maker of meaning, knowledge is qualitative, dependent on contexts.

Commitment Here the individual makes choices/decisions (career, values, personal relationships, politics, etc.) in the full awareness of Relativism

Appendix B

Piaget's Theory of Cognitive Development

Get a .pdf version of this Topic here
Return to beginning of main document

The body of work generated by Piaget (1896 – 1980) is considerable, most of which concerns the cognitive development of children (0 – 18 years). His theory that a child's cognitive development passes through four stages, where later stages are founded upon earlier stages, forms the foundation of his (and others) research. These periods (or stages) of cognitive development are:

Sensori–Motor stage (age 0–2) This period of behaviour is primarily motor. The child perceives and manipulates but does not reason.

Preoperational stage (age 2–7) During this period symbolic thought develops (uses language and mental representations). Also children are seen to remember, imagine and pretend.

Concrete operational stage (7–11) Whilst in this stage children begin to learn how to handle the basics of logical thought but still rely on concrete objects. That is, they can perform mental operations with concrete materials but not with abstract ideas.

Formal operations stage (11 plus) at this stage abstract problems can be solved and the ability to formulate hypotheses is reached.

It should be noted that the transition from one stage to the next is not discontinuous. Moreover the quoted ages are for guidance only, individual children will develop at different rates. Furthermore, there is no guarantee that every child/adult will attain the full faculties of the formal operations stage.

More importantly, for tertiary education, is the underlying processes that facilitate the cognitive development through these stages. Piaget uses four concepts to explain how and why mental development occurs. These are:

Schema These are an individual's self-constructed mental structures. When a child is born, it has few schema which, as cognitive development progresses, broaden and differentiate. That is, schema are not destroyed, but instead are qualitatively and quantitatively refined. This is achieved through assimilation and accommodation.

Assimilation is the "fitting" of a new stimulus into an existing mental structure (schema) - qualitative development.

Accommodation is the creation of new schemata (from old schemata) or the modification of old schemata - quantitative development.

Equilibrium is a balance between assimilation and accommodation.

That is, on encountering a new stimulus, one attempts to assimilate the stimulus into an existing schema. If successful, equilibrium is maintained. If assimilation is not possible, accommodation is attempted by modifying or creating a new schema. When this is achieved, assimilation of the stimulus can occur and equilibrium is reached. Cognitive growth proceeds in this manner through *all* periods of development, the schema of the adult being built upon those of the child. This view of cognitive development is known as *constructivism* (See section 13.4, Constructivism).

Appendix C

List of Additional Refeences

Get a .pdf version of this Topic here
Return to beginning of main document

These are additional references that were quoted within the annotated bibliography.

C.1 Perry

[Gray 1997] Gray, C, *A study of the Factors Affecting a Curriculum Innovation in Unversity Chemistry*. Ph.D. thesis University of Glasgow, 1997.

[Gray 1993] Gray, C, *Design and assessment of chemistry Projects for Sixth Year studies.*. B.Sc. thesis University of Glasgow, 1997.

C.2 Piaget

[Pascaul–Leone 1970] Pascaul–Leone, J., *Mathematical Model for the Transition Role in Piaget's Development Stages*. Acta psychologica, 63, 301–345, 1970.

C.3 Assessment

[Sato 1975] Sato, T., *The Construction and interpretation of S–P tables*. Tokyo: Meijo Tosho, 1975.

Contains information "caution indices"

[Cronbach 1946] Cronbach, W. J., *Response Sets and Test Validity*. Educational and Psychological Measurement,**6**(), 475 – 493, 1945.

C.4 Critical Thinking

[Ennis 1991] Ennis, R. H., *Critical Thinking; A Streamlined Conception*. Teaching Philosophy, **14**(1), 5 – 25, 1991.

[Holroyd 1985] Holroyd, C., *What is a Problem? What is Problem Solving?*. In A. H. Johnstone (Ed.), Problem Solving. Is There a Problem? (pp. 2 – 7), St Andrews, UK: The Royal Chemistry Society, 1985.

Appendix D

List of urls

Get a .pdf version of this Topic here
Return to beginning of main document

Below are the url's for the internet sites quoted in the bibliography. These are correct as of November 6, 2002

Journal URL's:

American Educational research Journal
`http://www.aera.net/pubs/aerj/`

.

American Journal of Physics
`http://www.kzoo.edu/ajp/online.html`

.

Chemistry Education: Research and Practice in Europe
`http://www.uoi.gr/conf_sem/cerapie/`

.

Education in chemistry
`http://www.rsc.org/lap/educatio/eic/eic.htm`

.

European Journal of Physics
`http://www.iop.org/EJ/S/UNREG/9RWNG2gqu5Zm9pTBhv1Haw/journal/EJP`

.

Educational and Psychological Measurement
`http://www.sagepub.co.uk/frame.html?http://www.sagepub.co.uk/journals/details/j`

.

Educational Psychology
`http://www.tandf.co.uk/journals/carfax/01443410.html`

.

Harvard Educational Review
`http://www.gse.harvard.edu/ hepg/her.html`

.

International Journal of Science Education http://www.tandf.co.uk/journals/online/0950-0693.html

Journal of Applied Psychology
http://www.apa.org/journals/apl.html

Journal of Chemistry Education
http://jchemed.chem.wisc.edu/

Journal of College Science Teaching
http://www.nsta.org/college

Journal of Experimental Education
http://www.heldref.org/html/body_jxe.html

Journal of Experimental Measurement
http://www.ncme.org/pubs/jem.ace

Journal of Research in Science Teaching
http://journals.wiley.com/0022-4308

Psychological Bulletin
http://www.apa.org/journals/bul.html

Physics Education
http://www.iop.org/EJ/S/3/60/journal/PhysEd

Psychology Review
http://www.apa.org/journals/rev.html

Physics Today
http://www.aip.org/pt/

Quarterly Journal of Educational Psychology
http://www.tandf.co.uk/journals/pp/02724987.html

Review of Educational Research
http://www.aera.net/pubs/rer/

Research in Science and Technological Education
http://www.tandf.co.uk/journals/carfax/02635143.html

Science Education
http://www.interscience.wiley.com/jpages/0036-8326/

Studies in Higher Education
http://www.tandf.co.uk/journals/carfax/03075079.html

Studies in Science Education

http://education.leeds.ac.uk/ edu/sse/home.htm

School Science Review
http://www.ase.org.uk/publish/jnews/ssr/

Theory Into Practice
http://www.coe.ohio-state.edu/TIP/

The Physics Teacher
http://www.aapt.org/pubs_catalog/tpt/tpt.html

University Chemistry Education
http://www.rsc.org/uchemed/uchemed.htm

Other URL's

A paper on chemorganisers
http://www.uoi.gr/conf_sem/cerapie/2002_February/06.html

An Annotated Bibliography of Cooperative Learning
http://www.wcer.wisc.edu/nise/cl1/cl/resource/annbib.pdf

An Annotated Bibliography of Chemistry Misconceptions
http://www.oise.utoronto.ca/~science/chemmisc.htm

An Annotated Bibliography of Biology Misconceptions
http://www.oise.utoronto.ca/~science/chemmisc.htm

An Annotated Bibliography of Physics Misconceptions
http://www.oise.utoronto.ca/~science/chemmisc.htm

Chemorganisers
http://www.gla.ac.uk/centres/scienceeducation/Chemorg/Topics.html

Concept Maps and Mind Maps online bibligraphy
http://users.edte.utwente.nl/lanzing/cm_bibli.htm

Flexable Learning Approach to Phyiscs (FLAP)
http://physics.open.ac.uk/flap/FLAPHome.html

Learnibg an Teaching Support Network (LTSN)
http://www.physsci.ltsn.ac.uk

Peer Instruction
http://galileo.harvard.edu/index.html

TRIAD

http://www.derby.ac.uk/ciad

Centre For Science Education, University of Glasgow
http://www.gla.ac.uk/centres/scienceeducation