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An Annotated Bibliography of Research into Teaching and Learning *Update 2003-2006*

A Physical Sciences Practice Guide

Roger Gladwin (editor)

March 2007

Physical Sciences Centre
Department of Chemistry
University of Hull
Hull HU6 7RX
Phone: 01482 465418/465453 Fax: 01482 465418
Email: psc@hull.ac.uk Web: www.physsci.heacademy.ac.uk

An Annotated Bibliography of Research into the Teaching and Learning of the Physical Sciences at the Higher Education Level

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Roger Gladwin (editor)
Physical Sciences Centre
University of Liverpool

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The section numbering system used above is that of the original document; where no updates have been added (sub)-categories are omitted, where new sub-categories have been included new sections have been added.

Introduction

The first issue of the practice guide, **An Annotated Bibliography of Research into Teaching and Learning of the Physical Sciences at the Higher Education Level**, was compiled by David Palmer and Norman Reid, from the Centre for Science Education at the University of Glasgow and covered the literature up to 2003. This update was compiled by members of the Physical Sciences Subject Centre team using the same list of journals and covering (mostly) the period from 2003 to 2006. This is by no means an exhaustive listing, in preference we have searched for key, informative or review papers in the journals in order to give a 'flavour' of the current research into teaching and learning in the physical sciences. In general we have grouped the references into the same hierarchy as used in the original issue of the guide but there are also some new headings where necessary to include more recent areas of research. This update should be used in conjunction with the first issue.

Roger Gladwin
Physical Sciences Centre
University of Liverpool
Liverpool   L69 7ZD
rgladwin@liv.ac.uk

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1. Journals

Here is a list of cited journals. 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. (Links checked February 2007).

The American Biology Teacher
Also available through Athens/ProQuest.
http://www.bioone.org/perlserv/?request=get-archive&issn=0002-7685

American Educational Research Journal
Also available through Athens/ProQuest.
http://www.aera.net/publications/?id=315

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.
http://www.kzoo.edu/ajp/online.html

Chemistry Education: Research and Practice in Europe
This is a peer-reviewed electronic journal available, free of charge, online. From 2005 (with Volume 6) Chemistry Education Research and Practice is published by The Royal Society of Chemistry (merging with University Chemistry Education – see below).
http://www.uoi.gr/cerp/

Education in chemistry
This journal is published by the Royal Society of Chemistry. Selected contents are available online.
http://www.rsc.org/Education/EiC/index.asp

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: abstracts can be downloaded for free.
http://www.iop.org/EJ/S/UNREG/9RWNG2gqu5Zm9pTBhv1Haw/journal/EJP

Educational and Psychological Measurement
Articles are available online.
http://www.sagepub.co.uk/journalsProdDesc.nav?prodId=Journal200914

European Journal of Science Education
Renamed to the International Journal of Science Education. Journals are available online.
http://www.tandf.co.uk/journals/titles/09500693.asp

Educational Psychology
Journals are available online.
http://www.tandf.co.uk/journals/carfax/01443410.html

Harvard Educational Review
Journals from 1998 onward are available online.
http://www.hepg.org/main/her/Index.html

International Journal of Science Education
Journals are available online.
http://www.tandf.co.uk/journals/online/0950-0693.asp

Journal of Applied Psychology
Contents pages available online.
http://www.apa.org/journals/apl/

Journal of Chemical Education
Published by the American Chemical Society with Journals from 1945 onward available online.
http://jchemed.chem.wisc.edu/

Journal of College Science Teaching
Contents pages available online.
http://www.nsta.org/college

Journal of Research in Science Teaching
Abstracts are available online.
http://www3.interscience.wiley.com/cgi-bin/jhome/31817

Journal of Experimental Education
Articles from January 1994 onward are available to search online.
http://www.heldref.org/jexpe.php

Journal of Educational Measurement
Available online.
http://www.ncme.org/pubs/jem.cfm
now published by Blackwells.
http://www.blackwellpublishing.com/journal.asp?ref=0022-0655&site=1

Psychological Bulletin
Available online.
http://www.apa.org/journals/bul/

Physics Education
An Institute of Physics publication that has journals from 1966 onward available online.
http://www.iop.org/EJ/journal/PhysEd

Psychological Reports
Summaries are available to non-subscribers.
http://www.ammonsscientific.com/

Psychological Review
Available online.
http://www.apa.org/journals/rev/

Physics Today
Published by the American Institute of Physics. Articles from July 2000, onward are available online (some free).
http://www.aip.org/pt/

Quarterly Journal of Experimental Psychology
Available online from 1996 onward. Section A (Human Experimental Psychology) and Section B (Comparative and Physiological Psychology) integrated into current journal in 2006.
http://www.tandf.co.uk/journals/pp/02724987.html

Perceptual and Motor Skills
Summaries are available to non-subscribers.
http://www.ammonsscientific.com/

Review of Educational Research
Also available through Athens/ProQuest.
http://www.aera.net/publications/?id=319

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

Science Education
Abstracts are available online.
http://www3.interscience.wiley.com/cgi-bin/jhome/32122

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

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.
http://www.ase.org.uk/htm/journals/ssr/index.php

Studies in Science Education
The homepage provides information regarding this journal. Also available through Athens/ProQuest.
http://www.education.leeds.ac.uk/research/cssme/studies_scienceed.php

Theory Into Practice
Only tables of contents and ordering information available at present.
http://www.coe.ohio-state.edu/TIP/

The Physics Teacher
This journal is primarily aimed at those teaching introductory physics at any level. Table of contents are available online.
http://scitation.aip.org/tpt/

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. Now joined with Chemistry Education: Research and Practice in Europe and named Chemistry Education Research and Practice.
http://www.rsc.org/Education/CERP/issues/index.asp

2. General Papers

R. E. Goldstein, P. C. Nelson, et al., Teaching Biological Physics. *Physics Today* **58**(3), 6, 2005.
Examines the reasons behind the difficulty of creating and sustaining courses for biological physics and offers some ideas for planning such courses.

J. Gollub, Reflections on Teaching: Learning from Students. *Physics Today* **58**(5), 2, 2005.
Emphasises the importance for physics teachers to engage students in the act of discovery of ideas to promote the learning process.

R. C. Hilborn and R. H. Howes, Why Many Undergraduate Physics Programs Are Good but Few Are Great. *Physics Today* **56**(9), 7, 2003.
Explores undergraduate physics education in the U.S.

L. Kadanoff, G. T. U. States, et al., An educational moment? *Physics Today* **59**(9), 2, 2006.
The article offers a few suggestions on how the physics community in the U.S. might help improve education in the sciences and allied areas.

D. J. Grayson, Rethinking the Content of Physics Courses. *Physics Today* **59**(2), 6, 2006.
The article discusses just some of the ideas that emerged from an international conference to discuss and debate what should go into 21st-century physics courses. The author explores the implication of the ideas for teaching and curriculum development.

C. Wieman and K. Perkins, Transforming Physics Education. *Physics Today* **58**(11), 6, 2005.
This article presents ideas on reforming science education to make it more effective and relevant.

2.3. Group work

P. Gustafsson, Physics teaching at a distance. *European Journal of Physics* **23**(5), 469, 2002.
The problem that some students do not complete their distance course, it is suggested, can be addressed by transforming established methods used in campus courses to encourage interactivity among students. A probable result of applying these methods would be an enhanced understanding of the concept of physics and problem-solving skills.

P. Gustafsson, Improved method in distance teaching of physics. *European Journal of Physics* **25**(2), 185, 2004.
Results of introducing cooperative working methods on a distance learning course in physics are reported. This has increased the throughput of students in the course.

2.4. Learning environments

K. de Adrianus, S. Peter, et al., New Learning and the Classification of Learning Environments in Secondary Education. *Review of Educational Research* **74**(2), 141, 2004.
This new classification scheme emphasises new forms of learning and is organised around three main aspects of learning environments that may be assumed to influence such learning: (a) learning goals, (b) the division of teacher and learner roles, and (c) the roles of the learners in relation to each other. It is then argued that teachers might use this classification scheme to design and evaluate their own learning environments.

K. T. R. Mary, A. T. Julie, et al., Teaching Courses Online: A Review of the Research. *Review of Educational Research* **76**(1), 93, 2006.
This literature review summarises research on online teaching and learning. It is organised into four topics: course environment, learners' outcomes, learners' characteristics, and institutional and administrative factors.

M. B. Robert, C. A. Philip, et al., How Does Distance Education Compare With Classroom Instruction? A Meta-Analysis of the Empirical Literature. *Review of Educational Research* **74**(3), 379, 2004.
A meta-analysis of the comparative distance education (DE) literature between 1985 and 2002 was conducted. In total, 232 studies containing 688 independent achievement, attitude, and retention outcomes were analysed.

A. Vincent, S. Elmar, et al., Help seeking and help design in interactive learning environments. *Review of Educational Research* **73**(3), 277, 2003.
This selective review (a) examines theoretical perspectives on the role of on-demand help in ILEs, (b) reviews literature on the relations between help seeking and learning in ILEs, and (c) identifies reasons for the lack of effective help use.

3. Lecturing

3.1. General papers on lecturing

Cedric Linder, Duncan Fraser, Using a Variation Approach To Enhance Physics Learning in a College Classroom. *The Physics Teacher* **44**(9), 589-592, 2006.
Describes the "variation approach to learning".

3.2. Peer instruction

Scott E. Lewis and Jennifer E. Lewis, Departing from Lectures: An Evaluation of a Peer-Led Guided Inquiry Alternative. *J. Chem. Educ.* **82**, 135, 2005.
The authors describe a scheme to improve a large-enrollment general chemistry course based on conventional lectures, in which they instituted a reform combining peer-led team learning with a guided inquiry approach, together called peer-led guided inquiry.

Carl C. Wamser, Peer-Led Team Learning in Organic Chemistry: Effects on Student Performance, Success, and Persistence in the Course. *J. Chem. Educ.* **83**, 1562, 2006.
This paper describes the results of instituting peer-led team learning workshop sessions as optional accompaniments for the first two years of chemistry (general chemistry and organic chemistry), courses taught in large-lecture format.

Marcelo Giordan, Tutoring through the internet: how students and teachers interact to construct meaning. *International Journal of Science Education* **26**(15), 1875-1894, 2004.
Two episodes of tutoring through the internet have been analysed in terms of situational, interactive and content perspectives. The episodes involved secondary students who submitted queries about chemistry issues to an online service provided by teachers. Studies of the asking of questions and of the dynamics of classroom interactions are employed to discuss the interactive and content factors of this approach to teaching-learning.

Shirley Simon, and Jane Maloney, Learning to teach 'ideas and evidence' in science: a study of school mentors and trainee teachers. *School Science Review* 75-82, June 2006.
This article reports on a small-scale evaluation of how trainee teachers undertaking a PGCE in secondary science worked collaboratively with their school-based mentors to enhance practice in the use of ideas and evidence in science.

4. Assessment

4.1. Multiple choice scoring schemes

Gary A. Morris, Lee Branum-Martin, Nathan Harshman, Stephen D. Baker, Eric Mzur, Suvendra Dutta, Taha Mzoughi and Veronica McCauley, Testing the test: Item response curves and test quality. *American Journal of Physics* **74**(5), 449-453, 2006.
This paper shows how item response curves can be used to analyse the efficiency and effectiveness of multiple choice questions, and to give a better understanding of the results obtained. Results from the use of the Force Concept Inventory are used to demonstrate the technique.

N. Sanjay Rebello and Dean A. Zollman, The effect of distracters on student performance on the force concept inventory. *American Journal of Physics* **72**(1), 116-125, 2004.
It is conjectured that in the ten years since the force concept inventory (FCI) was developed, changes in courses and environments may have changed the value of the MCQ distracters.

Chandralekha Singh and David Rosengrant, Multiple-choice test of energy and momentum concepts. *American Journal of Physics* **71**(6), 607-617, 2003.
This paper describes a study of the understanding introductory level energy and momentum concepts using a new 25 item MCQ test and interviews. The test is included, and can be used pre and post. Students had the greatest difficulties in applying the basic principles to quantitative physical problems.

4.2. Factors affecting test outcomes

Eleni Danili and Norman Reid, Assessment formats: do they make a difference? *Chem. Educ. Res. Pract.* **6**(4), 204-212, 2005.
This study explores the relationships between the results of various formats of paper-and-pencil classroom assessments in five classroom chemistry tests. The formats of assessment that have been used were: multiple choice, short answer, and structural communication grid. The correlations between the different formats of assessment tended to be between 0.30 and 0.71. This suggests that the best student found by one method is not necessarily the best student by another method.

Eleni Danili, and Norman Reid, Cognitive factors that can potentially affect pupils’ test performance. *Chem. Educ. Res. Pract.* **7**(2), 64-83, 2006.
The two cognitive styles, ‘field dependent/field independent’ and ‘convergent/divergent’, were explored in relation to three formats of assessment (multiple choice, short answer and structural communication grid) in five classroom chemistry tests. The study was conducted in Greece with the participation of Grade-10 (upper secondary school) pupils (age 15-16). This study suggests that some of the factors that affect pupils’ performance might be: (a) the content and presentation of the test, (b) the format of the test, (c) the psychology of the individual.

Georgios Tsparlis and Uri Zoller, Evaluation of higher vs. lower-order cognitive skills-type examinations in chemistry: implications for university in-class assessment and examinations. *UChemEd* **7**(2), 50-57, 2003.
The aim of this paper is to provide evidence for the effectiveness of higher-order cognitive skills (HOCS) learning, based on three relevant research studies. A different pattern of students' performance was revealed on examination questions requiring HOCS compared with that on questions requiring LOCS. A 'high-stake' examination, used for entry into higher education was found to select the best LOCS-performing students.

D. M. Bolt, A. S. Cohen, et al., Item Parameter Estimation Under Conditions of Test Speededness: Application of a Mixture Rasch Model With Ordinal Constraints. *Journal of Educational Measurement* **39**(4), 331-348, 2002.
When tests are administered under fixed time constraints, test performance can be affected by speededness. This article presents an item response theory strategy for reducing contamination in item difficulty estimates due to speededness.

4.3. Alternatives to multiple choice tests

Ian D. Beatty, William J. Gerace, William J. Leonard and Robert J. Dufresne, Designing effective questions for classroom response system teaching. *American Journal of Physics* **74**(1), 31-39, 2006.
This paper discusses the design and use of questions for use with question driven instruction using a Classroom Response System. A systematic framework for developing and evaluating suitable questions is described, identifying content, process and metacognitive goals for each question and tactics are discussed for stimulating cognitive processes through concept articulation and conflict leading to productive discussion.

Vincent P. Coletta and Jeffrey A. Phillips, Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability. *American Journal of Physics* **73**(12), 1172-1182, 2005.
Force concept inventory normalised gain scores are compared with Lawson's Classroom Tests of Scientific Reasoning, showing a strong correlation.

M. G. Jodoin, Measurement Efficiency of Innovative Item Formats in Computer-Based Testing. *Journal of Educational Measurement* **40**(1), 1, 2003.
In this study, examinee responses to conventional (e.g., multiple choice) and innovative item formats in a computer-based testing program were analysed for IRT information with the three-parameter and graded response models.

4.4. Scoring schemes

Jeffrey D. Marx and Karen Cummings, Normalized change. *American Journal of Physics* **75**(1), 87-91, 2007.
This paper discusses the parameterisation of the scores from pre and post tests, and proposes a simple method of normalising the scores a) to remove the bias inherent in low pre-test scores b) to remove possible ambiguities in the representation of negative changes.

Lei Bao, Theoretical comparisons of average normalized gain calculations. *American Journal of Physics* **74**(10), 917-922, 2006.
This paper discusses the difference in the two methods of obtaining the average normalised gain from the results of pre and post tests, and how difference between the two values could be used to infer changes in the population.

Bradley T. Erford and Lauren Klein, Technical Analysis of the Slosson–Diagnostic Math Screener (S-DMS). *Educational and Psychological Measurement* **67**(1), 132-153, 2007.
The Slosson-Diagnostic Math Screener (S-DMS) was designed to help identify students in Grades 1 to 8 at risk for mathematics failure. Internal consistency, test-retest reliability, item analysis, decision efficiency, convergent validity, and factorial validity of all five levels of the S-DMS were studied using 20 independent samples of students aged 6 to 13 years. The Woodcock-Johnson Tests of Achievement-Revised Broad Mathematics Cluster, the Wide Range Achievement Test-Revised Arithmetic subtest, and the KeyMath-Revised Operations Area were used as convergent validity measures.

4.5. ICT

Caroline V. Gipps, What is the role for ICT-based assessment in universities? *Studies in Higher Education* **30**(2), 171-180, April 2005.
This paper reviews the role of ICT-based assessment in the light of the growing use of virtual learning environments in universities.

K. Kelvin Cheng, Beth Ann Thacker, Richard L. Cardenas and Catherine Crouch, Using an online homework system enhances students' learning of physics concepts in an introductory physics course. *American Journal of Physics* **72**(11), 1447-1453, 2004.
The Force Concept Inventory (FCI) is used to compare students' understanding of physics concepts between groups exposed to interactive and noninteractive engagement and with ungraded homework and with graded online homework using WebCT. The increase in the average FCI normalised gain was statistically significant for students using the online homework.

Zacharias Zacharia, and O. Roger Anderson, The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics* **71**(6), 618-629, 2003.
This paper describes a test of whether the use of a simulation before an experiment will improve the efficacy of the laboratory. 13 students carried out 12 activities, and for each student half of these activities were preceded by use of an appropriate interactive simulation. Results indicated that the use of the simulations was indeed effective.

4.6. Feedback

David J. Nicol, and Debra Macfarlane-Dick, Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education* **31**(2), 199-218, April 2006.
These authors reinterpreted research on formative assessment and feedback to show how these processes can help students take control of their own learning, i.e. become self-regulated learners.

David Carless, Differing perceptions in the feedback process. *Studies in Higher Education* **31(**2), 219-233, April 2006.
This article seeks to examine the notion of written feedback on assignments and argue that this feedback process is more complex than is sometimes acknowledged.

O. Gioka, Assessment for learning in physics investigations: assessment criteria, questions and feedback in marking. *Physics Education* **41**(4), 342-346, 2006.
The teaching of four secondary school science teachers working in greater London was observed to assess the extent to which they used formative assessment *for* learning, i.e. the use of questions both in dialogue and in written feedback to provide additional information that can be used to modify the learning.

4.7. General

Stuart W. Bennett, Assessment in chemistry and the role of examinations. *UChemEd* **8**(2), 52-57, 2004.
This paper discusses the role of examinations in testing the full range of learning outcomes for a chemistry programme and the match between stated learning outcomes and assessment.

Robert A. Ellis, University student approaches to learning science through writing. *International Journal of Science Education* **26**(15), 1835-1853, 2004.
This study investigates the approaches adopted by students to a university writing programme designed to help them learn first-year undergraduate science.

S. Klassen, Contextual assessment in science education: Background, issues, and policy. *Science Education* **90**(5), 820-851, 2006.
This paper discusses the basis of assessment, and the changes in assessment practices in science education in recent decades. These changes gave rise to the development of various contextual assessment methodologies, for example, concept mapping assessment, performance assessment and portfolio assessment, and these are discussed.

5. Practical Work – the Laboratory

5.1. General papers

Deborah G. Herrington, and Mary B. Nakhleh, What Defines Effective Chemistry Laboratory Instruction? Teaching Assistant and Student Perspectives. *J. Chem. Educ*. **80**, 1197, 2003.
This paper identifies qualities that students and teaching assistants perceived to be important for effective instruction within the introductory university chemistry laboratory context.

Christine L. McCreary, Michael F. Golde, and Randi Koeske, Peer Instruction in the General Chemistry Laboratory: Assessment of Student Learning. *J. Chem. Educ*. **83**, 804, 2006.
This paper reports the first systematic comparison of conventional and workshop labs where undergraduates act as the teacher, mentor, and facilitator for a small group of students during lab sessions.

Miriam Reiner, and John K. Gilbert, The symbiotic roles of empirical experimentation and thought experimentation in the learning of physics. *International Journal of Science Education* **26**(15), 1819-1834, 2004.
This study was an attempt to identify the epistemological roots of knowledge when students carry out hands-on experiments in physics.

Katrina Fox, Authentic alternatives to practical work. *School Science Review* 45-52, September 2006.
Given the negative perceptions of school science amongst many young people, science teachers must develop a range of strategies to engage pupils with science. Authentic learning experiences, often involving complex practical work, are designed to engage and motivate pupils, but are often too demanding in terms of time and resources to be incorporated into everyday practice. In this article, strategies for incorporating authentic learning experiences based on discussion rather than practical work are described. Evaluation indicated that this approach helped pupils engage with the lesson and enhanced enjoyment.

Peter Borrows, Chemistry outdoors. *School Science Review* 23-32, March 2006.
Teachers can use the local environment to reinforce important ideas of elementary chemistry. Concrete can be used to discuss acids, bases, indicators and neutralisation, rates of reaction, acid rain, diffusion, thermal decomposition, reversible reactions, composite materials, hazards in everyday life. In churchyards it is usually possible to explore the physical properties of metals, their reactivity with air and water, the rusting and expansion of iron, the action of acids on carbonates, the effect of rate of cooling on the size of crystals, rock types, and so on. These and many other ideas are discussed in this article.

Francisca Wheeler, Unorthodox ways of teaching physics: making use of your surroundings. *School Science Review* 61-64, March 2006.
There are many opportunities to teach physics in our local environment. Using them will help physics teachers to set the subject in a context that students know and understand, and will also provide opportunities to learn practical skills that are not easily practised in the classroom or laboratory. This article describes some tried-and-tested activities that have been used to teach many areas of physics through observation of weather, alternative sources of energy and pollution topics.

5.4. Problem based learning (PBL)

Pasl A. Jalil, A Procedural Problem in Laboratory Teaching: Experiment and Explain, or Vice-Versa? *J. Chem. Educ*. **83**, 159, 2006.
This work describes two different approaches to teaching the laboratory segment of a freshman chemistry course. In Approach I, each experiment was explained and demonstrated to the students before they participated; the expected results were also discussed. In Approach II, the students conducted the experiments themselves with minimal help from the instructor.

Alison M. Mackenziea, Alex H. Johnstone and R. Iain F. Brown, Learning from Problem Based Learning. *UChemEd* **7**(1), 13-29, 2003.
This paper describes the form of PBL currently in use in a medical school where PBL is the main method for learning the content of the course and for generating self-driven, independent learning and for fostering the skills of organisation and communication. The course has been independently evaluated to discover if the claims for PBL can be substantiated. The PBL technique and the evaluation results are presented and suggestions are made about how this might be applied to the teaching and learning of the sciences.

D. Teresa, Using a guided-inquiry approach for investigating metabolic rate in mice. *The American Biology Teacher* **64**(6), 449, 2002.
This paper offers an effective strategy for converting traditional "recipe-based" lab experiences into "student-governed" investigations. The lesson plan uses a guided-inquiry approach for investigating metabolic rate in mice.

Thomas Lord and Terri Orkwiszewski, Moving from Didactic to Inquiry-Based Instruction in a Science Laboratory. *The American Biology Teacher* **68**(6), 342, 2006.
While previous studies have shown that inquiry teaching can have a positive impact on learning (Blank, 2000; Marbach-Ad & Sokolove, 2000), comparing college student performance taught by two different instructional methods in a science laboratory has not been done.

D. Raine and J. Collett, Problem-based learning in astrophysics. *European Journal of Physics* **24**(2), S41, 2003.
The authors compare three examples of PBL in undergraduate astrophysics programmes, and discuss the strengths and weaknesses of the various approaches.

G. David, D. Filip, et al., Effects of Problem-Based Learning: A Meta-Analysis From the Angle of Assessment. *Review of Educational Research* **75**(1), 27, 2005.
This meta-analysis investigated the influence of assessment on the reported effects of problem-based learning (PBL) by applying Sugrue's (1995) model of cognitive components of problem solving.

6. Problem Solving

6.1. General papers

Chance Hoellwarth, Matthew J. Moelter, and Randall D. Knight, A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms. *American Journal of Physics* **73**(5), 459-462, 2005.
The effectiveness of conventional lecture/tutorial classes are compared directly with the studio method using pre and post Force Concept Inventory and Force and Motion Conceptual Evaluation tests. Numerical problem solving skills were measured by conventional examination questions. It was found that the normalised learning gain for conceptual understanding was substantially greater in the groups using the studio method, but that there was no overall gain in numerical problem solving ability with the studio method.

David E. Meltzer, Relation between students' problem-solving performance and representational format. *American Journal of Physics* **73**(5), 293-384, 2005.
Students' performances at similar problems posed in different formats (e.g. verbal, diagrammatic, mathematical) were compared. Most differences were small, but diagrammatic presentation revealed difficulties with understanding of vector representations. Some gender difference was noted with circuit diagrams.

S. K. Barry and A. G. Patricia, Problem-Based Learning in the Biology Curriculum. *The American Biology Teacher* **66**(5), 348, 2004.
Now often used in the curricula of medical, dental and nursing schools, Problem-based learning (PBL) is a pedagogical approach to learning that involves presentation of a curriculum-related problem or situation whose solution requires students to practice skills of analysis, integration, and application. Here, the authors describe PBL in two different settings: one in Introductory Biology laboratory for non-majors, and the other involves a colloquium for senior biology majors.

George M. Bodner, Problem Solving: The difference between what we do and what we tell students to do. *UChemEd* **7**(2), 37-45, 2003.
This paper discusses the difference between problems and exercises and describes some models of problems solving. The author discusses successful approaches to solving non-traditional problems.

Colin Wood, The development of creative problem solving in chemistry. *Chem. Educ. Res. Pract.* **7**(2), 96-113, 2006.
The object of this paper is to show how research has gone hand in hand with development to produce materials for teaching and learning which take problem solving above the level of algorithmic manipulation.

Torsten Witteck and Ingo Eilks, Using the learning company approach to allow students to investigate acids and bases. *School Science Review* 95-102, December 2006.
A ‘learning company’ is a classroom-based activity analogous to existing or ‘ideal’ realworld companies. This article describes a lesson plan worked out and tested for German grade 10 chemistry lessons (age range 15–16) on the topic ‘The chemistry of acids and bases’. The concept of the learning company is used to motivate and encourage cooperative learning. This plan integrates the idea of a learning company with more open approaches to experimentation and with learning through multimedia in school science. Experiences in the classroom are also reported.

F. F. M. De Mul, C. M. i. Batlle, et al., How to encourage university students to solve physics problems requiring mathematical skills: the adventurous problem solving approach. *European Journal of Physics* **25**(1), 51, 2004.
In this new approach, students have to find the solution by developing their own problem-solving strategy in an interactive way.

Boris Korsunsky, Ready, Set, Go! A Research-Based Approach to Problem Solving. *The Physics Teacher* **42**(8), 493-497, 2004.
A description of a set of problem-solving approaches and teaching strategies.

6.2. Problem types

Vasileios Zikovelis and Georgios Tsaparlis, Explicit teaching of problem categorisation and a preliminary study of its effect on student performance - the case of problems in colligative properties of ideal solutions. *Chem. Educ. Res. Pract*. **7**(2), 114-130, 2006.
In this work, the authors suggest a categorisation scheme for problems in the special topic of colligative properties of ideal solutions. They report on the results when such a scheme was taught to an experimental group (n = 41) of eleventh-grade upper secondary students (age 16-17), and was compared with a control group (n = 26) who were taught in the traditional manner. The experimental group showed a superior performance, but it was not statistically significant.

Dimitrios Stamovlasis, Georgios Tsaparlis, Charalambos Kamilatos, Dimitrios Papaoikonomou, and Erifyli Zarotiadou, Conceptual understanding versus algorithmic problem solving: Further evidence from a national chemistry examination. *Chem. Educ. Res. Pract*. **6**(2), 104-118, 2005.
This paper analyses the results of a national examination from the perspective of conceptual learning versus algorithmic problem solving.

6.3. Factors affecting success in problem solving

Joanne McCalla, Problem Solving with Pathways. *J. Chem. Educ*. **80**, 92, 2003.
This paper presents a method that permits the students to work out their own logical pathway to a solution, rather than having to recall a previously learned series of solution steps.

G. Tsaparlis, Non-algorithmic quantitative problem solving in university physical chemistry: a correlation study of the role of selective cognitive factors. *Research in Science & Technological Education* **23**(2), 125-148, 2005.
This paper discusses the role of cognitive variables on problem solving in physical chemistry. The author found that functional mental capacity and disembedding ability plays an important role in problem solving. Scientific reasoning and working memory capacity proved to have little relevance.

S. Bruce, Common sense clarified: The role of intuitive knowledge in physics problem solving. *Journal of Research in Science Teaching* **43**(6), 535-555, 2006.
This article discuss three related questions: (1) What role, if any, does intuitive knowledge play in physics problem solving? (2) How does intuitive physics knowledge change in order to play that role, if at all? (3) When and how do these changes typically occur?

6.5. Conceptual understanding and problem solving

L. Spier-Dance, J. Mayer-Smith, N. Dance and S. Khan, The role of student-generated analogies in promoting conceptual understanding for undergraduate chemistry students. *Research in Science & Technological Education* **23**(2), 163-178, 2005.
This paper discusses the use of student generated analogies for conceptually difficult chemistry topics. It was found that students who generated their own analogies performed significantly better in an exam and demonstrated a greater level of conceptual understanding than those students who were presented with a teacher derived analogy.

M. Gunel, B. Hand and S. Gunduz, Comparing student understanding of quantum physics when embedding multimodal representations into two different writing formats: Presentation format versus summary report format. *Science Education* **90**(6), 1092-1112, 2006.
Gunel et al have completed a study with a group of Turkish school students. The study explored the use of different writing-to-learn formats for building conceptual understanding of physics topics. Students used either a presentation format using multimodal representations (text, mathematical, graphical and pictorial) or a summary report format, to convey their understanding at the end of the two topics studied. It was found that the presentation format enabled construction of a richer set of conceptual understanding to be generated, and suggests that the use of multiple modes to explain understanding, with a limited amount of text, is beneficial to learning.

M. Barak and Y. J. Dori, Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment. *Science Education* **89**(1), 117-139, 2005.
This study aimed to investigate students' learning outcomes while they were engaged in project-based learning (PBL) in undergraduate chemistry courses. The results indicate that students who participated in the PBL performed significantly higher. The results suggested the incorporation of PBL enhances students' understanding of chemical concepts, theories and molecular representations.

6.6. Cooperative problem solving

J. Murray, M. Randy, et al., Cooperative learning - part I cooperative quizzes. *The American Biology Teacher* **64**(1), 29, 2002.
Cooperative quizzes are not a reliable testing tool because they cannot accurately measure an individual's knowledge, but they are a versatile learning tool that can be used in both the lecture and lab. The authors describe the structure needed for a cooperative quiz, document how the quizzes can be used in different settings, and compare students' performances on a group vs. individual quiz.

7. Critical Thinking

7.2. Critical thinking, assessment and improvement strategies

Richard F. Yuretich, Encouraging critical thinking. *Journal of College Science Teaching* **33**(3), 40-47, 2004.
Methods to promote high level reasoning in large classes were applied. Methods included in-class mini-investigations, robust multiple-choice exam questions, online quizzes or review and cooperative learning, particularly during exams. Data gleaned from observing student performance, surveys and interviews confirm the efficacy of these techniques.

Claus Jacob, Critical Thinking in the Chemistry Classroom and Beyond. *J. Chem. Educ*. **81**, 1216, 2004.
This paper postulates that undergraduate chemistry curricula could be improved if chemists were trained more explicitly in critical thinking.

8. Working Memory

8.4. Investigations into the overload of working memory

Slava Kalyuga, Rapid Assessment of Learners' Proficiency: A cognitive load approach. *Educational Psychology* **26**(6), 735-749, December 2006.
This paper discusses a diagnostic approach based on monitoring immediate traces of students' knowledge structures in working memory.

10. Concept Maps and Mind Maps

10.1. Articles on concept maps

S. B. David, High school biology: A group approach to concept mapping. *The American Biology Teacher* **65**(3), 192, 2003.
Concept mapping has been shown for the past 20 years as being an ideal strategy for promoting meaningful learning. In a concept-rich unit such as one on photosynthesis and cellular respiration, students are able to talk through misunderstandings of science concepts and teach one another these biology concepts in high school classrooms where mapping in groups occurs.

Martin Graff, Differences in concept mapping, hypertext architecture, and the analyst–intuition dimension of cognitive style. *Educational Psychology* **25**(4), 409-422, 2005.
This paper describes a study of the extent to which the structure of web-based or hypertext instructional systems are contingent upon an individual's cognitive style for effective recall of information. Results confirmed the effect, and found that concept maps drawn by participants with different cognitive styles differed between different hypertext structures.

11. Misconceptions

11.1. References to misconceptions

Vicente Talanquer, Commonsense Chemistry: A Model for Understanding Students' Alternative Conceptions. *J. Chem. Educ*. **83**, 811, 2006.
Research results provided here indicate that many students' conceptual difficulties result from commonsense reasoning.

Ellen J. Yezierski and James P. Birk, Misconceptions about the Particulate Nature of Matter. Using Animations To Close the Gender Gap. *J. Chem. Educ*. **83**, 954, 2006.
In this study, a newly developed instrument called the Particulate Nature of Matter Assessment was used as a pretest and posttest to measure students' conceptual understanding of the PNM regarding phases of matter and phase changes.

Diana J. Grayson, Concept substitution: A teaching strategy for helping students disentangle related physics concepts. *American Journal of Physics* **72**(8), 1126-1133, 2004.
The author describes a number of examples of students' misconceptions (in this case in DC electric circuits) and suggests that the method of "concept substitution" can be an appropriate strategy for remediation.

Paula Vetter Engelhardt and Robert J. Beichner, Students' understanding of direct current resistive electrical circuits. *American Journal of Physics* **72**(1), 98-115, 2004.
This paper describes some of the common misconceptions that students hold about DC circuits, and describes the design, development and validation of a diagnostic instrument comprising 29 questions. It is described as being suitable for the evaluation of student progress or of instructional methods.

L. I. Ella and E. N. Craig, Using discussions of Multiple Choice Questions To Help Students Identify Misconceptions & Reconstruct Their Understanding. *The American Biology Teacher* **68**(5), 275, 2006.
Student use of past learning increases as students work through problems, and future recall is enhanced by the creation of additional conceptual frameworks and reinforcement of prior frameworks. The course in whole is interdisciplinary; the scientific component of the course focused on evolutionary science as a model of critical thinking.

M. Harold, M. Joel, et al., Helping the Learner To Learn: The Role of Uncovering Misconceptions. *The American Biology Teacher* **67**(1), 20, 2005.
The authors discuss the goals of "misconceptions" research, which was to uncover conceptual difficulties in a particular discipline and to gain insight about the origins of these misconceptions. Several years ago, educators began to explore the prevalence of certain misconceptions held by undergraduate students entering physiology courses. Their intent was to gain better understanding of the conceptual and reasoning difficulties that might impede entering students' ability to construct robust mental models of physiological systems and phenomena.

C. Singh, M. Belloni, et al., Improving students' understanding of quantum mechanics. *Physics Today* **59**(8), 7, 2006.
To address the misconceptions that students typically hold concerning quantum mechanics, the authors advise that instructors should couple computer-based visualisations with research-based pedagogical strategies.

M. C. Wittmann, J. T. Morgan, et al., Addressing student models of energy loss in quantum tunnelling. *European Journal of Physics* **26**(6), 939, 2005.
The authors find inconsistencies between students' conceptual, mathematical and graphical models of quantum tunnelling. As part of a curriculum in quantum physics, they have developed instructional materials designed to help students develop a more robust and less inconsistent picture.

E. Ali, Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. *Journal of Research in Science Teaching* **39**(10), 1001-1015, 2002.
The purpose of this study was to investigate the effects of conceptual assignments and conceptual change discussions on students' achievement and misconceptions about force and motion.

12. Attitudes

12.2. Attitude change

C. Anders R. Berg, Factors related to observed attitude change toward learning chemistry among university students, *Chemistry Education: Research and Practice* **6**(1), 1-18, 2005.
This paper describes how six students who displayed major attitude changes were identified through a pre- and post-course attitude questionnaire administered to sixty-six first-year university chemistry students. A positive attitude change was associated with evidence of motivated behaviour, while a negative change was linked to less motivated behaviour.

12.4. Attitudes toward the study of science

Adrian Kirkwood and Linda Price, Learners and learning in the twenty-first century: what do we know about students' attitudes towards and experiences of information and communication technologies that will help us design courses? *Studies in Higher Education* **30**(3), 257-274, June 2005.
This article reports on issues relevant for teachers and instructional designers anticipating using information and communication technologies (ICTs) in higher education, particularly those wishing to adopt a flexible learning approach aimed at improving the quality of the student experience.

Renée S. Cole and John B. Todd, Effects of Web-Based Multimedia Homework with Immediate Rich Feedback on Student Learning in General Chemistry. *J. Chem. Educ*. **80**, 1338, 2003.
This paper describes a series of Web-based homework and tutorial programs implemented through WebCT that are designed to help students gain a better understanding of chemistry.

Larry S. Miller, Mary B. Nakhleh, John J. Nash and Jeanne A. Meyer, Students' Attitudes toward and Conceptual Understanding of Chemical Instrumentation. *J. Chem. Educ*. **81**, 1801, 2004.
The authors evaluate (i) the attitudes students have toward using instrumentation, (ii) how students relate the underlying chemical concepts to the instrumentation, and (iii) how working in a group impacts students' attitudes toward, and their conceptual understanding of, chemical instrumentation.

Maria T. Oliver-Hoyo and DeeDee Allen, Attitudinal Effects of a Student-Centered Active Learning Environment. *J. Chem. Educ*. **82**, 944, 2005.
This report examines the effect on student attitudes toward learning chemistry in an active learning environment that has incorporated elements believed to positively influence student attitudes toward science including cooperative learning, hands-on activities, real-world applications, and engaging technology.

Melanie M. Cooper and Timothy S. Kerns, Changing the Laboratory: Effects of a Laboratory Course on Students' Attitudes and Perceptions. *J. Chem. Educ*. **83**, 1356, 2006.
In this study, the authors report the results a yearlong examination of the effects of an organic laboratory course on students' perceptions about what they were learning and why, and the roles of the instructor and the students in the course.

Dawn Del Carlo, Dana Mazzaro and Shanese Page, High School Students' Perceptions of Their Laboratory Classroom and the Copying of Laboratory Work. *J. Chem. Educ*. **83**, 1362, 2006.
In this study data from students responses to a partially open-ended survey were collected and analysed, providing insight into students' perceptions of their laboratory classroom and subsequent feelings toward the copying of lab work.

Paul Charlesworth, Debra D. Charlesworth and Chelley Vician, Students' Perspectives of the Influence of Web-Enhanced Coursework on Incidences of Cheating. *J. Chem. Educ*. **83**, 1368, 2006.
This paper investigates what students define as cheating, why students cheat, and their perceptions of a course management system's effect on the level of cheating in a first-year chemistry program.

Peter J. Smith, Learning preferences and readiness for online learning. *Educational Psychology* **25**(1), 3-12, February 2005.
This paper focuses on the dispositional variables that influence online learning engagement.

Shelley Yeo, Robert Loss, Marjan Zadnik, Allan Harrison, and David Treagust, What do students really learn from interactive multimedia? A physics case study. *American Journal of Physics* **72**(10), 1447-1453, 2004.
This paper describes a study of how students interacted with multimedia materials about projectile motion. It was found that without guidance the student's interaction was superficial.

Catherine H. Crouch, Adam P. Fagen, J. Paul Callan and Eric Mazur, Classroom demonstrations: Learning tools or entertainment? *American Journal of Physics* **72**(6), 835-838, 2004.
The effectiveness of three modes of demonstration presentation were compared, students observing only, students being required to predict the outcome, and the predictions being discussed after the demonstration. The results showed that students learned little when they passively observed, that their learning improved when they were required to predict the outcome, but that the discussion did not greatly improve the learning further.

Deborah O'Connell McManus, Rita Dunn, et al., Effects of traditional lecture versus teacher-constructed & student-constructed self-teaching instructional resources on short-term science achievement & attitudes. *The American Biology Teacher* **65**(2), 93, 2003.
McManus et al compare the effects of three different instructional strategies perceived as requiring more or less active student engagement to determine whether they are equally effective for, or appreciated by, students. The instructional approach for the tactual and kinesthetic treatments are also described.

J. Hehn and M. Neuschatz, Physics for All? A Million and Counting! *Physics Today* **59**(2), 7, 2006.
In this article the author examines the growth in high-school physics enrollment in the U.S.. Some strategies needed for continued growth are indicated.

E. H. Simmons, How to Popularize Physics. *Physics Today* **58**(1), 6, 2005.
This article provides information on how to popularise physics and tips to consider in preparing for an effective outreach.

D. F. Jeremy, M. P. Gina, et al., The "why's" of class size: Student behavior in small classes. *Review of Educational Research* **73**(3), 321, 2003.
This article forwards the hypothesis that when class sizes are reduced, major changes occur in students' engagement in the classroom.

Noah Podolefsky and Noah Finkelstein, The Perceived Value of College Physics Textbooks: Students and Instructors May Not See Eye to Eye. *The Physics Teacher* **44**(6), 338-342, 2006.
The usage and efficacy of students reading text books is investigated. Time spent reading and academic performance are not necessarily positively correlated.

Katherine K. Perkins and Carl E. Wieman, The Surprising Impact of Seat Location on Student Performance. *The Physics Teacher* **43**(1), 30-33, 2005.
Evidence is presented suggesting that rather than good students choosing to sit at the front of a classroom, it may instead be true that seat position affects the performance of the student.

Li-fang Zhang, Does Student–Teacher Thinking Style Match/Mismatch Matter in Students' Achievement? *Educational Psychology* **26**(3), 395-409, 2006.
The Thinking Styles Inventory was used with students and staff, and students' also self-rated their abilities. The results were analysed in the context of the students' academic achievement. The effects of thinking style mismatch was found to vary with discipline (maths, physics and public administration) and the self-ratings were different from the tested ratings.

John Richardson, Students' Approaches to Learning and Teachers' Approaches to Teaching in Higher Education. *Educational Psychology* **25**(6), 673-680, 2005.
This is an overview of 25 years of research into learning and teaching in HE and describes a range of tools useful for developing our understanding of teaching and learning.

12.5. Reviews and general papers

W. Jian and J. O. Sandra, Mentored learning to teach according to standards-based reform: A critical review. *Review of Educational Research* **72**(3), 481, 2002.
This article analyses literature on mentored learning to teach in ways consistent with the standards reform movement. It suggests that although reformers encourage mentoring for standards-based teaching, the assumptions underlying mentoring programs are often focused not on standards but on emotional and technical support.

J. S. Peter, Workplace learning and flexible delivery. *Review of Educational Research* **73**(1), 53, 2003.
This article reviews some of the conceptualisations of workplace learning and its cognitive bases. It also examines workplaces as learning environments and considers the special challenges involved in the flexible delivery of training to workplaces.

12.6. Gender

Darrell J. Wiens, Dayna J. Depping, Stacey R. Wallerich, Emily S. Van Laar and Angela L. Juhl, *Journal of College Science Teaching* **33**(1), 32-37, 2003.
This paper summarises a survey of 271 college students in the gender-neutral field of biology to learn when they became interested and what factors determined their origin and maintenance of interest in science. Males' and females' reasons for choosing science were found to be different.

Ivan A. Shibley Jr., Louis M. Milakofsky, David S. Bender and Henry O. Patterson, College Chemistry and Piaget: An Analysis of Gender Difference, Cognitive Abilities, and Achievement Measures Seventeen Years Apart. *J. Chem. Educ*. **80**, 569, 2003.
This study revisits an analysis of gender difference in the cognitive abilities of college chemistry students using scores from "Inventory of Piaget's Developmental Tasks" (IPDT), the Scholastic Assessment Test (SAT), and final grades from an introductory college chemistry course.

B. L. Whitten, S. R. Foster, et al., What Works for Women in Undergraduate Physics? *Physics Today* **56**(9), 6, 2003.
Examines the factors relevant to women in undergraduate physics and the issues concerning the recruitment of a diverse physics faculty.

P. Gustafsson, Gender inclusive physics education - a distance case. *European Journal of Physics* **26**(5), 843, 2005.
In earlier studies, it has been demonstrated that cooperative work has a positive influence on physics distance learning at university entrance level. In this paper, it is shown clearly that this teaching method in physics is advantageous for both genders.

Mark J. Gierl, Jeffrey Bisanz, et al., Identifying Content and Cognitive Skills that Produce Gender Differences in Mathematics: A Demonstration of the Multidimensionality-Based DIF Analysis Paradigm. *Journal of Educational Measurement* **40**(4), 1, 2003.
This paper illustrates and evaluates an application of a multidimensionality-based DIF analysis paradigm as it is applied to the study of gender differences in mathematics.

L. H. Peter Häussler, An intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching* **39**(9), 870-888, 2002.
The purpose of this study was to examine whether hypothetically effective measures lead to an improvement of the situation for girls when implemented in the physics classroom.

13. Learning Theories

13.4. Constructivism

P. A. Burrowes, Lord's constructivist model put to a test. *The American Biology Teacher* **65**(7), 491, 2003.
Burrowes discusses the use of Lord's constructivist teaching method, based on the Constructivist Learning Model as described by Yager. It was found that teaching in a constructivist, active learning environment is more effective than the traditional instruction in promoting academic achievement, increasing conceptual understanding, developing higher level thinking skills, and enhancing students' interests in biology.

13.6. General works

Amy J. Phelps and Cherin Lee, The Power of Practice: What Students Learn from How We Teach. *J. Chem. Educ*. **80**, 829, 2003.
This paper offers the reader the opportunity to hear from students about the beliefs they hold, based in large part on their experiences in science classrooms at the college level.

John T. E. Richardson, Special Issue: Developments in Educational Psychology: How far have we come in 25 years? *Educational Psychology* **25**(6), 673-680, December 2005.
This article covers research into learning and teaching in higher education over the last 25 years which has provided a variety of concepts, methods, and findings that are of both theoretical interest and practical relevance.

L. Boyer and W. M. Roth, Learning and teaching as emergent features of informal settings: An ethnographic study in an environmental action group. *Science Education* **90**(6), 1028-1049, 2006.
Discusses the use of visual representation in learning materials, and how this may not necessarily lead to better learning results. The theories that address this issue of learning from verbal and visual displays are discussed, along with the guidelines they offer for instructional design.

Laura Lising and Andrew Elby, The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics* **73**(4), 293-384, 2005.
This paper deals with the way that a student's "personal framework for science learning" can affect the way in which the student deals with new concepts.

Rhett Allain, David Abbott and Duane Deardorff, Using peer ranking to enhance student writing. *Physics Education* **41**(3), 255-258, 2006.
A description of peer ranking, and about how the students' involvement with the work continues and how students' critical thinking and writing ability both improve.

Fernando Espinoza, Enhancing mechanics learning through cognitively appropriate instruction. *Physics Education* **39**(2), 181-187, 2004.
High school students' understanding of and use of force and momentum was investigated, and the results were found to imply that the order of dealing with topics was important. It is suggested that conservation laws should be dealt with before dynamics and kinematics, due the students' better informal understanding of momentum compared to that of forces.

Simon Cassidy, Learning Styles: An overview of theories, models, and measures. *Educational Psychology* **24**(4), 419-444, 2004.
This paper aims at clarifying the central themes and issues surrounding learning styles, despite the wide diversity of reported research from disparate educational domains. It should allow for a broader appreciation of learning style, and provide information about appropriate tools for measurement.

Graham Hendry et al., Helping students understand their learning styles: Effects on study self-efficacy, preference for group work, and group climate. *Educational Psychology* **25**(4), 395-407, 2005.
A study of the educational effects of the composition of small tutorial groups. No effects were found, but students reported greater awareness of their and others' learning styles.

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- key references to research which is orientated toward the teaching and learning of the physical sciences.

Roger Gladwin is the Communications Coordinator for the Physical Sciences Centre and is based at the University of Liverpool.