



LTSN Physical Sciences News

...supporting learning and teaching in chemistry, physics and astronomy

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Special points of interest:

- Student recruitment
- Improving student learning
- Problem Solving
- SIG on Formative Assessment
- New Development Projects

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In this issue

In this, our tenth issue, you will find articles written by our distinguished guest speakers, Lillian McDermott who toured the UK in March and George Bodner who similarly toured in May. These practitioners, from the USA, write in detail about their experiences in research into teaching and learning practice in the

physical sciences and elucidate several factors which are demonstrated to make improvements to student learning and those which are likely to result in failure.

Essential reading! ■

Student recruitment and retention-it must be the employability!

What do student recruitment and employability have in common? It's simple, good employability prospects ensure good student recruitment! Not convinced? Read on, all will become clear...

We are in the era of student loans, tuition fees and associated debts. The current generation of students are more aware of 'value for money' factors than perhaps ever before. Choice of institution and subject are now strongly influenced by the career prospects at the end of the course. The increasing numbers of graduates flooding into the workplace has resulted in fierce competition for limited vacancies. Taking a proactive approach to the employability of graduates can only prove a positive factor when recruiting students to departments.

At the LTSN Physical Sciences Centre we are very aware of, not only departmental moves to enhance student employability, but also the current government initiative in this area. By consulting with experienced lecturers, a resource pack has been developed designed specifically for physical scientists. The pack comprises free standing activities that can be used to produce a module or to support other employability/careers activities. There are a wide range of topics

considered, from initial career planning through to interview techniques. All of the exercises use examples that are directly relevant to the physical sciences. This approach makes it more interesting for the students and enables them to relate to the activities much more than generic exercises. There is a tutors' guide for each of the activities, with a suggested marking scheme to enable simplicity of implementation.

In October 2003 we will be running a workshop addressing the issues of student employability with the emphasis on the physical sciences. Speakers will share their expertise on enhancing student employability. In addition, the resource pack will be formally launched and there will be the opportunity to trial some of the activities.

Staff from the Centre will be happy to visit your department and run either, a staff training seminar on using the pack, or a workshop for students. The pack and the support from the centre are available to all Higher Education institutions free of charge.

Contact us now! ■



Database of Practicals - Special offer

One of the problems of designing new experiments for students is the time required for development or a lack of practice someone has in a particular experimental method. This can come about if the academic does not have the time to dedicate to develop and test a new practical or if that person belongs to a small department or unit that lacks in-depth experience of running a particular experiment.

Therefore, in response to a call for help from the physical sciences subject community, we have initiated a project to develop a database of practicals that academics can use in their teaching activities. The aim of this project is to allow someone interested in running an experiment to be able to download a practical from the database and use it with their students.

To make this database a valuable and extensive resource which all academics can tap into, we are looking for help from the

community to provide examples of experiments which they are willing to have included in the database. Even if most people only offered one example from their own work, this could soon add up to several hundred practicals which the whole community could benefit from. For the last quarter of 2003, anyone submitting a practical, that is accepted for inclusion in the database, will receive £100.

If you would like to submit a practical for inclusion in the database we have produced a short web form which asks you to provide us with an outline of your work. After submission we will also ask you to provide an electronic copy of your practical script, which other academics could use or adapt for their own teaching activities. We will be encouraging users to offer feedback on the success of any practicals used, to help future development of this service and the resources contained within it. ■

New from the LTSN Physical Sciences Centre

New services for 2003/4

Starting September 2003 the Centre is increasing the range of services available through *site visits*.

We will still be offering *Departmental workshops*, which are tailored to the needs of an individual department. Departmental workshops are usually arranged for an afternoon's duration and may include a buffet lunch, talks and/or demonstrations/hands-on sessions. The events are free and the Centre will pay for the refreshments. We can bring computers, a projector and copies of our publications. We would expect the host to liaise with their colleagues and the Centre to draw up the programme for the visit and to advertise the event locally to those involved in teaching and learning in the physical sciences. All we need is a room for the talks/demonstrations/buffet lunch and an overhead projector and screen

These will be augmented by two alternatives...

Open Days on the Road (or Open Road). These will, as the name suggests, be 'open' events designed to be as flexible as possible. They can be organised as *drop-in surgeries* with registration not committing participants to staying for the whole day. Colleagues might attend the Open Road event to discuss some aspect of teaching

and learning or the use of technology in education with colleagues from the Centre and associated projects.

Initially we are looking for hosts. If you would like to be considered let us know. Hosts would be expected to organise a room (which could house 15-20 people and with tables for laptops/publications etc) for the day, arrange a buffet lunch and tea/coffee, advertise the event locally and put up direction signs on the day. We would advertise the event nationally, organise the contributions and pay for the refreshments.

Implementation Workshops

These events, initially covering Student Employability, are designed to provide a workshop for your colleagues and/or students in your department on a topic of interest. If you would like us to run a workshop in your institution let us know. The events will be free. All we need is a room for the talks/demonstrations and an overhead projector and screen. ■



Special Interest Group on Formative Assessment

This FDTL 4 project is aimed at examining how students' formative assessment experiences affect their learning. In doing so it will look at how feedback to students can be made more effective by maximising the learning students gain from their assessments. The project is based at The Open University and Sheffield Hallam University.

"As student numbers have increased there have been economies of scale in teaching methods but not in assessment: assessment costs have increased in direct proportion to the number of students. This has placed extreme pressure on assessment practices in all subject areas and particularly in science where traditionally students tackle assignments (such as lab reports and problem sheets) more frequently than in other subjects. In particular formative assessment has suffered, often involving a reversion to the use of summative exams and reductions in the number and size of coursework assignments and reductions in the frequency, quantity and quality of feedback to students on their learning and progress. Due to the volume of marking and teachers' workloads, feedback is often being provided too slowly to be effective. There is an urgent need to develop new and effective approaches to formative assessment which are cost-effective and which:

- Capture students' time and attention
- Generate appropriate kinds of learning activity
- Provide regular and timely feedback which has an impact on student learning

We believe that improving formative assessment (including the formative role of summative assessment) could have a major role to play in improving student progression and retention, especially in first year courses."

As part of this work a Special Interest Group has been created in conjunction with LTSN Biosciences and our own Subject Centre.

This Special Interest Group is concerned with all those aspects of assessment that support learning (rather than those that are concerned with measurement) especially:

- the design of assignments and assessment processes that capture students' time and energy and engage them in high quality learning
- the provision of feedback on learning that students learn from and use to direct further learning.

The main activities of the SIG will include:

- a survey of formative assessment practices in sciences courses, evaluating the way students respond to and use formative assessment, and funded development projects in SIG members' courses.

Membership of the SIG is open to anyone interested in formative assessment in Science, regardless of discipline. The SIG has £12,000 over two years, so those involved can be supported well!

To join the SIG an email should be sent to Jill Anderson Clarke:

jea@ltsnbio.leeds.ac.uk

The first meeting will be held 18 September, 2003 at University of Leeds/ Bioscience LTSN but should you miss this date, you are still welcome to join and get involved in future events.

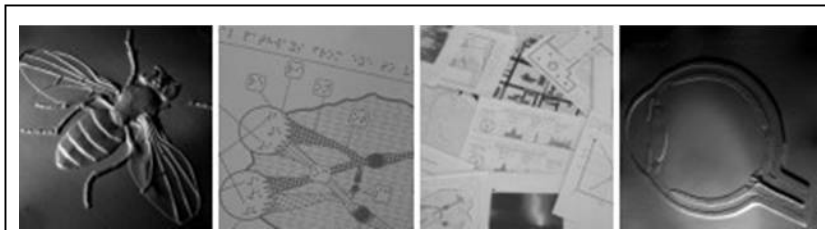
Further information can be obtained in the networking section of the LTSN Physical Sciences web site. ■

'We believe that improving formative assessment... could have a major role to play in improving student progression and retention, especially in first year courses.'

National Centre for Tactile Diagrams

The National Centre for Tactile Diagrams (NCTD) is a non-profit organisation based at the University of Hertfordshire since 1999, specifically to aid the support of blind and visually impaired students in Higher Education. The Centre is funded by donations and support from the UK Higher Education Funding Councils, the HEROB Fund (HEFCE, DTI, DfES, DHFETE) and the Kirby Laing Foundation and is headed by Dr Sarah Morley Wilkins and Dave Gunn.

Amongst their many activities, the NCTD is currently running a project with the 'Centre for Assistive Technology and Enabling Research' (CATER) at the Open University, to provide electronic, ready-to-produce tactile graphics for eight of their most popular courses, which cannot be presented any other way. Other work is a HEFCE/DELNI funded pilot project into core graphics for degree level psychology.



Examples of tactile images

'Tactile diagrams, maps and pictures are a translation of visual information into raised lines, shapes and textures which can be felt with the fingertips instead of viewed with the eyes.'

Blind people are routinely provided with text materials in braille, audio or large print, but the pictures, diagrams and maps (collectively "graphics") which accompany the text materials are often omitted or only very briefly described. Tactile diagrams, maps and pictures are a translation of visual information into raised lines, shapes and textures which can be felt with the fingertips instead of viewed with the eyes. Since exploring a surface with the fingers is radically different from looking at it with the eyes, the visual material usually requires considerable modification and re-design to be effective in tactile form.

Tactile graphics can be made in a number of different formats and can have labels and explanatory material in braille or other tactile forms. However, not all blind people know braille, so audio-taped descriptions are also very useful to support tactile graphics.

The NCTD provides a wide range of services, including the design and production of tactile graphics; a web site providing extensive information about their production and use; training and workshops for blind and partially sighted students in the best use of tactile graphics; consultancy services for Higher Education; evaluation of their use; and research to improve the design, production and use of tactile graphics.

During 2003 and 2004 the NCTD plans to send a sample pack to all UK Universities and LTSN Centres, which will contain sample materials and basic guidance for students and staff. Our subject centre will hold this pack as reference material for any interested parties, but to find out more about tactile graphics and the services the NCTD offers, visit their web site at <http://www.nctd.org.uk>. ■

PSIgate

PSIgate (Physical Sciences Information Gateway) is the physical sciences hub of the Resource Discovery Network (RDN). PSIgate provides free access to high quality Internet resources for students, researchers and practitioners in the physical sciences, specifically in: astronomy, chemistry, earth sciences, physics, and science history and policy.

Each resource in the main PSIgate Catalogue has been selected by information professionals and subject specialists (mainly PSIgate staff and research post-graduates) to ensure relevance and quality. A full description of each resource is provided, together with a range of other information and direct access to the resource itself.

PSIgate has developed additional services in support of the needs of the physical sciences community such as current awareness services (jobs, news, conferences), science reference materials, tools, the hosting of other searchable databases and other community features. This process is ongoing and new features are added regularly.

Resource Guides

The huge growth in the availability and choice of resources to support learning, teaching and research can make the business of finding quality resources relevant to your subject area both time consuming and frustrating. To make life easier, the JISC Resource Guides support staff and students engaged in HE activities by directing them to a selection of key, high quality resources in seven subject areas.

Each Guide is compiled by a dedicated Resource Guide Adviser who selects the key resources for the subject area and presents them in both print and web format. Advisers offer a programme of outreach activities in response to your subject needs, including hands-on workshops and training events. They also play a crucial role in soliciting community feedback, helping to ensure that communication about the provision and use of resources and support and advisory services remains two-way.

Resource Guide Advisers compile each Guide in consultation with subject-based advisory groups comprising librarians, academics and other relevant parties. Resources considered for inclusion include those from partner organisations, such as the Learning and Teaching Support Network (LTSN) and the Research Councils.

PSIgate is being led by the University of Manchester on behalf of CALIM (Consortium of Academic Libraries in Manchester). The service is located on hardware housed at Manchester Computing, and is a JISC-funded service.

The Service Manager for PSIgate is:
John Blunden-Ellis
Red 1.1
John Rylands University Library
University of Manchester
Oxford Road
Manchester M13 9PP
Tel: 0161 275 8729
Email: j.blunden-ellis@man.ac.uk

PSIgate's web site address is:
<http://www.psigate.ac.uk> ■

Resources are arranged in 6 categories:
Bibliographic, reference and research information
Publications online
Subject gateways
Data services
Learning and teaching
Support services

New Resource Guides will be available from the beginning of October FREE OF CHARGE to anyone in UK HE. The Resource Guide will list the key resources within the physical sciences including reference, bibliographic and teaching resources. The guides are freely available in quantities of up to 300 for distribution to students, researchers, academics etc.

The contact for the Physical Sciences is:
Dr Gillian Sinclair
Resource Guide Adviser for the Physical Sciences
John Rylands University Library
University of Manchester
Oxford Road
Manchester M13 9PP
Tel: 0161 2758728
Email: gillian.sinclair@man.ac.uk

The resource guides web address is:
<http://www.jisc.ac.uk/resourceguides> ■

'PSIgate and the Resource Guide Adviser support students and academics engaged in learning, teaching and research in the physical sciences in UKHE'

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Acknowledgments

I wish to thank the Learning and Teaching Support Network for the opportunity to give a series of invited lectures on the work of the Physics Education Group at universities in the U.K. in March 2003. Special thanks are due to the current faculty in the group: Paula R.L. Heron and Peter S. Shaffer. In addition to past and present members of our group, I want to express my appreciation to the past and present leadership of the Physics Department and the University of Washington. I would like to recognize the early intellectual influence of Arnold B. Arons and the contributions by our physics colleagues in the U.S. and abroad. This paper was first presented at the annual meeting of the Council of Scientific Society Presidents (U.S.) upon the occasion of receiving the 2000 CSSP Award for Achievement in Educational Research. I am grateful to the National Science Foundation for enabling our group to engage in the work that has led to recognition such as the LTSN Lectureship and CSSP award.

References

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Improving Student Learning in Science

Improving Student Learning in Science through Discipline-based Education Research

I. Introduction

For more than 30 years, the Physics Education Group at the University of Washington has been engaged in a coordinated program of research, curriculum development, and instruction to improve student learning in physics (K-20). The work of the group is guided by ongoing discipline-based research. This type of research differs from traditional education research in that the emphasis is not on educational theory or methodology in the general sense but rather on student understanding of science content. For both intellectual and practical reasons, discipline-based education research must be conducted by science faculty within science departments. I shall present some evidence that this is an effective approach for improving student learning. The emphasis here will be on introductory university students and K-12 teachers.

II. Context for research

A brief description of the Physics Education Group can set a context for our research. Our group is an entity within the Physics Department in the same sense that there are groups in other sub-fields of physics. The courses in the Department provide the primary environment for our investigations. Most of our work involves two populations: undergraduates in the introductory calculus-based course and prospective and practicing K-12 teachers who are taking special courses designed to prepare them to teach physics and physical science by inquiry. Our investigations also include students in engineering and in advanced undergraduate and graduate physics courses.

As part of our research on how to improve student learning in physics, we try to identify specific difficulties that students encounter in the study of various topics. The results are used to design instructional materials that target these difficulties and help guide students through the reasoning required to overcome them and to develop a coherent conceptual framework. Assessment of effectiveness with students is an integral part of the iterative process through which the Physics Education Group develops curriculum. To ensure applicability beyond our own university, our materials are also tested at pilot sites (e.g., Georgetown, Harvard, Illinois, Maryland, Purdue).

Our two major curriculum projects are *Physics by Inquiry* (Wiley, 1996) and *Tutorials in Introductory Physics* (Prentice Hall, 2003). The development of both is guided by research. The first is a self-contained, laboratory-based curriculum for the preparation of K-12 teachers; the second is a supplementary curriculum that can be used in conjunction with any standard text.

III. Perspective on teaching as a science

The perspective that teaching is a science, as well as an art, motivates our work. Considered as a science, teaching is an appropriate field for scholarly inquiry by scientists. This view is in marked contrast to that held by many science faculty.

A more traditional view was expressed in 1933 in the first article in the first journal published by the American Association of Physics Teachers (AAPT). In *Physics is Physics*, F.K. Richtmyer (Cornell) argued that teaching is an art and not a science. He quoted R.A. Millikan (Cal-Tech) in characterizing science as comprising "a body of factual knowledge accepted as correct by all workers in the field." Prof. Richtmyer went on to say "Without a reasonable foundation of accepted fact, no subject can lay claim to the appellation 'science.' If this definition of a science be accepted – and it seems to me very sound – then I believe that one must admit that in no sense can teaching be considered a science."

Although this is a somewhat limited definition of science, I would like to challenge the implication that it is not possible to build "a reasonable foundation of accepted fact" for the teaching of physics (and, by extension, other sciences). For example, we have found that most people encounter many of the same conceptual and reasoning difficulties in learning a given body of material. These difficulties can be identified, analyzed, and effectively addressed through an iterative process of research, curriculum development, and instruction. Both the learning difficulties of students and effective means for addressing them are often generalizable beyond a particular course, instructor, or institution.

If one documents intellectual outcomes for student learning, teaching can be treated as a science. If the criteria for success are clearly stated and the results are reproducible, findings from research can contribute to "a reasonable foundation of accepted fact." This foundation is represented by a rapidly growing research base¹.

Improving Student Learning in Science

The personal qualities and style of an instructor contribute to the aspect of teaching that can be viewed as an art (a benefit confined to the instructor's class). However, when student learning is used as the criterion (as distinct from student enthusiasm), we have found that effective teaching is not as tightly linked as is often assumed either to self assessment of learning by students or to their evaluation of the course or instructor.

IV. Focus on the student as a learner

The focus of our research is on the student as a learner, rather than on the instructor as a teacher. We try to determine the intellectual state of the student throughout the process of instruction. To the degree possible, we try to follow the procedures and rules of evidence of an experimental science. We conduct our investigations in a systematic manner and record our procedures so that they can be replicated. We use two general methods: individual demonstration interviews (which allow deep probing into the nature of student difficulties) and written tests (which provide information on prevalence). Continuous pre-testing and post-testing enables us to judge the effectiveness of instruction.

Although experienced instructors know there is a gap between what they say and what students learn, most do not recognize how large the gap can be. The usual means of evaluation in physics courses – the ability to solve standard quantitative problems – is not adequate as a criterion for a functional understanding and unfortunately reinforces the perception of physics as a collection of facts and formulas. Success on numerical problems does not provide adequate feedback for improving instruction. Questions that require qualitative reasoning and verbal explanations are essential.

Our investigations have shown that on certain types of qualitative questions, student performance in physics is essentially the same: before and after standard instruction by lecture and textbook, in algebra-based and calculus-based courses, whether or not there is a standard laboratory, whether or not demonstrations are used, whether classes are large or small, and regardless of the proficiency of the instructor as a lecturer. The situation has been the same in introductory mechanics, electricity, magnetism, waves, optics, and thermodynamics. We have also found that advanced students often have difficulty with qualitative questions on introductory physics, as well as on topics such as special relativity and quantum mechanics.

There is by now ample evidence that teaching by telling is ineffective for most students. They must be intellectually active to develop a functional understanding. The instructor of a course determines the emphasis, motivates students, and can promote a view of science as a human endeavour. However, he or she cannot do the thinking for the students. They must do it for themselves. Some are reluctant to do so; others do not know how.

A. Science courses for introductory students

Introductory science courses should help students construct basic concepts, integrate them into a coherent conceptual framework, and develop the reasoning ability necessary to apply them in situations not explicitly memorized. Significant progress toward these goals is not usually made in a traditional course. In particular, scientific reasoning skills must be expressly cultivated.

Physics instructors present lectures that include detailed derivations, lucid explanations, and suitable demonstrations. However, they often proceed from where they are now and do not remember where they were (or think they were) as students. They frequently think of students as younger versions of themselves. This approach is not well-matched to an introductory class since fewer than 5% of the students will major in physics. (The percentages in chemistry and biology are a little higher.)

Meaningful learning requires active mental engagement. The challenge, especially in large courses, is how to achieve the necessary degree of intellectual involvement. Much of our research has been directed toward responding to that challenge in ways that are effective not only at our own university but in other instructional settings as well. We are developing *Tutorials in Introductory Physics* to engage students actively in learning physics.

B. Science courses for K-12 teachers

Science departments have a major responsibility for the education of K-12 teachers, both prospective and practising. Many science faculty assume that this is a role solely for education faculty. In fact, the only place that the subject matter preparation of teachers can occur is in science courses. The study of educational psychology and methodology cannot help teachers develop the depth of understanding of science content that they need in order to teach effectively. The effort to improve pre-university science education will not succeed without the direct involvement of science faculty.

'Introductory science courses should help students construct basic concepts, integrate them into a coherent conceptual framework, and develop the reasoning ability necessary to apply them...'

Improving Student Learning in Science

The courses offered by most science departments do not provide adequate preparation for K-12 teachers. Descriptive courses are useless for preparing elementary and middle school teachers to help students learn basic concepts and reasoning skills. High school teachers are not adequately prepared by mainstream courses, including the se-

quence for majors. For example, the traditional introductory physics course and (to an even greater extent) upper division physics courses emphasize mathematical formalism.

The breadth of topics covered allows little time for acquiring a sound grasp of the underlying concepts.

In addition to deficiencies in subject matter preparation, traditional science courses have another major shortcoming. Teachers tend to teach as they were taught. If taught through lectures, they are likely to teach that way. Moreover, this type of instruction is unlikely to lead to an understanding of the nature of science and thus does not help prepare teachers to teach science as a process of inquiry.

Teachers need to learn (or re-learn) science in a way that is consistent with how they are expected to teach. For more than 25 years, our group has provided that opportunity through special physics courses for prospective and practicing K-12 teachers.

These classes have provided an environment for research on

the preparation needed for teaching physics and physical science by inquiry. The results have guided the development of *Physics by Inquiry*.

V. Research as a guide for curriculum development: an example

Research guides the development of all of our curriculum. The topics in *Tutorials in Introductory Physics* respond to the questions: "Is the standard presentation in textbook and lecture adequate to develop a functional understanding?" If not, what can be done? The illustrative example below is discussed more fully in two published articles^{2,3}.

In teaching geometrical optics, most instructors begin with the premise that university students have a functional understanding of the rectilinear propagation of light. Virtually all students can state that "light travels in straight lines" and many can elaborate that "light travels outward from every point on an object in straight lines." To determine whether students can apply these concepts in a simple situation, we designed a written question.

A. Pretest

Students were asked to predict the image formed on a screen by various light sources located in front of a small aperture in a mask. This question has been given as a pretest to thousands of introductory physics students and to more than 100 teaching assistants in our physics Ph.D. program. The question is called a "pretest" because it usually precedes the tutorial that we developed to address the difficulties that the responses of students revealed. (The question is actually a post-test in that students have already had the relevant material in their university course or K-12 education.)

One part of the question involves a long-filament bulb, a mask with a small triangular hole (~ 1 cm), and a screen. (See Figure 1.) For a correct response, students must recognize that light travels in straight lines and that a line source can be treated as a series of point sources. The image can be found by treating each point on the bulb as a point source that produces a triangular image on the screen. Since the points are closely spaced, the images overlap substantially. The result is a vertical rectangle terminating at the top in a triangle.

Although the amount of prior instruction varied, the results did not. (See Table 1, p10.) Only about 20% of the students answered correctly, either before or after instruction. About 70% predicted that the image would be triangular. In this and many other instances, we have found that certain conceptual difficulties are not overcome by traditional instruction. Persistent difficulties must be explicitly addressed.

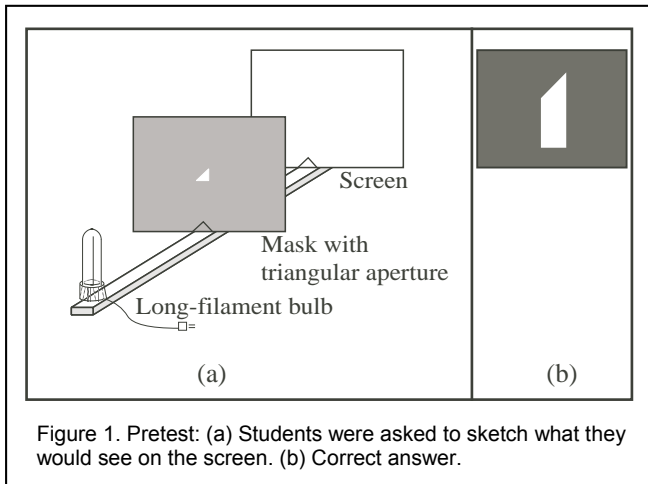


Figure 1. Pretest: (a) Students were asked to sketch what they would see on the screen. (b) Correct answer.

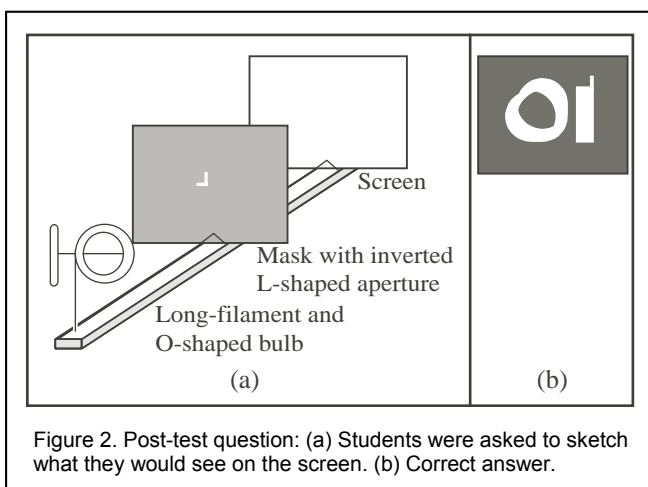


Figure 2. Post-test question: (a) Students were asked to sketch what they would see on the screen. (b) Correct answer.

Improving Student Learning in Science

B. Tutorial

The emphasis in the tutorials is on constructing concepts, developing reasoning ability and relating physics formalism to the real world, not on solving standard quantitative problems. The tutorials are intended for use in a small section of about 24 students, in which groups of three or four work together. The structure in these 50-minute sessions is provided by worksheets that guide students through a series of exercises and simple experiments by asking questions.

With results from questions like the one described above as a guide, we designed a tutorial entitled *Light and Shadow*. The tutorial begins by having students predict the images formed by point and line sources with apertures of various sizes and shapes. After making predictions and explaining their reasoning to one another, the students observe what actually happens and try to resolve any discrepancies with their predictions. They are then asked to predict and explain up-down and left-right inversions of images formed by asymmetric sources. These and other exercises help students recognize how the shape and relative size of the source and aperture and the distances involved affect the image.

Systematic monitoring in the classroom helped us improve the tutorial. One exercise that was added had a pronounced effect on student understanding of the geometric model for light. The students are asked to predict what they would see on the screen when a frosted light bulb is placed in front of a mask with a triangular hole. Many are surprised to see the inverted image of the bulb. Eventually, they realize that the entire bulb can be considered as a collection of point sources.

The students recognize that superposition of the images from the continuum of point sources produces an image that closely resembles the extended source, but is affected by the shape of the aperture. They also note that whether a light source can be treated as a point or extended source depends on a variety of factors.

C. Post-test

Throughout the development of the tutorial, assessment played a critical role. In Figure 2 is one of several post-test questions that we administered on examinations to about 360 students in several introductory courses. The percentage of correct or nearly correct responses was 80%, an increase from 20% on the pretest. Only 10% drew images the same shape as the aperture, in sharp contrast to the 70% who

made this error on the pretest. (See Table I, p10)

The TAs and post-docs who lead the tutorial sessions participate in a weekly graduate teaching seminar in which they work through the pretests and tutorials. About 65% have given a correct, or nearly correct, response for the question described above. This result is consistent with our experience that advanced study may not increase student understanding of basic topics.

We consider the pretest performance of graduate students to be a reasonable post-test goal for introductory students. As shown in Table I (p10), the latter demonstrate a better functional understanding than the graduate students had initially had.

D. Commentary

It is tempting for instructors to think that the rectilinear propagation of light is such a simple concept that only a brief discussion of the topic is needed. Evidence to the contrary comes not only from our own research but from the experience of colleagues in our department. Recently, instructors of an honours section and a regular section of the calculus-based course used other approaches to teach this concept. Their students did not work through the tutorial.

In the honours section, the instructor demonstrated the image that is formed when light from an object passes through a pin-hole. He asked questions to guide the students in explaining what they saw. He assigned homework based on equipment similar to that used in the tutorial. Only about 30% of the students responded correctly on the homework. The instructor then distributed solutions. In the regular section, the instructor did not lecture on the propagation of light through an aperture. However, he assigned homework problems that were similar to the instructional sequence in the tutorial. Prompt feedback was given in the form of written solutions.

Questions similar to the post-test question in Figure 2 were asked on midterm examinations in both classes. Only 45% of the students in the honours section and 35% in the regular section gave correct, or nearly correct, responses. Although the time they spent on this material in lecture and on homework was not monitored, we do not believe that this factor alone could account for the large difference in post-test performance between these students and those who had worked through the tutorial. (See Table I, p10.)

(Continued on page 10)

'... if instruction does not engage students in confronting and resolving their underlying conceptual and reasoning difficulties, they do not develop the ability to do the reasoning necessary to apply concepts to problems that cannot be solved by memorized formulas.'

Improving Student Learning in Science

It has been our experience that if instruction does not engage students in confronting and resolving their underlying conceptual and reasoning difficulties, they do not develop the ability to do the reasoning necessary to apply concepts to problems that cannot be solved by memorized formulas.

thinking transcends the learning of physics or any other science.

Our group has demonstrated, in the context of physics, that discipline-based education research can help improve student learning. Recently, there has been a

Table I. Results from pretest and post-test questions administered in introductory physics courses and graduate teaching seminars.

	Introductory course		Graduate seminar
	Pretests (before tutorial) (N ~ 1215)	Post-tests (after tutorial) (N ~ 360)	Pretests (before tutorial) (N ~ 110)
Correct or nearly correct	20%	80%	65%
Incorrect: image mimics shape of hole in mask	70%	10%	30%

We attribute the success of students who worked through the tutorial to the detailed knowledge of student difficulties that informed its development.

The tutorials are a means of engaging students intellectually within the constraints of large, rapidly paced courses. More can be achieved if students can go through similar material more slowly and thoroughly. Teachers who have worked through the development of a ray model for light in *Physics by Inquiry* can deal successfully with more complicated combinations of light sources and apertures.

Research in physics education has shown that the development of a qualitative understanding greatly improves student performance on conceptual problems. Moreover, we and others have found that time spent in this way does not detract from (and often improves) proficiency in solving standard problems. Therefore, increasing the emphasis on qualitative reasoning can help set a higher (yet realistic) standard for student learning.

VI. Conclusion

A major goal of a science course that is likely to be terminal in the discipline is to help students recognize whether or not they understand the basic concepts. In *Physics by Inquiry*, and to a lesser extent in the *Tutorials in Introductory Physics*, we try to help students learn to answer and to ask the kinds of questions that are necessary to assess and improve their understanding. This ability is critical for all students, but especially for those who plan to teach. Learning to reflect on one's own

steady increase in the number of physicists who are pursuing this type of research. The results are reported at professional meetings and in articles in refereed journals that are readily accessible to physics faculty¹. Thus, colleagues who are not involved in education research have a rich resource from which to draw in developing print and computer-based instructional materials. Our experience indicates that it is difficult to develop effective curriculum that yields consistent positive results. Therefore, unless faculty can devote a long-term effort to the development and refinement of their own instructional materials, they should take advantage of already existing curriculum that has been carefully designed and thoroughly assessed.

Without a research base on student learning, we lack the knowledge necessary to make cumulative progress in improving instruction. There is a need in all the sciences for research on the intellectual development of students as they progress through a given body of material. Investigations of this type demand a depth of understanding that ordinarily is found only among specialists in a field. Therefore, such research must be conducted by science faculty in the context of courses offered by science departments.

The American Physical Society has issued a statement in support of research in physics education as a scholarly activity by faculty in physics departments⁴. By taking similar action, other scientific societies could help strengthen efforts to improve student learning in their disciplines. ■

'Our group has demonstrated, in the context of physics, that discipline-based education research can help improve student learning.'

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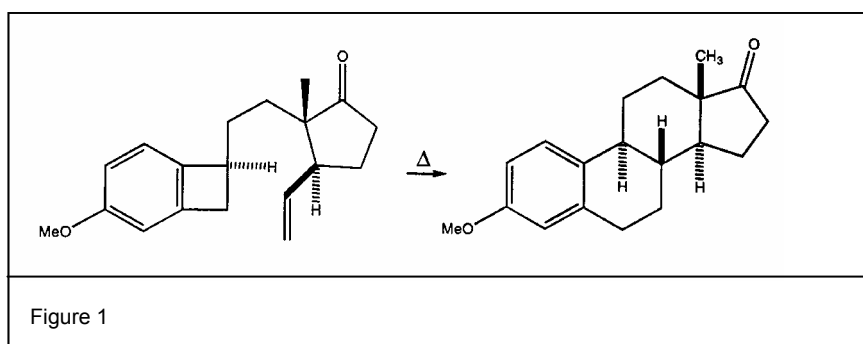
Problem Solving

Problem Solving: The Difference Between What We Do and What We Tell Students To Do

Introduction

Most of our insight into problem solving has come from research that uses qualitative methods, in which we interview people struggling to solve problems and ask them to talk about what they are doing or what they are thinking while they are involved in

- Explain the reaction shown in Figure 1
- Starting from thermal equilibrium (with M° aligned along the Z axis) and assuming no delays between pulses, predict in which plane the magnetization vector M will lay after experiencing the following pulse sequence. Assume the RF transmitter is aligned along the +X axis. 90°_x , 90°_x , 180°_x , 90°_x , 270°_x , 90°_x , 90°_x



this process. Another useful source of information has been the analysis of answers to exam questions coupled with informal discussions with students about why they gave a particular answer when they took the exam. We've worked in a variety of courses, from general chemistry through the sophomore organic and inorganic courses, to physical chemistry, and even advanced organic chemistry courses taken by graduate students.

Samples of the kinds of questions we have asked participants in our interviews are shown below. The first question is from an early study of problem solving by science and engineering majors enrolled in a general chemistry course at Purdue. The second is from a study of undergraduates, graduate students, and faculty trying to predict the product of an inorganic reaction. The third comes from a study of students enrolled in a graduate-level organic chemistry course. The fourth is from a study of graduate students' understanding of aspects of 2D FT NMR.

- Uranium reacts with fluorine to produce a compound which is a gas at 57°C . The density of this gas is 13.0 g/L at 57°C and 1 atm pressure. What is the molecular formula of this compound? (a) UF_2 (b) UF_3 (c) UF_4 (d) UF_5 (e) UF_6
- Predict the products of the following reactions:

$\text{Na} + \text{H}_2\text{O} \rightarrow$	$\text{NaOH} + \text{Cl}_2 \rightarrow$
$\text{MgO} + \text{H}_2\text{O} \rightarrow$	$\text{H}_2\text{S} + \text{Cl}_2 \rightarrow$
$\text{Ba}_3\text{N}_2 + \text{H}_2\text{O} \rightarrow$	$\text{NaOH} + \text{SO}_2 \rightarrow$
$\text{XeF}_4 + \text{D}_2\text{O} \rightarrow$	$\text{NO}_2 + \text{H}_2\text{O} \rightarrow$

Problems versus Exercises

To help the reader understand one of the insights we've developed from this work, I'd like you to look at a problem that we have given to perhaps as many as a thousand practicing chemists who were either working in industry or participating in a training program for teaching assistants.

Two trains are stopped on adjacent tracks. The engine of one train is 1000 yards ahead of the engine of the other.

The end of the caboose of the first train is 400 yards ahead of the end of the caboose of the other. The first train is three times as long as the second. How long are the trains?

Let's assume that the two trains are headed in the same direction and remind ourselves of the definition of a caboose - the car that used to be placed at the end of a train, which was used by the crew on the train.

Industrial chemists and teaching assistants to whom this problem is given do essentially the same thing. They start with a drawing, in which they use some convention to identify the engine versus the caboose. They typically label the length of one train as " x " and the other as " $3x$." They label the distance between the engine of one train and the engine of the other; between the caboose on one train and the caboose on the other (see Figure 2, p12) They then write an equation in one unknown, solve for " x ", and report the answer.

(Continued on page 12)

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$$\begin{aligned} 3x + 400 &= x + 1000 \\ 2x &= 600 \\ x &= 300 \end{aligned}$$

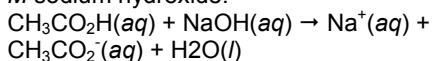
The only fundamental difference between the two groups is the tendency for those in industry to write “ $x = 300$ ” and for those in academia to write “ $x = 300$ yd.”

When I tell the industrial chemists that there is no partial credit in this course, and they therefore get a zero, they get mad. They get a zero for the obvious reason - they haven't answered the question! The graduate teaching assistants, when they're told that they get a zero, shrug this off. They're used to not getting the credit they feel they deserve on exams.

For now, let's focus on two observations about this problem. First, when faced with a novel problem, practicing chemists almost always start with a drawing, of some kind. Second, practicing chemists stop their problem solving activities when they get to the point that they fully understand the problem; not when they get the “answer.”

Now let's look at another question:

What is the molarity of an acetic acid solution, if 34.57 mL of this solution is needed to neutralize 25.19 mL of 0.1025 M sodium hydroxide.



What would you expect practicing chemists to do? Would they start with an equation or formula, such as: $n = M \times V$? Or with a drawing such as shown in Figure 3? The answer should be obvious - in the absence of explicit instruction to do so, no practicing chemist would draw a picture when solving this problem. They would all start by feeding numbers into an equation.

These results suggest that a given individual might exhibit fundamentally different behaviours on different problem-solving tasks. To help the reader understand the source of these differences, we need to define the terms *problem* and *problem solving*. We'll start with John Hayes' definition of the term *problem*¹.

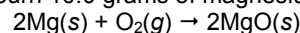
Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem.

According to Hayes, the presence of a gap between where you are and where you want to be isn't sufficient to generate a problem. There also has to be an element of uncertainty, confusion, if not downright ignorance about how one is going to cross that gap.

Almost 20 years ago, one of my colleagues in mathematics education (Grayson Wheatley) proposed the only acceptable definition of problem solving I have found. He said, problem solving is “what you do, when you don't know what to do”². If you'll accept the two definitions I've offered, then you have to accept their logical consequence: there is a fundamental difference between a *routine exercise* and a *novel problem*.

Some have said that the difference between an exercise and a problem is one of difficulty; others have said it is one of complexity. I'm going to argue that problems are neither inherently difficult or complex. The only difference between an exercise and a problem is the element of familiarity. Consider the following question from a general chemistry exam.

What weight of oxygen is required to burn 10.0 grams of magnesium?



This is a routine exercise for a practicing chemist, but a novel problem for students who encounter chemistry for the first time. Or consider the following question from a sophomore organic chemistry course.

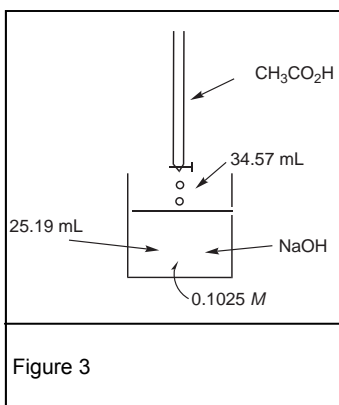
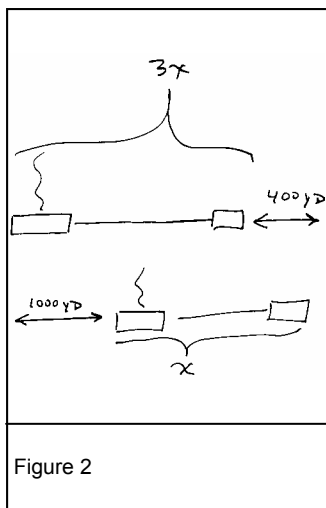
Robinson annulation reactions involve two steps: Michael addition and aldol condensation. Assume that Michael addition leads to the intermediate shown in Figure 4. What would be produced when this intermediate undergoes aldol condensation?

This is a problem for most chemists, but a routine exercise for those who teach organic chemistry.

The distinction between the exercises or problems is important because it is a potential source of miscommunication between instructors and their students. We tend to put a content expert in the classroom, for whom tasks that arise in the course of the semester are routine exercises, and expect that individual to “teach” students for whom the same task is a novel problem.

The difference between the way exercises and problems are worked is particularly well demonstrated by the examples that appear in so many textbooks. These examples have several fundamental characteristics.

- They are logical sequences of steps. (It is rare for a textbook author to be deliberately illogical.)
- They string together in a linear fashion



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- like links on a chain.
- They proceed from the initial information to the solution. (Except, of course, in organic synthesis, where we start from the solution and work back to the initial information.)

These textbook solutions, which are often mirrored by instructors in the classroom, are examples of a phenomenon that has been called "forward-chaining" or "forward-working." As such, they are examples of how routine exercises are worked by individuals with years of experience with similar tasks³. As our work has shown, however, they have little, if any, similarity to the approach successful problem solvers use when they encounter novel problems.

Models of Problem Solving

The goal of our work is the development of a model of problem solving that has two characteristics. First, it must fit our experimental data from interviews with successful problem solvers working on what is, for them, a novel problem. Second, it must be "teachable." It must be a model that can be given to students that can improve their problem solving performance in chemistry.

Let's therefore look at several models of problem solving that have been proposed. The first of which is Polya's stage model⁴.

- *Understand the problem*
- *Devise a plan*
- *Carry out the plan*
- *Look back*

This model makes sense. It seems logical that we would start by understanding the problem, then devising a plan, then carrying out the plan, and then looking back to check our work and consolidate our gains. It is so logical this model can be described as "exocharmic"⁵. It seems to exude charm, particularly for high-school chemistry and physics teachers, who argue that this is exactly what they do.

Unfortunately, Polya's model is not consistent with our work. To try to convince the reader of this, consider the following problem which is based on the experimental data collected when one of the first xenon fluoride compounds was analyzed⁶.

A sample of a compound of xenon and fluorine was confined in a bulb with a pressure of 24 torr. Hydrogen was added to the bulb until the pressure was 96 torr. Passage of an electric spark through the mixture produced Xe and HF. After the HF was removed by reaction with solid KOH, the final pressure of xenon and unreacted hydrogen in the bulb was 48

torr. What is the empirical formula of the xenon fluoride in the original sample? We've given this problem to many practicing chemists who do not have a history of teaching general chemistry. They inevitably get to the correct answer, but they almost never get there by following the four stages of Polya's model. Indeed, a common comment heard when they finally get the answer is: "Oh, it's an empirical formula problem!" In other words, this problem - like the two trains problem cited earlier - suggests that the process of problem solving is over when one gets to the point that they understand the problem.

Several other models of problem solving that are logical extensions of Polya's model have been discussed elsewhere³. They all have the disadvantage of not being consistent with the patterns we've observed for successful problem solvers working on novel problems. Let's therefore turn to a model proposed by Alex Johnstone and co-workers⁷. This model assumes that each learner has a working-memory capacity (X) and that each problem has a working-memory demand (Z), which is defined as the maximum number of steps activated by the least able individual.

The Johnstone-EIBanna model assumes that when the working-memory capacity of the individual is larger than the demand on working memory ($X \geq Z$), we have a necessary, but not sufficient condition, for success. It isn't sufficient because success depends on prior knowledge; whether the prior knowledge is easily accessible; on the student's motivation (inclination, interest, etc.); and so on.

This model assumes that students won't be successful when the demand on working memory exceeds the capacity of working memory ($Z > X$), unless the student can organize the demand on working memory so that it is smaller than his or her working-memory capacity. Johnstone and co-workers note that there is a sharp drop in performance when the demand of the problem exceeds capacity. But, some students ($\approx 10\%$) seem to be able to solve problems for which the demand exceeds capacity ($Z > X$) because of chunking devices that reduce the demand on working memory.

Let's assume that the Johnstone-EIBanna model is correct when it is applied to situations that meet the six criteria proposed by Tsarpalis, et al.⁸. Furthermore, let's assume that Niaz is correct when he concludes that: "Teachers can facilitate suc-

(Continued on page 14)

'problem solving is "what you do, when you don't know what to do"... There is a fundamental difference between a routine exercise and a novel problem.'

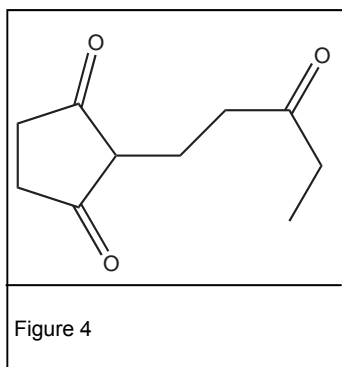


Figure 4

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cess by decreasing the amount of information required for processing, and thereby avoiding working memory overload⁹. Now what? From the perspective of this model, there isn't much we can do to improve student performance in our classes. We simply have to accept the limitations our students bring to the classroom, and conclude that the only way we can improve their performance is to lower the intellectual rigour of the tasks we give them.

I'm going to argue that we can do more than this. Based on research in mathematics education, Grayson Wheatley proposed an anarchistic model of problem solving that describes what successful problem solvers do when they work on novel problems². As noted most recently by Calimsiz¹⁰, this model is consistent with the results of our problem-solving interviews.

An Anarchistic Model of Problem Solving

- Read the problem
- Now read the problem again
- Write down what you hope is the relevant information
- Draw a picture, make a list, or write an equation or formula to help you begin
 - to understand the problem
- Try something
- Try something else
- See where this gets you
- Read the problem again
- Try something else
- See where this gets you
- Test intermediate results to see whether you are making any progress
 - toward an answer
- Read the problem again
- When appropriate, strike your forehead and say, "son of a ..."
- Write down "an" answer (not necessarily "the" answer)
- Test the answer to see if it makes sense
- Start over if you have to, celebrate if you don't

There are several stages in the model that deserve explicit attention. In the "two trains" problem, we saw the role that a drawing that is annotated with relevant information can play in solving a novel problem. We've also seen, in the molarity calculation, that drawings aren't done when we encounter a routine exercise.

I've often described the steps "try something" and "try something else" as "playing with the problem." Unfortunately, all too

many of our students believe you can't "play" with a problem. This is important to me because I have talked to far too many beginning students - particularly those who are struggling with the course - who believe that "trial and error" is not a legitimate strategy for problem solving. That scares me, because it is the most powerful strategy I own.

There is abundant evidence in our data that successful problem solvers routinely encounter a cue during problem solving that causes them to ask: "Am I getting anywhere?" Many beginners forget to do this. They exhibit a "garden-path syndrome," working the problem the way they might walk through a garden - smelling the roses along the way - but not noticing that they aren't getting anywhere. Successful problem solvers tend to start over when they find that they aren't making any progress toward the answer; beginners often fail to do this.

The penultimate step in this model is particularly important to me. In 1966, I took a PChem lab in which I was asked to measure the "heat of reaction" in an acid-base neutralization reaction. I did the experiment, worked out the value of ΔE for the reaction, and reported something on the order of 13,000 kcal/mole.

When the TAs handed back the lab, they told me my answer was stupid. (They were right; it should have been 13 kcal/mole). They told me that I should have known better. I asked: "How?" At no point in my academic career had anyone begun to give me the information that would have allowed me to deduce what would have been a reasonable answer for a heat of reaction measured in a calorimeter.

We have found that beginners seldom test their answer to see if it makes sense, for two reasons. First, they haven't ever seen anyone do this when they've watched their instructors work out the solutions to tasks that are exercises for the instructors. Second, they haven't been given the information they would need to do this.

In summary, I would like to argue that Polya's model is an ideal approach to working a routine exercise. One reads the question, understands the task, devises a plan, and so on. I would like to argue that one of the characteristic tests of whether a task is an exercise is to ask: "How is the solution found?" Exercises are worked in a linear, forward-chaining, rational manner.

Our model suggests that problem solving is

'We have found that beginners seldom test their answer to see if it makes sense, for two reasons. First, they haven't ever seen anyone do this... Second, they haven't been given the information they would need to do this.'

'Interviews with students struggling with organic chemistry has led us to conclude that there is a fundamental difference between what the instructor writes on the blackboard and what students write in their notebooks'

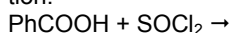
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cyclic, reflective, and can appear irrational. Experts who watch students struggle with a problem are tempted to intervene; to show the "correct" way of obtaining the answer. This makes the expert feel good, but it doesn't necessarily help the individual struggling with the problem for the first time.

Representations and Representational Systems

Our first hint into the role that representations and representational systems play in problem solving in chemistry came from a study in which we looked at students' answers to the following question¹¹.

Predict the product of the following reaction:

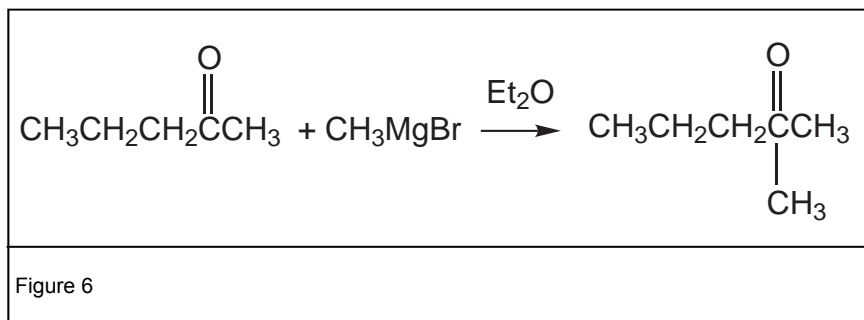


A couple of typical incorrect answers are

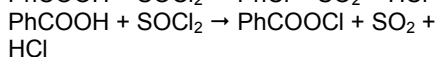
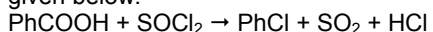
Some would argue that the "PhCO₂H" with which the starting material was presented is a "symbolic" representation. I'd like to argue that it *can be* a symbolic representation, but it often is not. For many students, particularly those who struggle with organic chemistry, it is a verbal/linguistic representation that consists of letters and numbers that aren't symbols because they don't symbolize anything.

Interviews with students struggling with organic chemistry has led us to conclude that there is a fundamental difference between what the instructor writes on the blackboard and what students write in their notebooks, in spite of the fact that one seems to be a direct copy of the other.

Similar external representations are written



given below.



When people who teach general chemistry look at these equations, they often comment: They aren't balanced. That doesn't bother me because organic chemists seldom worry about the mundane details of writing balanced equations. What bothers me is the fact that these equations are absurd. There is no way to go from the starting materials to the products of these equations by making and breaking of bonds.

When we did this experiment, we noted that some of the students who answered this question successfully wrote a symbolic representation in the margin of the exam paper. It seldom looked as regular as the symbolic representation one would find in a journal (see Figure 5).

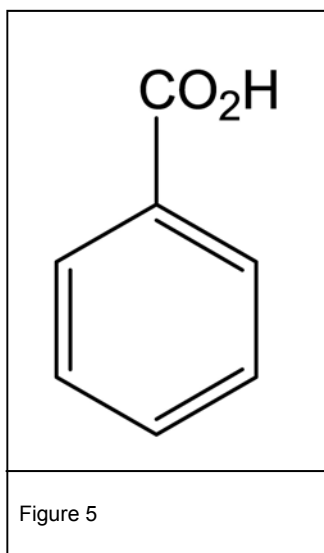
Sometimes the ring looked as if it had six "bumps" corresponding to the six carbons of a benzene ring, often it did not. The ring sometimes contained one double bond, sometimes two, sometimes three. Sometimes it didn't contain any double bonds. But the -CO₂H portion was always clearly written.

by individuals with different internal representations. What students write in their notebooks seems to be a direct copy of what the instructor writes on the blackboard. In spite of this, there is a fundamental difference between what the instructor and some students write. The instructor writes *symbols*, which represent a physical reality. All too often, students write *letters and numbers and lines*, which aren't symbols because they have no physical meaning to them. Interviews suggest that it is the students who are trapped in verbal/linguistic representation systems who are most likely to write the equation shown in Figure 6 for attack by a Grignard reagent on a ketone.

It isn't until the letters, lines and numbers in this equation become symbols that this answer becomes wrong. One can draw as many lines to a "C" as one wants; it is only bonds to a carbon atom that are limited to four.

In an earlier paper in *University Chemistry Education* we presented the results obtained when we analyzed student answers to an examination question in which they were asked to predict the products of the photochemical bromination of methylcyclopentane¹². We used this example as the

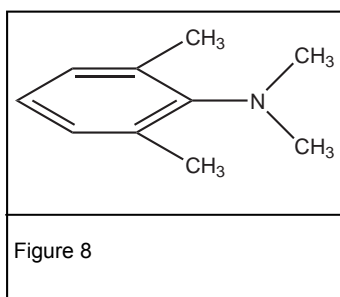
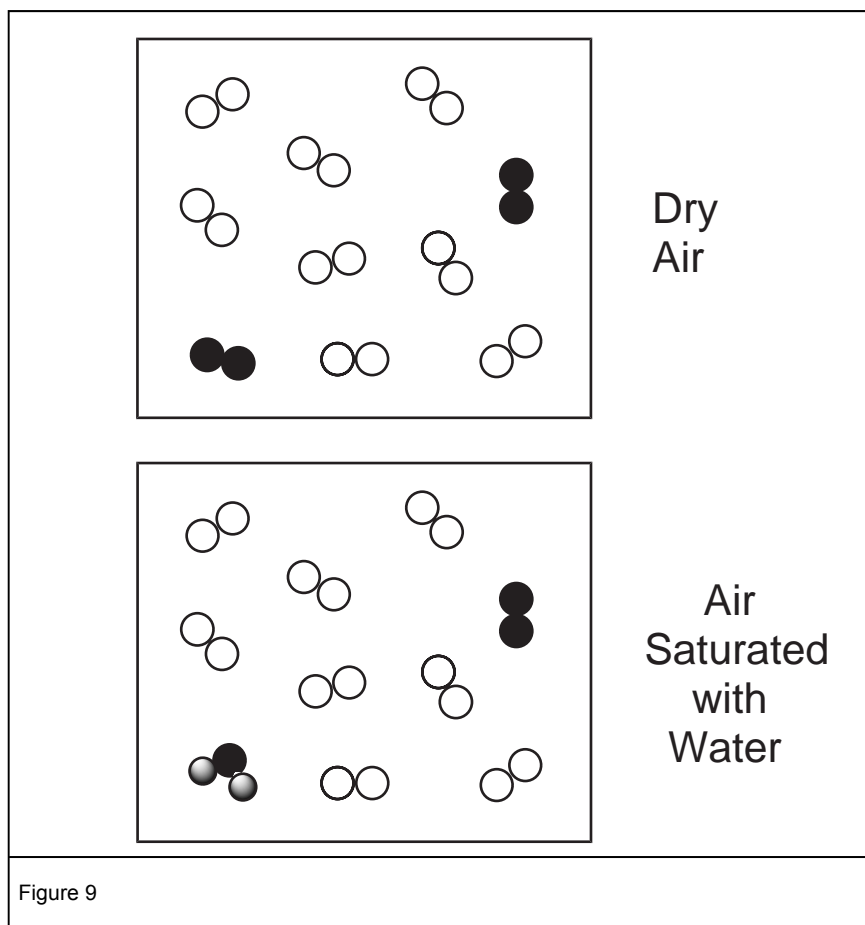
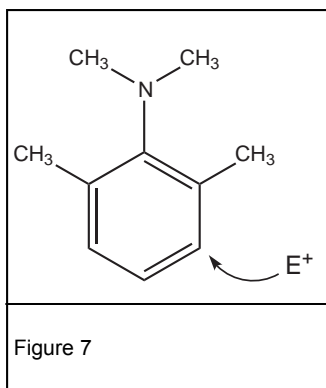
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basis for arguing that successful problem solvers construct significantly more representations while solving a problem than those who aren't successful, even though neither group constructed very many representations while solving the problems. This time, let's look at another example of the power of a second representation at getting to the answer to a novel problem. Several years ago, one of my physical organic chemistry colleagues put the following question on a homework assignment

asked me if I knew the answer. I admitted that I didn't. I was in good company, however, because none of the students knew how to answer the question. When I talked with the instructor, he was surprised. He said the answer is obvious. You just need to look at the molecule from a different perspective. What I would call using a second representation. When this is done (see Figure 8), the answer becomes obvious. The steric effect of the methyl groups on C(2) and C(6) keeps



for a graduate level organic course.

Explain why electrophilic aromatic substitution occurs at the indicated position (see Figure 7).

As "everyone" knows, amines are notoriously good ortho/para directors. Thus, if one follows the arguments in virtually any introductory organic textbook, electrophilic attack should occur at C(4). Experiment, however, suggests that electrophilic aromatic substitution occurs at C(3).

I was introduced to this "problem" because one of the 15 students in the class was in my research group. He noted that he had no idea how to answer this question, and

the *N,N*-dimethylamine substituent from lying in the same plane as the aromatic ring. This turns off the resonance effect of the amine, with the net effect that attack at C(3) becomes favourable. Regardless of what system I use to make my point, our work has repeatedly shown that people who use more than one representation to solve a problem are more likely to get the correct answer than those who struggle with a single representation.

I'm not arguing that it is impossible to get to the answer from the first representation one builds of the problem. There is abun-

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dant evidence that this can happen, particularly for those for whom the task is an exercise.

I'm not asking for many representations to be applied to a problem. Our work suggests that all one typically needs is a second representation.

I'm not arguing that a second representation will always get you to the answer to a problem because the first representation (when incorrect) can lead to a second incorrect representation, which leads to an erroneous answer. I'm just arguing that bringing two representations to a problem increases the probability of getting the right answer.

As a test of this hypothesis, consider the following question:

Which weighs more, dry air at 25°C and 1 atm, or air at this temperature and pressure that is saturated with water vapour? (The average molecular weight of air is 29.0 g/mol.)

When they first see this question, some claim that it isn't fair. They're right; it isn't. I don't tell you the volume of either the sample of dry air or the sample of air saturated

with water vapour. That's deliberate because it is only in general chemistry (and perhaps organic chemistry) that one encounters tasks that have all the information needed to solve them, and only the information needed to solve them. In the real world, tasks come to us that are poorly defined. The only way to answer this question is

to make a reasonable assumption: That we are talking about the same volume of the two gases. i.e., one litre of dry air versus one litre of air saturated with water vapour.

A lot of very bright chemists, when they encounter this question for the first time, conclude that the air saturated with water vapour has to be heavier than the dry air. They are in good company; the vast majority of beginning students reach the same conclusion. The source of the error in their thinking is simple: They build a verbal/

linguistic representation of the question when they read it, and try to get to the answer from that representation. When shown the symbolic representation given in a diagram (see Figure 9), they often change their mind.

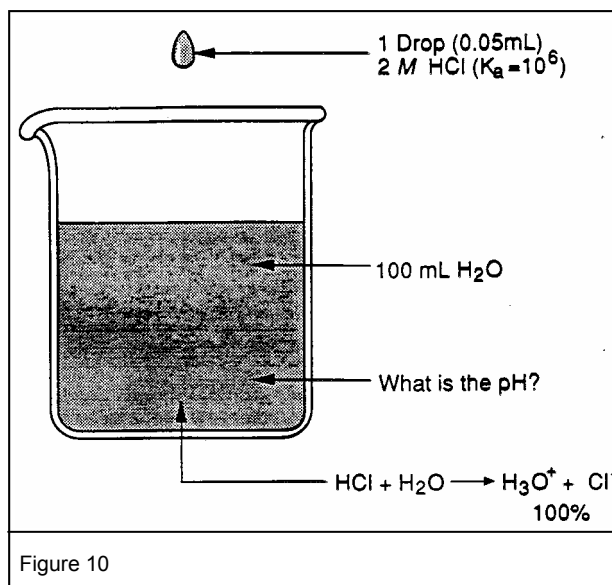
Every representation one brings to a problem carries different information. This one reinforces what we should have known - that the number of particles in a given volume of a gas at constant temperature and pressure remains the same. Thus, when we replace an O₂ molecule with a mass of 32 amu (or an N₂ molecule with a mass of 28 amu) by an H₂O molecule with a mass of 18 amu, the gas doesn't get heavier. It gets lighter.

Implications for Teaching

For some time now, we've been recommending that instructors draw a picture for every single task they work in class from the beginning of the Fall semester until the end of the Spring semester. We find that when this is done, the number of "C's" in the class goes down and the number of "B's" and "A's" goes up. An example of this is shown below.

Question: What is the pH of 100 mL of water to which one drop of 2M HCl has been added (see Figure 10)?

This diagram contains all of the information extracted from the statement of the problem as well as information that is derived while one struggles to get to the



answer. Part of its success comes from the fact that it is a symbolic representation. Part comes from the fact that it is a second representation, which often brings to our attention details that might not have been obvious from reading the problem. It is also important to recognize that this diagram is a chunking device, as called for in the Johnstone-EIbanna model. It brings together information, thereby reducing the demand on working memory. ■

'For some time now, we've been recommending that instructors draw a picture for every single task they work in class from the beginning of the Fall semester until the end of the Spring semester.'

Dick Bacon
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IMS Question and Test Interoperability.

This is a summary of the current position of the new international standard for computer based questions and tests, for those of you who are using, or planning to use, computer based assessments in your courses.

What is this?

Computers are increasingly being used to help assess learning, knowledge and understanding. IMS Question and Test Interoperability (QTI) is an international specification for a standard way of sharing such test and assessment data. It is one of a number of such specifications being produced by the IMS Global Learning Consortium to support the sharing of computer based educational material such as assessments, learning objects and learner information.

This new specification is now being implemented within a number of assessment systems and Virtual Learning Environments. Some systems store the data in their own formats but support the export and import of question data in IMS QTI format. Other systems operate directly on IMS QTI format data. Having alternative systems conforming to this standard format means that questions can be shared between institutions that do not use the same testing systems. It also means that banks of questions can be created that will be useable by many departments.

Technical details

The QTI specification uses XML (Extensible Markup Language) to record the information about assessments. XML is a powerful and flexible markup language that uses 'tags' rather like HTML. The IMS QTI specification was designed to be pedagogy and subject neutral. It supports five different type of user response (item selection, text input, numeric input, xy-position selection and group selection) that can be combined with several different input techniques (radio button, check box, text entry box, mouse xy position dragging or clicking, slider bar and others). It is able to display formatted text, pictures, sound files, video clips and even interactive applications or applets. How any particular question appears on the screen and what the user has to do to answer it may vary between different systems, but the question itself, the knowledge or understanding required to answer it, the marks awarded and the feedback provided should all remain the same.

The current position

The specification is relatively new. Version 1.2 was made public in 2002, and a minor upgrade to Version 1.2.1 was made early in 2003, that corrected some errors and ambiguities. The specification is a complex entity comprising nine separate documents. Various commercial assessment systems (e.g. Question mark, Granada, MedWeb, Canvas Learning) have already implemented some degree of IMS QTI compatibility for their assessments. A number of new academic systems are also being developed to comply with the specification. These include the TOIA project system which will have editing and course management facilities, the SToMP project testing system which was used with students for the first time during this last academic year, and a Scottish Enterprise system called Oghma which is currently being developed.

In the Sciences

One of the disadvantages of any such standard system within the sciences is the lack of support for facilities like the entry of algebraic expressions, the handling of both accuracy and precision of numbers, the use of alternative number bases, the provision of randomised values, and graphical input. All of these have, in one form or another, been included in science specific systems in the past, but they have not been included in this specification. Due in part to the fact that one of the members of the Physical Sciences LTSN Centre is taking a close interest in the specification, the handling of numbers is now being addressed. A proposal has been lodged with the IMS Consortium for an extension to the specification that would support the four features mentioned above to do with the handling of numbers (accuracy, precision, randomisation and number bases). Two QTI compatible systems have already been modified to support these features and one of them (the SToMP system) is available for free trial now, so you can see how such questions appear.

What this means to you

If you are starting or planning to start using computer based tests, then you need to be aware of the advantages of using a standard-compliant system. It is clearly a good idea to choose a system that will allow you to move your assessments to another system at a later time with the minimum of effort or to be able to import assessments authored elsewhere.

IMS Question and Test Interoperability.

A consideration to bear in mind, however, is that at this early stage in the life of the specification there will be a range of legacy differences between various implementations. It will also remain possible with some 'compliant' systems to create non-standard question formats if implementation specific extensions are used. The degree of conformity of any one system is a parameter that is difficult to assess at any time. Tools to assist with this are now beginning to be discussed, but it will be some time before objective measures of conformance will be available. In view of this it is a good idea to keep in touch with those interested in the development of the specification, and the best way within UK HE is probably via the CETIS Assessment Special Interest Group website listed below.

It is clearly important that a specification such as this should have subject specific input from interested academics. The needs of different disciplines are not always well known, and the lack of specific features can make adoption difficult. If you can spare the time, have a look at the examples on the CETIS web site and let us know where your needs are not being met.

More information

The full QTI specification, along with other IMS specifications is published on the IMS Global Learning Consortium website
<http://www.imsglobal.org>

CETIS is the JISC funded Centre for Educational Technology Interoperability Standards. It has a website containing useful information on all the IMS specifications
<http://www.cetis.ac.uk>

The CETIS Assessment Special Interest Group has a website at
<http://www.cetis.ac.uk/assessment>

Some websites of commercial or academic testing systems and support.

Questionmark
<http://www.questionmark.com>

Canvas Learning Author and Player
<http://www.canvaslearning.com>

Testwise (Granada Learning)
<http://trp.demo.granada-learning.com/preview.html>

SCAAN (Scottish Computer Assisted Assessment Network)
<http://www.scaan.ac.uk/ims.html>

Scottish Centre for Research into On-Line Learning and Assessment
<http://www.scrolla.ac.uk>

QTI Ready (XDL Soft)
<http://www.xdlsoft.com/products.html>

Assesst Designer
<http://www.xdlsoft.com/ad/ad.html>

Jcourse (Carnegie Mellon University)
<http://www.phil.cmu.edu/projects/jcourse-author/>

Learn eXact (Giunti Labs)
<http://www.learnexact.com/>

Act Elearning
<http://www.actelearning.com>

Respondus
<http://www.respondus.com>

Intrallect
<http://www.intrallect.com>

TOIA
<http://www.toia.ac.uk>

SToMP
<http://www.stomp.ac.uk>

WebMCQ
<http://www.webmcq.com>

Miranda
http://cvu.strath.ac.uk/new_information/miranda.html

MAP: Monitoring Assessment and Provision
<http://alto.aber.ac.uk/caa/maphome.asp>

Riva e.test
<http://www.riva.com/etest/etest.asp> ■

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Development Projects due to start September 2003

Understanding Spectroscopy using Web Based Learning

Dr A Bridgman & Dr N Young, *Department of Chemistry, University of Hull*

Design, Development & Delivery of an Independent Learning Module in Pharmaceutical Chemistry

Dr S Stanforth, J Perry & B Tomlinson, *School of Applied Sciences, University of Northumbria*

Developing an Undergraduate Module in Public Science

Dr G Jones & Prof N Evans, *School of Chemistry & Physics, Keele University*

School Teacher Fellows in Chemistry

Prof D Cole-Hamilton, *Department of Chemistry, University of St. Andrews*

Computer Aided Assessment (CAA) in Chemistry

Dr K Adams, Dr R Cole & Dr D Ruddick, *University of Ulster* and Dr M Cole, Dr J Dickinson & Dr B Murphy, *MMU*

Quantitative Skills in Forensic Science

Dr C Adam, Dr P Haycock & Dr V Zholobenko, *School of Chemistry & Physics, University of Keele*

Development of a CDrom Programme titled 'Sampling and Sample Pre-treatment Methods in Practical Analysis'.

Dr A Holden, Mr B Woodget & Dr I Mueller- Harvey

A Collaborative Database of Inorganic Compounds

Dr M Winter, *Department of Chemistry, University of Sheffield*

Creating a Physics Academic Network for Innovation at Level 1

Dr P Klein, *Department of Physics & Astronomy, University of Leeds*

Embedding Ethical Problems into Physics Curricula

Dr D Skryabin, Dr G Mathlin & Dr S Crampin, *Department of Physics, University of Bath*

The Production of Generic Resources for Computer-aided Assessment & Learning

Dr D Adams, *University of Sunderland*

Widening Participation in Learning: Physical Sciences

Dr P Taylor, *Dept of Chemistry* and Dr G Cousin, *Centre for Academic Practice, University of Warwick*

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Events —2003—

- Creative Science Teaching, 17th-19th Oct 2003, The Earth Centre, South Yorkshire (to be confirmed)
- Continuing Student Development - A Strategic Approach, 22nd Oct 2003, Birmingham
- Using VLEs to Support Learning & Assessment, 19th Nov 2003, Cardiff
- New Courses - New Students, 3rd Dec 2003, Manchester

Building for the future

The importance of the LTSN Physical Sciences web site grows steadily and is now really a full-time activity.

By the time you read this our new Web Developer, Garry Pilkington, will be working at the Centre. Garry is an Astrophysics graduate and has been working in the web development field for the Aintree Hospitals NHS Trust.

Initially Garry will take over the day-to-day maintenance of our existing web site but longer term he will be developing a new database-driven, Content Management System website to ensure easier maintenance of the site and facilitate future - proofing of our web.



Garry will be based at Liverpool. To contact him call 0151 794 3576 or email cappilk@liv.ac.uk

Contact us or visit our web site for details.