UniServe•Science

Proceedings
of
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UniServe•Science

UniServe•Science was set up by the Committee for the Advancement of University Teaching (CAUT) in 1994. The Committee established a nationwide network of clearinghouses (modelled on the Computers in Teaching Initiative [CTI] project in Britain) for the collection and dissemination of teaching materials throughout the whole Australian university system. Other members of the network are:

- Engineering at the University of Wollongong;
- Health at the University of Newcastle;
- Law at the Australian National University;
- Humanities & Social Sciences at the Royal Melbourne Institute of Technology; and the
- Coordinating centre at the Australian National University.

UniServe•Science caters for all sciences taught at undergraduate level in the Earth, Life, and Physical sciences. It aims to inform university science teachers of materials in the new technologies that are available to help them in their teaching, and whether those materials may be useful. Its main activities include: finding out what materials are being produced in Australia and overseas, organising reviews of packages by teaching academics, and disseminating all this information, by newsletters catalogues and electronic means. It also seeks to promote the use of IT in teaching by organising networks of personal contacts, by visiting other institutions and giving seminars, and by organising workshops.

TABLE OF CONTENTS

SUMMARY PAPER

IAN JOHNSTON & MARY PEAT

What did we learn from the dry labs workshop? 1

KEYNOTE PAPERS

JON PEARCE

The role of IT in teaching experimental science: The multimedia perspective 4

ROB LEARMONTH

IT in teaching experimental science: The scientific perspective 9

PAPERS

ROB CAPON

The reality of virtual laboratories: A chemist's perspective 13

FRED PAMULA, YVONNE PAMULA, AND JOHN WHELDRAKE

The use and benefits of computer mediated learning in teaching biology 19

BILL LONERAGAN

Escuela Practica: An introduction to vegetation sampling using computer simulation 25

ROB LEARMONTH

Dry Labs in Biochemistry Departments 28

RALF CORD-RUWISH

From Overhead Projection to Effective Interactive Learning Software for Science Students 32

AUDREY WILSON & ROGER LEWIS

Multimedia Preparation for First Year Chemistry and Physics Laboratories 38

PHOTO 41

LIST OF PARTICIPANTS AND EMAIL ADDRESSES 42

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What did we learn from the dry labs workshop?

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Why a workshop devoted to Dry Labs?

The original reasons for proposing this workshop were clear. Many science departments in this country are finding difficulty in maintaining their traditional teaching programs in experimental laboratories. In some cases this is because of pressure of student numbers and the cost of laboratory work. In others, it is the difficulty posed by the use of hazardous chemicals or animal experimentation or radioactive substances. The problems are particularly acute in those departments with large first year classes.

It has been suggested many times that first year students could be offered alternative experiences to some of their traditional 'wet' labs — perhaps simulated laboratory experiments, perhaps structured computer managed tutorials. The arguments in favour of such an approach are not only on the grounds of cost efficiency. There is no doubt that practical skills can be taught, and taught well, by computer simulations — teaching airline pilots or astronauts by flight simulators is an obvious example.

However there is sincere opposition to the very idea of 'dry' labs from many academics, which mainly centres round the key role that experiment plays in science. They argue that to take away from students the reality of experimental experience, is to denature the subject itself.

In order to judge which of these points of view we should be most swayed by, we need answers to these two questions:

(1) have any departments in this country introduced dry labs successfully, as a major, formal part of their teaching curriculum? and

(2) how did they solve the problems they must have faced?

That is why this workshop was organized.

What we saw at the workshop

The workshop began with overviews given by speakers from two different perspectives — from someone in a big multimedia unit (Jon Pearce, from the University of Melbourne's Science Multimedia Teaching Unit) and from someone with links to the scientific profession outside the University circuit (Rob Learmonth, who is a member of the editorial board of The Journal of Biochemical Education).

Next there were workshops run by two people who have been responsible for introducing a substantial program of computer experiences to first year students in their home departments, as alternatives to standard 'wet' labs — Rob Capon, School of Chemistry at Melbourne University, and Fred Pamula, Department of Biology at Flinders University.

There were demonstrations of particular packages which are being used as alternative-to-laboratory experiences, from Bill Loneragan (University of Western Australia) and Ralf Cord-Ruwish (Murdoch University of Technology). And lastly there were examples of materials designed to prepare students for traditional laboratory work — "pre-lab" packages from Audrey Wilson and Roger Lewis of the University of Wollongong.

What did we learn?

(1) Teaching effectiveness

For those who might not have been convinced already, it was clearly demonstrated that it is possible to develop new materials which contribute substantially to the learning experiences of students in the laboratory setting. It was shown that computers can bring to life difficult concepts, especially in the visualization of three-dimensional structures in chemistry, biology and biochemistry. They can offer a rich compendium of resources on which students can graze at their leisure, which should, in principle, lay down patterns of learning they will use for the rest of their lives.

At the same time it was stressed that the development of these kinds of materials is inordinately time-consuming and costly. Were it not for the CAUT teaching development grant scheme, it is doubtful if many of the items on show would ever have seen the light of day. How the next generation of innovations is to be financed, or how any updating is to be achieved is anybody's guess.

It was agreed however that the greatest area of deficiency at present lies in the *evaluation* of materials being produced. Flinders University takes steps to monitor how students perform in standard examinations after having been exposed to the new materials; but by and large the questions of whether the new materials really do improve learning is too difficult. Perhaps that is the next hurdle, and we can only hope that future teaching development initiatives will provide the necessary funding to ensure that research into student learning is part of the deal.

(2) Teaching efficiency

Perhaps the most striking fact that emerged from the workshop was that, of the 200 or so university science departments in Australia, only a very small number indeed (of order 10) have actually replaced wet labs with dry labs. Of particular interest were the two examples where the first year practical (wet) laboratory teaching has been cut in half, and 50% of the time formerly allocated to that is now filled with computer-centred experiences. These are mainstream courses, taken by the majority of first year students in those institutions. The question begged to be answered: how did the two developers persuade their host departments to allow this Trojan horse into their midst?

There seemed to be two major considerations.

(a) The Melbourne model was careful to single out for replacement, only those particular learning exercises which didn't necessarily belong in a laboratory in the first place (construction of molecular models). "Real" laboratory experiments were left alone.

(b) The Flinders model took care to identify particular experiments which were particularly expensive (spectroscopy) or dangerous and to replace those. Again, the safe, inexpensive "real" experiments were not touched.

Perhaps it was this concern for the sensitivities of their colleagues which won the day.

In both cases, the projects were carried out because of the enthusiasm of particular persons, and the question must be asked: what will happen to those courses when those people leave, or go on sabbatical or move on to different teaching duties? With many teaching innovations, when the person responsible bows out, the innovation is often allowed to stop, simply because that is the easiest thing for the host department to do. In these two cases, since the dry lab courses are a major component in the curriculum, it would in fact be quite expensive for the department to replace them. Perhaps these two do represent a permanent change to the way we teach science. Only time will tell.

Conclusions

It is not surprising that the workshop did not come up with definitive answers to any of the big questions. What was interesting was that, of the nearly one hundred academics who attended, and who were all there because (presumably) they were pre-disposed to look favourably on the idea of dry labs, not one believed that science courses should abandon the ideal of having students perform real experiments in 'wet' laboratories. Rather every one believed that the proper job of the new technology was to *enhance* the laboratory experience, whether by pre-lab packages, or by streamlining analysis of results, or by better graphical representations of theoretical models — or by replacing some experiments.

At the same time, however, everyone was aware of the costs of the new technology. It may well be that the crippling expense of re-equipping computer labs every few years may yet sink the whole enterprise. But at least the financial burden of *developing* materials can be contained.

The way universities organize their teaching has often been likened to a cottage industry. Each teacher develops their own course from the ground up with little reference to what has gone before. In some respects this is a feature, not a bug. It guards against students' continuing to receive ideas and opinions that have passed their use-by date. But, because of the expense of the new technologies, we must join the industrial revolution. We cannot all afford to develop our own materials. We must get into the habit of working in consortiums and share the load. The fact that this workshop brought together many of the active developers in the country may make that goal just a little less remote, and perhaps UniServe•Science might be able to take a leading role in making such consortiums happen.

On that there was agreement.

The role of IT in teaching experimental science: from the multimedia perspective

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Why a Workshop on Dry Labs?

Many motivations might bring one to examine the role of computers in the laboratory class: concern over the expense of *real* labs; concern over the encroachment of computers into these labs; a feel of excitement that computers might be able to add something to lab work that is currently missing. For whatever reason, it is maybe appropriate to begin by thinking about our motivations for doing *real* lab work in the first place.

Why Practical Work?

When talking amongst physicists and raising the suggestion that a lab experiment might be better simulated, the response is often "But they *must see* the real thing; must *do* the real physics (or chemistry or biology)." For some reason we, as scientists, have a strong belief that there is intrinsic value in lab work. We see the lab as fulfilling several roles: as an essential part of students' experimental training; giving them activities of an experiential nature; "proving" or "illustrating" concepts; setting a role model as to "what science is all about".

We persist with lab work in the face of some research that suggests not all is well. Students often dislike it; are confused about its purpose; come away with dubious learning outcomes and even take away a misleading message regarding "what practical science is all about".

Professor Fred Goldberg, an American physicist and science educator, makes significant use of both practical experiments and computers in his physics courses. His use of the computer is novel in that he uses it as an instrument to enable students to make visible their thinking — to draw on the screen their reasoning about the equipment they are working with. Whilst he clearly advocates the beneficial role of practical work, he makes an interesting observation (Goldberg and Bendall 1995) of students *observing* the results of a simple experiment, yet, due to their prior *expectations*, recording the outcome as just the opposite! This should remind us that there are many more subtleties to student learning outcomes than students simply completing a successful experiment.

Is it appropriate that we take the time to ask ourselves two questions in order to help place the role of computing in context:

What do students benefit *uniquely* from lab work?

What *message* do students take away with them from labs?

This workshop should give an opportunity to focus on these questions.

Should We Simulate?

We are all aware of the traditional reasons often trotted out for using computer simulations: cost, danger, time, complexity, *etc*. But now we have two new players in the game which might give us new reasons to turn to simulations. They are *virtual reality* and *on-line experiments.*

(a) Virtual reality

Although virtual reality is still very much in the realm of research tools, it is already being taken seriously as a simulation environment for teaching science (see, for example, *Project ScienceSpace*, at http://www.vetl.uh.edu/ScienceSpace/ScienceSpace.html). Once the virtual reality headset it put on, a world of new experiences are possible: test tubes can explode safely, balls can bounce around with their vectors attached and frogs can be dissected odourlessly!

(b) On-line experiments.

There are a vast number of Web sites that connect in some way to a piece of physical equipment (point your Web browser to http://www.awe.com/mark/fave-inter.html for a starting list). From the banal of viewing coffee pots brewing to the joy of watching a busy street in Los Angeles! Some of these sites offer useful experiences for science students: controlling a robot or driving a telescope, for example.

Simple science experiments are possible, although not many have been set up to date. Maybe there is a place for such “on-line experiments” in which students reap all the benefits we attribute to Web-based activities: do it anywhere (don’t even have to enter the lab!), do it in their own time, do it on any computer.

This could become particularly powerful when coupled with virtual reality—students could “see” and “feel” the experiment from the security of their armchair. But is this for good or evil? Would students ever *really* know whether the experiment was real or simulated, wet or dry? Maybe an analogy to the Turing Test is appropriate here, along the lines that if you can find no way to distinguish your experience from the real thing… then will anyone care??

This poses another, rather obvious, question for us to ponder:

What benefits can simulations offer to a practical science experience?

Modes of Use of Multimedia

The remainder of this presentation looks at various examples of using multimedia in the lab environment within the University of Melbourne.

(a) Pre-Lab and Post-Lab Support

Computing can be used *before* students enter the lab, and *after* they leave, in a manner to help them prepare, or digest, the lab material.

A project in the School of Botany at the University of Melbourne (Pauline Ladiges) presents students with much general information about their subject, but also shows them some aspects of the up-coming lab in the hope that they will see and understand it better when they get to the real lab. Figure 1 shows an image from this package in which a section from a leaf is shown as seen through a microscope.

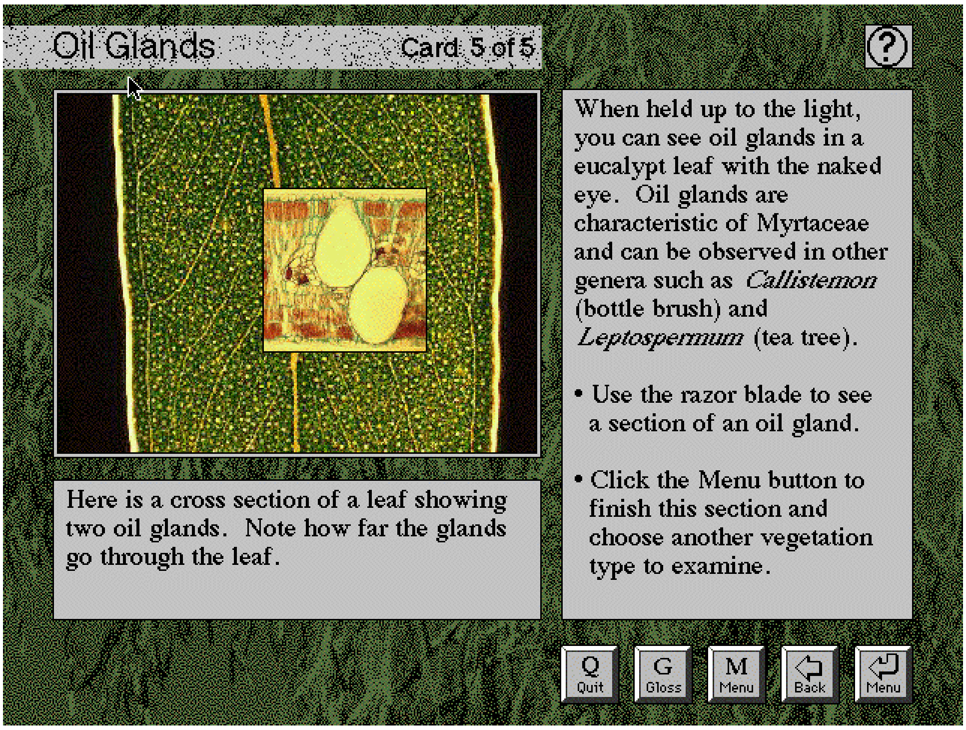

Figure 1. An image in which a section from a leaf is shown as seen through a microscope.

The School of Chemistry has replaced some of its wet lab time with computer software designed to teach students both practical and analysis techniques which they will use in subsequent labs.

Within Physics, second year students use a commercial circuit simulation package (*B²Spice*, Beige Bag Software) to play with circuits *before* entering the lab, as well as afterwards.

Each of the above examples seeks to prepare students better for their lab work so that they may carry it out more effectively and benefit more from it.

(b) Support During Labs

Clearly the computer has a strong role to play as a device to aid in *analysis* within the lab. But its potential is much greater than that.

Once computers are present on the lab benches, they can be used to provide testing and on-line manual support. In Pharmacology, data-logging by computer was introduced as an alternative to using obsolete chart recorders. Once in place, the computers could also be used to present information about the lab work, including *QuickTime* video clips of various techniques which are hard to explain in words. Figure 2 shows a screen from one of the packages developed (Darren Williams) with the *QuickTime* movie in the top left-hand corner of the screen.

Figure 2. One of the packages with the *QuickTime* movie in the top left-hand corner of the screen.

In Physics, the commercial virtual instrumentation package *LabView* (National Instruments) is used by students to construct "programs" which control the equipment they use for monitoring circuits in an electronics lab. They make their lab experience more efficient while learning up-to-date techniques in instrumentation and control.

A slightly different approach to using the computer during a lab is to use a simulation to help in the explanation of the experiment being performed. The School of Physics uses the optics simulation *RayTrace* (Ian Moore, Queensland University of Technology) alongside optical benches, encouraging students to make links between the *real* physics and the representation by the simulation.

(c) In Place of Labs (!)

Dare we *replace* labs with computer activities?

Three recent CAUT projects come close to this but each offers experiences not possible in an undergraduate laboratory.

A Zoology project (Rob Day & Michael Nott) is using the Web to enable students to explore population dynamics with real and simulated data. For practical reasons, this kind of experiment can only be done by students using a simulation. Choosing the Web as an environment gives students access to a powerful communications medium which they utilise to query each other as well as their tutors.

A Physics project (Jon Pearce & David Jamieson) provides students with a simulation with a difference: most of the data are research data from one of the School's research groups. This gives students added motivation as they play with data which are *real* and not contrived or simulated. The experimental environment is that of an expensive research machine (nuclear microprobe) which is certainly inaccessible to undergraduate students. Figure 3 is a screen from this "simulator" showing a diagrammatic representation of the microprobe together with the data that students can explore.

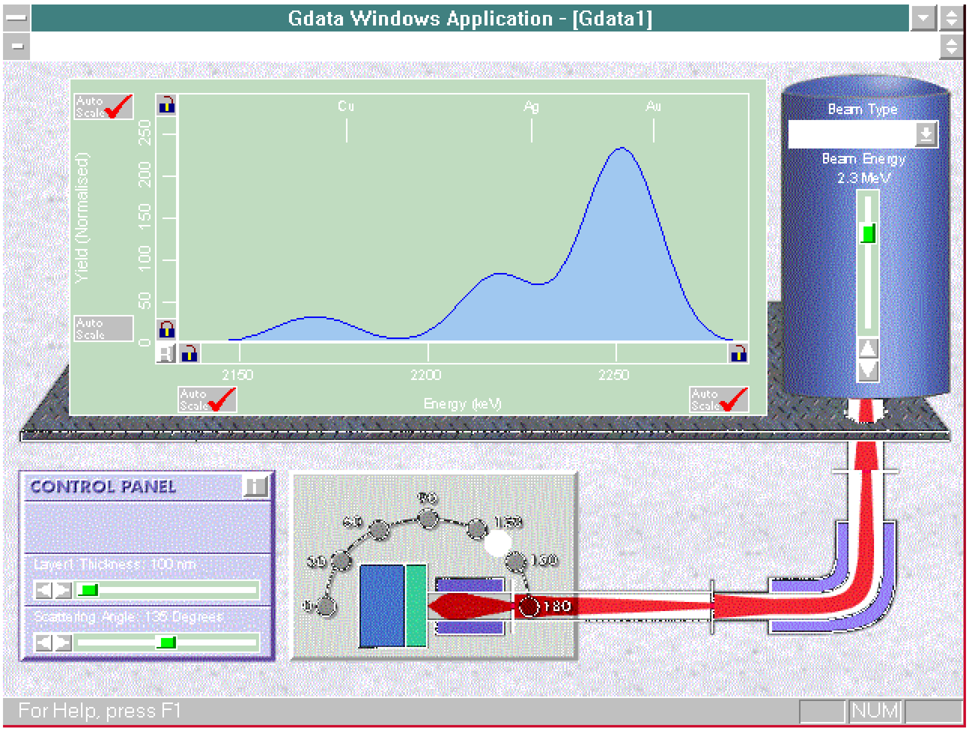

Figure 3. A “simulator” showing a diagrammatic representation of the microprobe together with the data that students can explore.

A further Physics CAUT project (Michelle Livett & Jon Pearce) just under way takes students *out* of the lab by making *QuickTime* videos of everyday physics available for analysis, via the Web. The concept here is that much *real* physics takes place outside and cannot be studied in a lab. A reasonable substitute is to give students video clips, together with powerful analysis software, and let them explore in their own time.

What Technology *Now* Offers?

Current technology offers us many temptations that were not readily available on a few years ago. We have user-friendly front-ends that make using sophisticated software less complex. Computing power is such that we can produce advanced visualisations, animations and carry out very complex analysis. The World Wide Web gives us the potential of on-line experiments, vast databases, communications and collaboration, and “do it anywhere, on anything, at anytime” computing.

With all this being laid before us, it would appear that now is an appropriate time to re-examine some of our sacred cows and to examine critically what these new technologies can offer.

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IT in teaching experimental science: the scientific perspective

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Introduction

Experimental investigation provides the foundation of science. Theoretical models describing the natural world result generally from practical observation of phenomena. Thus it is important that our students, who will be the next generation of scientists, understand the experimental basis of the "facts" in their textbooks, and gain experience in the practical side of scientific investigation. Therefore, it has traditionally been considered important that training scientists are exposed to 'wet' laboratory sessions. An extension of this approach is that replacement of practicals with other activities devalues a practical course. However, this view must be tempered by other important factors.

One needs to consider the orientation and perspectives of different groups of students, and the appropriateness of their practical experience. Taking an example from my own field of biochemistry, there are some groups of students for whom 'wet' practical work is not highly appropriate (Learmonth *et al.* 1988). For example, students of medicine and nursing do not need to develop biochemistry laboratory skills, but rather gain an understanding of the experimental basis and interpretation of clinical test data. In some medical courses biochemistry practical work has been replaced altogether by other activities such as clinical case problem solving (Scott and Shanley 1988).

In contrast, for students studying the experimental sciences in their own, 'wet' practicals are critical to the learning experience. Nevertheless, the question must be asked whether a traditional laboratory course meets the needs of our students. There are commonly significant limitations in that it is not possible to expose students to all of the vast array of techniques and scientific equipment, nor in many cases provide sufficient repetition for students to gain mastery of a technique. We are generally capable of providing tuition in a selection of techniques and approaches, and hopefully impart the culture of scientific investigation and encourage the ability to adapt and operate in diverse environments. Thus we cannot fulfil all our objectives with 'wet' practicals alone. There is much to be gained from stepping back and looking at 'dry' lab activities, which can supplement and enhance the 'wet' lab experience. One needs to identify where computers can be effectively applied to extend and enrich the curriculum, and how the computer-based activities can be integrated into learning experiences in non-trivial and meaningful ways. The same questions should be asked of 'dry' and 'wet' activities, in summary whether they meet the objectives. Further, do the students, and for that matter the instructors, have a clear idea what the objectives are? Objectives of practical classes have been summarised by Bender (1986).

Key elements of computer-based 'dry' laboratories

There are a number of issues to be considered in the implementation of 'dry' laboratory sessions in a practical course. Foremost amongst these are questions of intellectual appropriateness of individual exercises, and teaching efficiency and effectiveness. Logistical considerations also need to be addressed, including availability and location of computer laboratories. Often the major driving force for implementation of 'dry' labs is reducing the expenses in terms of laboratory consumables and staff time. However if materials are to be developed in-house it must be recognised that establishment costs will be high. Key elements of successful computer aided learning include the software, the instructors and the learners.

Software considerations include validity, appropriateness, ease of use, flexibility and quality. Validity for example of the theoretical model or database used in a simulation program should be confirmed. It should be asked whether it is appropriate or better to present the material by computer or via another medium. A program should show flexibility in its design, including variation of data or sequence so users do not become bored, preferentially with different levels of complexity or challenge and providing user control over sequence of activities or variables in a simulation. The software should also be easy to use and robust.

Instructor-related factors include attitude, selectivity and integration. It is important that all instructors are comfortable with the technology and confident and skilled in its use. Both positive and negative attitudes influence student perception of the value of an exercise, which will affect learning outcomes. It is important to apply selectivity in the choice of appropriate software, and that the computer-based activities are truly integrated into the course.

Learner-related factors include attitude, engagement and preparedness. Students' attitudes are often related to the instructor's attitude, but also reflect their confidence in using the system, prior computer awareness and knowledge, preparation for the exercise and perception of its value. Engagement is a reflection of commitment, and may be evidenced by total time spent on the activity or enjoyment. Engagement is necessary, but not sufficient to ensure a positive learning outcome. User control and feedback on progress seem to be major contributors to keeping interest. Cognitive preparedness is also important and relates to integration of the activities.

Other important factors include the number of students per workstation, the setting and the formality of the activity. I have generally found that it is better to have 2-3 students working together. To proceed they must discuss steps or actions to take and reach agreement on theoretical points and concepts. The setting can be important for integration of computer-based activities, for example it seems to be better to have computers available in or near the regular class location, as opposed to a central facility distant from the normal work environment. Formality of classes can also be important, for example formal classes provide strong temporal and contextual links between computer-based and other learning activities. However this is often constrained by the number of students and time available, often meaning that students must cycle through the computer-based and other integrated activities. The activities may also have to be pursued out of class hours.

Types of computer-based activities

There is a great potential for computer-based exercises to supplement and extend practical experience, provided they are truly integrated with the other activities in a course. Such exercises fall into a number of categories including those that assist students in preparation for 'wet' laboratory work and those that extend the course by providing practice in data analysis or simulating data from equipment not available, or techniques too difficult for students to master within the constraints of the timetable. A variety of alternative exercises have been developed over the years to supplement practical classes. Many of these are not computer-based, for example "pen and paper" calculations assignments and activities designed around textbooks, lecture notes, diagrams and "feelware" such as molecular or anatomical models. Such resources have been around for a long time and some are now being used successfully as adjuncts to computer based material. The discussion here will be limited to computer-based applications, outlined in various categories below. Specific examples will be discussed in the paper for the workshop "Dry Labs in Biochemistry Departments".

Assistance with 'pre-prac' preparation

Lack of preparedness of students and the danger of becoming engrossed in technical and logistic aspects have been identified as major problems in biochemistry practical classes (Parslow 1993). Computer-based simulations of experiments have been applied to assist students prepare for biochemistry practical work (Learmonth 1994). This helps students to become familiar with the conceptual, logistical and numerical aspects of a practical before coming to the laboratory. Programs have also been developed to simulate the operation of specific items of equipment such as spectrophotometers, HPLC or NMR equipment. These may be used prior to practical classes to provide background and training in equipment that students will use. In some cases they may provide simulated use for data collection from equipment that is not available for student use.

Assistance with data manipulation and calculations

Computer programs have been devised to assist in laboratory calculations (*e.g.,* Carrington 1993; Wiseman *et al.* 1995) or to assist in analysis of data obtained at the bench (*e.g.,* Jones *et al.* 1985; Pamula *et al.* 1995). These programs variously find application before, during or after practical classes. The emphasis of these types of program is on the correct processing and analysis of data. This should enhance the understanding and interpretation of the data obtained either at the bench or by computer simulation. Such programs may also assist students in their drawing of valid inferences and conclusions from their data.

Simulated data acquisition

Examples include combined 'wet' practical/data simulation, which may be to extend analysis to areas that cannot be covered in a practical session (*e.g.,* Bender 1986). Another approach is to simulate experimental data that must be recorded in traditional fashion, possibly providing further assistance in analysis of the simulated data (*e.g.,* Jenkins and Cartledge 1995). A third approach is to simulate the entire experiment (*e.g.,* Day *et al.* 1996; Fyfe and Fyfe 1996) or a process such as purification of a protein (Booth 1987). Applications of computer simulations in biochemistry have been reviewed previously (Learmonth 1991).

Summary and Conclusions

A combination of 'dry' and 'wet' laboratory activities can be used effectively to separately address important facets such as obtaining results, data manipulation and formulation of conclusions from the data. Often the focus of 'wet' practicals is on obtaining experimental data, which may be of dubious quality. 'Dry' activities can be used to teach problem solving and data manipulation using “good” data. Practice in data handling and calculations will stand students in good stead when subsequently performing “real” experiments, as can simulation activities designed for training equipment use, or simulation of processes. If we can assist in preparation of students for practicals, then we can make the whole experience more valuable. Furthermore we may also be able to open up a window of opportunity by simulating experiments not practicable in existing courses.

The use of computer-based activities may not guarantee learning, although the question may be asked whether anything can provide such a guarantee. However it seems likely that the power and flexibility of computers combined with speed and ease of use for simulation and analysis of experimental data may take some pressure from the learner and potentially promote engagement and motivation. The latter is perhaps the most important aspect of learning. The bottom line is that the quality of the learning experience will largely determine the quality of our graduates and their ability to adapt and operate as professional scientists.

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The reality of virtual laboratories: a chemist's perspective

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Some Background

A Chemists Perspective…

The observations outlined in this presentation are those of the author and focus on the introduction of new teaching technologies, in particular Computer Aided Learning (CAL), to undergraduate chemistry "laboratories" at The University of Melbourne.

The Venue…

Founded in 1856, the School of Chemistry at The University of Melbourne is one of the oldest in Australia. Some 35 academic staff are engaged in all areas of chemical research, and collectively instruct more than 2000 undergraduate and over 85 graduate students each year.

As with chemical education the World over, the School of Chemistry provides instruction in both the theory (Lectures & Tutorials) and practical (Laboratory) aspects of chemistry (organic, inorganic, physical). With more than 1600 undergraduate students studying first year chemistry each year alone, the logistics associated with this process are formidable. In 1993 as part of a major review of the undergraduate chemistry curriculum, the School of Chemistry undertook to implement both new strategies and new technologies into its first year teaching program.

New Strategies

In keeping with University directives the first year chemistry unit (Chemistry 101) was semesterized, and in order to more effectively support individual student abilities each semester unit was further partitioned into advanced (121 & 122), intermediate (141 & 142) and basic (161 & 162) streams. Individual selection into a given stream was determined at enrolment based on demonstrated academic ability in secondary level chemistry, physics and maths, while transfer between streams in second semester was a function of first semester performance. The precise formula for selection into streams continues to evolve, reflecting changes in both content and assessment at the secondary level. While the total lecture (39) and tutorial (13) load for each semester unit remained the same, the depth of coverage varied between streams in a predictable fashion. Perhaps one of the more controversial innovations to arise from this restructuring was a reduction in traditional Laboratory instruction (wet lab) from thirteen 3 hour to six 3 hour laboratory sessions, with the remaining seven 3 hour sessions being transferred to Workshops (dry labs). Over three years these Workshops have come to be exclusively CAL based. The rest of this paper will focus on the evolution and success of the Workshop concept.

Our First Workshop (Dry Lab)

The genesis of the Workshop concept, as currently implemented in the School of Chemistry, began to emerge in 1990/1991 as a handful of staff from the School of Chemistry became aware of and began to explore the application of computer technology in tertiary education. It is worth noting that in these formative times progress was entirely dependent on the efforts of a small number of enthusiasts, a situation which despite significant advances is regrettably all too often still the case today. In one foray into the application of computer technology a lecture theatre was equipped with computer projection capability and experiments performed to define and refine a methodology for "multimedia lecturing" to large undergraduate classes (over 250 students). Such "multimedia presentations" are now commonplace with most lecture and tutorial teaching spaces across the campus either upgraded or scheduled for upgrade to multimedia status.

Sponsorship

In late 1991 The University of Melbourne Interactive Multimedia Learning Unit (IMLU), with sponsorship from the Department of Employment, Education and Training (DEET), seconded as Senior Teaching Fellows three academics who through their actions had been identified as champions of multimedia technology. These individuals were supported (equipment, programmers & time-release) to more formally explore the application of interactive multimedia, and to provide tangible evidence for its future role in tertiary education. The author was fortunate to be awarded one of these Senior Teaching Fellowships, and used the opportunity to further refine methodology for lecturing with interactive multimedia, and to design and implement what was to become the first "dry lab" in the School of Chemistry, the Molecular Models Workshop.

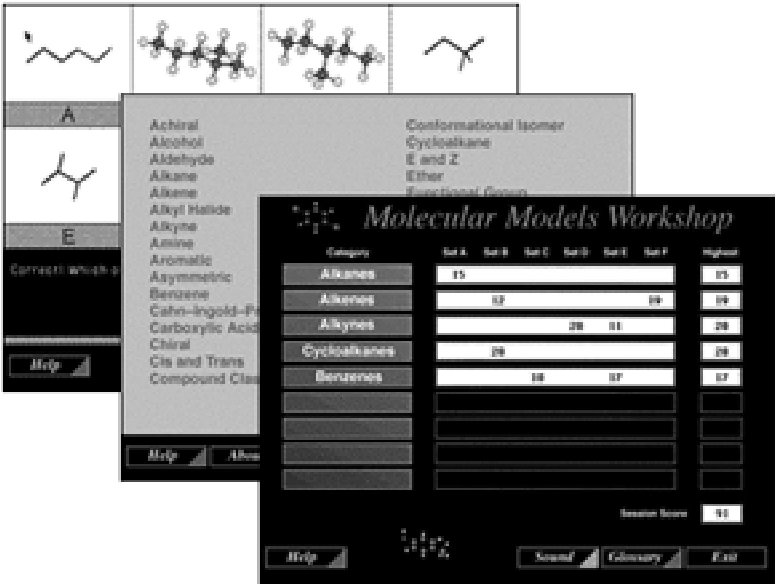
The Challenge…

One of the more challenging concepts encountered by undergraduate chemistry students is that of molecular shape. To properly grasp the fundamental principles of molecular interactions — that is to predict the outcome of chemical reactions — it is necessary to fully appreciate the 3D shape of molecules, and to effectively integrate this knowledge into mechanistic theory. Traditional methods of instruction on blackboards *etc*. inevitably represent molecules in a 2D format, and require students to mentally recreate and comprehend the "correct" 3D structure. The speed with which individual students successfully acquire this ability to visualise the 3D structure of molecules is typically slow and varied. Traditional Molecular Model Kits are a valuable educational resource that offer students a tangible 3D "hands on" experience. Recognising the need to instruct students on the 3D nature of molecules, most Chemistry Departments run a Laboratory class where students are provided with a Molecular Model Kit and a printed set of instructions plus questions to work through. Over many years the School of Chemistry at The University of Melbourne ran just such an operation.

Molecular Models Laboratory Class…

During a given week, twice a day for three hours at a time, groups of up to 160 students would attend a Laboratory class. Prior to the class technical staff would check and lay out one Molecular Model Kit per student. Students would be divided into laboratory groups of 16 students per group with a graduate research student as a demonstrator. A member of academic staff would also be in attendance for the three hours of the Laboratory class. Over the allotted three hours students would assemble a series of molecular structures and attempt to answer questions about these structures (structural vs geometric vs stereo vs conformational isomers, *etc*.). During this period the students could ask questions of their demonstrator and the attending academic. At the conclusion of the class each student would hand up a report to the demonstrator. Over the next week each demonstrator would mark (not correct) these reports which were handed back to their respective owner at the commencement of the next Laboratory class. The demonstrator would then manually enter a grade for each student (mark out of 10) onto a student record card. This grade would in time be "double typed" into the computerised student record for incorporation into the final assessment for the semester. Clearly this Laboratory class does not demand the costly resources and infrastructure of a chemistry laboratory. This Laboratory class appeared a prime candidate for re-development as a "dry lab" or Workshop.

Molecular Models Workshop



The Molecular Models Workshop (MMW) is a self-paced CAL package developed for use by undergraduate chemistry students. MMW presents students with a selection of problems focused around the shape of organic molecules — structural, geometric, conformational and stereoisomers, plus nomenclature *etc*. These problems are extensively supported by interactive molecular animations, on-line Help and Glossary functions, as well as real time assessment and feedback. Students are encouraged to explore MMW at their own pace, and to attempt additional questions to optimise their Session Score. This latter feature has been particularly successful in that individual students can immediately identify areas of weakness and respond accordingly. Student performance can be monitored and Class Assessment Lists generated automatically. MMW can be used by students for free range learning, or in a more formal tutorial/assessment setting. Class Attendance Lists can be preloaded into MMW for up to one month in advance to automate control over student access — an important consideration in our experience with more than 1600 students using only 40 computers over two weeks.

An early implementation of MMW saw the software loaded onto 40 computers in the School of Chemistry CAL Laboratory. Over two weeks, twice a day for 3 hours at a time, groups of 80 students would attend the CAL Laboratory to complete this Workshop. Although limited hardware resources required students to work in pairs, in due course this initial compromise was recognised as a bonus. Dialogue between pairs of students as they attempted to optimise their session score provided a powerful educational medium as each attempted to justify their version of the "correct" answer. Since student names, student ID numbers and allotted Workshop times were preloaded into the software, management of student access was fully automated. Likewise, on-line assessment ensured that students were immediately alerted to incorrect answers and encouraged to explore more questions on that topic. Not only did students know their final assessment at the end of the Workshop, but this score was automatically logged and used to generate a consolidated assessment list for all students. At no time were student names, numbers or grades re-typed, rather they were uploaded direct from the MMW logfile output into the University assessment archive. Once the MMW software was loaded onto the CAL Laboratory computers, instructional support for each group of 80 students was possible by a single academic, and the entire assessment upload of more than 1600 students achieved in about 15 mins by one person.

The design and development of MMW required consideration of many issues, both academic and technical.

Academic Content & Design

MMW was designed to replace an existing laboratory class. As such both the content & design needed to acknowledge that link. Sparse access to demonstrator support during the traditional laboratory could be compensated for by immediate on-line assessment (Am I correct or incorrect, and if so how do I proceed?) and Glossary (What does this term mean?). In the event that students first attempt at a set of questions was poor (low score) they should be given the opportunity to immediately try another set of related questions. The students are encouraged to take responsibility for assessing areas of strengths and weakness, and respond accordingly. The incentive for the students to focus on an area of weakness is that by trying another set of questions they will learn more about the concepts covered in these questions, and in the process improve their session score. Descriptions in the Glossary were kept deliberately brief — sufficient to remind a prepared student but insufficient to fully explain the meaning of a difficult concept. At all times students were encouraged to make reference to a chemistry textbook. The MMW was not designed as an alternative to, but rather complimentary to existing textbooks. The design was also required to provide automated support for student access and assessment.

Hardware (Production vs Delivery)

QuickTime animation technology which is the ‘nucleus’ of MMW was initially released on Macintosh platform, and as the School of Chemistry is overwhelmingly a Macintosh environment, this clearly identified the development and delivery hardware.

Authoring Software (Production vs Delivery)

Available programmer support combined with the need to manage emerging QuickTime technology in a Macintosh environment readily identified HyperCard as the Authoring software of choice, both for production and delivery.

On-line Help and On-line Glossary

With conceivably more than 1600 users/year it was essential that all user notes *etc*. be incorporated into MMW. The on-line Help feature is accessible at all times and clearly explains both the academic and technical design, requirements and objectives in using MMW.

Timetabling limitations consistently resulted in students using MMW *before* attending lectures on most of the topics assessed in the Workshop. An on-line Glossary is accessible to students at all times during a session and provides brief descriptions that may be sufficient in themselves or may serve as points of entry into a chemistry textbook. The Glossary is HyperText linked to facilitate browsing.

Distribution

Although MMW was initially developed to demonstrate the effective application of this technology, it was recognised early in the development process that MMW would have application outside of the University of Melbourne. Indeed, many other Universities across Australian and overseas have expressed interest in obtaining MMW. Realistically, commercial distribution of MMW is only viable if a dual Macintosh/PC version can be created. Having refined MMW in a Mac environment we are currently contracting its porting to PC, as a prelude to commercial distribution late in 1996.

Evaluating MMW

Having created a working version of MMW more than 2500 students used the package over two years. These students were invited to answer an "electronic" questionnaire on all aspects of the software. Likewise, the logfiles for each student usage contained additional information that was used to measure the effectiveness of individual questions. Impromptu interviews with students during Workshops also provided a valuable level of feedback. The feedback from both questionnaires, logfile analyses and interviews was used to refine MMW.

Our experience with MMW was very successful. Students benefited from both the self-paced nature of the product, the built in assessment and feedback, and the visual clarity of interactive molecular animations. Tedious administrative issues (marking attendance roles and reports, entering student assessment *etc.*) were handled by computers and valuable academic and demonstrator support redeployed to student instruction. Although the first CAL Workshop, MMW was not the last. Many effective CAL packages have since been adopted as integral components to the undergraduate chemistry curriculum.

School of Chemistry CAL Laboratory

Establishment

Trials of CAL were undertaken in 1992, making use of the University of Melbourne, Information Technology computer laboratories. Although not traditionally a teaching venue, these laboratories were opened up to the School of Chemistry to provide the large number of computers needed. Remote from the chemistry building and subject to numerous practical constraints, access to these laboratories still provided the means to successfully implement CAL and unambiguously demonstrate its potential in tertiary education. Following on from this success the School of Chemistry undertook to construct its own CAL Laboratory by commencement of the 1993 academic year.

Discussion so far has focused on Workshops as 'dry' labs, that is computer based versions of traditional laboratory classes. While the viability of such operations has been well demonstrated, CAL Laboratories offer far more. The School of Chemistry has had considerable success with an in-house development, Tutorial Tools, which has facilitated the production of numerous self-paced interactive tutorials. Furthermore, copies of electronic lecture material, "worked" answers to tutorials and past exam papers, all feature in the repertoire of resources made available to students through the CAL Laboratory.

Management

The Chemistry CAL Laboratory is supported by a full time programmer, charged with both ensuring the smooth and efficient operation of the laboratory as a teaching environment, and in monitoring and supporting future development and the implementation of emerging technologies.

Access

The CAL Laboratory is scheduled for Workshops 10am-1pm and 2pm-5pm each day Mon to Fri. Times 8am -10am and 5pm -7pm are variously available for scheduled classes and/or free access for private study. In 1996 at least one Workshop is scheduled 6pm-9pm. The physical location of the CAL Laboratory together with security and safety considerations make it difficult for late night and/or weekend access to undergraduates.

“Commercial” Workshops (dry labs)

Another laboratory exercise which derives no obvious benefit from being in a chemistry laboratory is the spectroscopic identification of an organic unknown. Permutations of this experiment occur in all years of undergraduate instruction and invariably require the identification of an unknown substance given a selection of spectroscopic data. While first year students traditionally solve one such unknown, second year students solve two and third year students three. In all cases the students write and submit a report which is marked/assessed and after some delay (up to 1-2 weeks in third year) returned to the student. In first year the large number of students involved frequently ensure that this unknown is marked but not corrected — providing little educational feedback to the student. Ideally students should have an immediate answer to their effort at assigning a structure and, if incorrect, receive hints at why they were wrong and be prompted to try again. Likewise, whether students get the correct or incorrect answers all would benefit from the opportunity to attempt numerous examples. Enthusiastic students should be encouraged and supported in this regard. For practical reasons it is impossible to offer these ‘ideal’ opportunities in a traditional laboratory class format — they are however attainable through the use of CAL.

Several commercially successful CAL software packages are available to support a Spectroscopic Unknowns Workshop. Two that we have made use of in first and second year are Introduction to Spectroscopy and Proton NMR Simulator.

Future Directions

Hardware

At present Universities making use of CAL are obliged to provide access to and maintain expensive CAL laboratories. Whether this will be necessary in the future is open to speculation. As the cost of powerful laptop and desktop computers/modems *etc*. falls, students will increasingly invest in this equipment. To provide access to CAL content it may be sufficient to provide network access both on or off campus. In the final analysis, quality software with on-line support/assessment may be made available to students on demand, with occasional electronic communication to a rostered “human tutor”.

Software

As mentioned above, should CAL software be accessed from off campus then the very real opportunity exists to supply these software resources as a worldwide service. Smaller institutions lacking infrastructure for software development may choose to purchase site licenses and/or enter into collaborative associations with software suppliers. These suppliers need not necessarily be other Universities but may be specialist software development teams working in concert with skilled educators — in the same country or overseas. Indeed, these technological developments may provide the most effective means yet to forge a practical association between individual discipline and educational experts.

Networking

Arguably the short to medium term future for CAL delivery is the World Wide Web. This environment offers cross platform support, allows for full networking and all the benefits that flow from that (managing corrections, upgrades, access, *etc*.). Whether this networking is campus restricted or supports off campus access is a local issue. It is however inevitable that WWW sites will emerge that offer excellent, high quality, technologically advanced, educational resource material.

Individual academics responsible for course development may feel justified in ignoring these exciting technologies, but it is doubtful that students in search of quality education will be so inclined.

The use and benefits of computer mediated learning in teaching biology

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Fred Pamula is interested in understanding the molecular mechanisms behind development of organisms. His other interests include understanding how students learn and how computers can be used to facilitate learning. Much of the literature on this subject suggests that there are only modest gains in using computers in teaching. Fred thinks that the major factor behind this lack of success is that the software used to write multimedia is at a primitive state of development. At present he is co-ordinator of the Computer Mediated Learning Unit in the Faculty of Science and Engineering at the Flinders University of South Australia.

Introduction

Of increasing concern among higher education institutions is the problem of maintaining the quality of education in the face of increased student numbers and continuing funding cuts. These concerns, coupled with the advent of readily accessible and relatively cost effective computer technology, has seen a marked increase in the use of computer-based education delivery systems in universities. Much debate now centres on how effective and beneficial computer-based learning (CBL) is, particularly with respect to learning and cognitive processes (Brown *et al*. 1989; Rowe 1993), student performance (Mevarech *et al*. 1991; Stewell and Delpierre 1992; Blackmore and Britt 1993; Mevarech 1993; Chambers *et al*. 1995), gender and age related performance (Massoud 1991; Lee 1993; Colley *et al*. 1994; Dyck and Smither 1994) and software design and mode of delivery (Ahern 1993; Jackson *et al*. 1993; Rowe 1993; Chambers *et al*. 1995). Addressing these questions is difficult due to a lack of published data and because comparisons of student performance are difficult given the highly diverse ways in which CBL is approached, implemented and evaluated.

One area to which CBL readily lends itself is the use of computer simulations in practical or laboratory teaching. Laboratory classes aim to teach students principles of experimental design, data collection, data processing as well as the correct usage of commonly used laboratory equipment. The application of computer simulations can be beneficial if (i) the costs of running a particular experiment are prohibitive (ii) time constraints apply *e.g.,* growth or breeding experiments (iii) ethical or humane considerations are involved *e.g.,* experiments involving euthanasia of large numbers of animals (iv) it is difficult to observe or manipulate the phenomenon under consideration *e.g.,* nutrient cycling in a plant community (v) it is important that students are familiar with a piece of equipment or procedure prior to undertaking an experiment *e.g.,* familiarity with the use of a spectrophotometer (vi) rapid and efficient feedback on a students understanding of the subject material is desirable (vii) the experiments are technically demanding (ix) require the use of dangerous or radioactive compounds. This talk will be primarily on the use of computer simulations in biology but I will talk about laboratory marking programs and tutorial assessment programs.

Spectrophotometry Simulation

The spectrophotometry simulation takes a novel approach to teaching the concepts of spectrophotometry since it provides a tutorial on the spectrophotometer, simulates experimental data and assesses the student's processing of the data. The program has several parts. An introductory section presents instructions on how to proceed through the exercise. The sections that follow introduce the properties of light, the spectrophotometer, the Beer-Lambert law and finally the alcohol dehydrogenase assay which is used in the simulation. After reading through the tutorial, the student proceeds with the simulation and is asked to calculate the blood alcohol concentration for five patients using the Beer-Lambert law. The simulation presents the absorbances and the assay incubation time for the five patients measured using the alcohol dehydrogenase assay. The assay absorbance and sample volume are randomly generated, the absorbance ranges from 0.05 to 0.40 while the sample volume from 4 to 20 μl. The student's calculations are assessed by the program.

Advantages to the student

The delivery of content is consistent between classes because the human factor is largely removed from delivery of the material. Students can work through the material at their own pace, which is an advantage given that students have varying backgrounds and therefore the rate with which they acquire concepts varies from student to student. The background information provided in the computer simulations is designed to facilitate understanding of the simulation and often this is not the case when students are required to prepare for traditional experiments. More background information can be presented in a computer simulation than is possible in a traditional practical exercise and its presentation and delivery can be of a much higher standard because it is possible to use graphic images and animations to show dynamic processes. Interest in an exercise can be maintained by the judicious use of graphics and animations, which is usually not possible for traditional experiments. Students get immediate feedback as they progress through the exercise which is in marked contrast to traditional laboratory work. Although students have rostered computer sessions, they have fairly wide access to the computer suite so they can return to the programs when it is most convenient for them.

Advantages to the assessor

Assessment is more equitable and thorough as it is no longer subjective since the computer program follows well defined rules that are known at the outset of the exercise by the student and applied equally. Once a problem has been identified the student can seek help from the program or the tutor. The assessor is able to keep track of responses to individual questions thus evaluating any difficulties that students may be having with the material. Class results are easily and readily incorporated into a spreadsheet program thus saving time and costs in data entry. There are considerable savings in personnel costs associated with marking the simulations (especially in marking calculations) and the assessor is liberated of the tedium of marking.

Disadvantages

Of course as with all forms of teaching there are advantages and disadvantages. There are two important disadvantages (i) students forego valuable exposure to a laboratory environment and (ii) students are not exposed to preparing for experiments and performing the experiment. To offset this, it should be remembered that many students develop a disliking for experimental work because the experiments often do not work correctly. Although we have developed many simulation, it would be unwise to advocate the complete replacement of laboratory experiments with computer simulations because biology is an experimental science and as such the acquisition of skills in working in a laboratory is crucial.

Results

In our first year biology course we alternate between a wet and a dry practical exercise throughout the year. For some of the exercises (Table 1) the introduction of computer simulations has seen an improvement in grades (Spectrophotometry) and others a worsening of grades (DNA melting point).

Program	1993	1994
Spectrophotometry	74.6 (n = 245)	98.1 (n = 303)
DNA melting point	79.7 (n = 254)	74.3 (n = 304)
Genetics	77.8 (n = 250)	84.4 (n = 306)
Bacterial growth curve	68.7 (n = 233)	68.6 (n = 260)

Table 1. Mean final student marks for the four exercises in 1993 and 1994.

Fungicide Resistance Simulation

One of the great problems facing farmers and horticulturists is the management of fungicide resistance genes in populations of fungal pathogens. The understanding of this problem requires consideration of the ecology (epidemiology) of the fungus and the population genetics of the resistance genes. This computer simulation is intended to give the student insight into the population biology of the evolution of fungicide resistance by single gene mutations that give resistance to a specific fungicide. The student is able to vary the magnitudes of several parameters of the fungal population and the properties of the fungicide resistant mutant. This computer simulation was written because it is impossible to perform this kind of experiment in class.

Laboratory Marking Programs

Laboratory courses are very expensive to stage, not only in materials and equipment, but also in the personnel required to manage and assess them. A typical laboratory exercise requires students to collect, process and analyse experimental data. Unfortunately, the analysis of data by students is often flawed because the processing of experimental data is carried out in an unsatisfactory manner. To address the deficiencies outlined above, interactive computer programs were written to provide accurate and immediate feedback to students while they are processing experimental data. This approach was implemented in several laboratory exercise:

- Introductory exercise
- Glycolysis and fermentation of grape juice
- Induction of β-galactosidase in *Escherichia coli*
- Water relations in plants
- Genetics
- Purification of acid phosphatase

Although the steps involved in performing calculations from the observed and supplied parameters require only simple arithmetic operations, it has been our experience that a large proportion of students in second year classes encounter great difficulty in carrying out this process. This fact, combined with the relative simplicity of the calculations and the large class size (up to 200 students), meant that this laboratory exercise lent itself to a computer-aided learning approach. Students have unrestricted use of the computer program until the deadline for submission, which is usually two weeks after the laboratory exercise has been completed. At the end of this period, laboratory notebooks are collected and each student's data analysis is assessed while the student's computer record is used to assess the data processing component of the exercise. Assessment of this laboratory exercise is in two parts: (i) proficiency and accuracy in processing data and (ii) integrating and understanding experimental results. The two sections are weighted equally and passing grades are required in each section to get an overall passing grade for the exercise.

Advantages to the student

Breaking down a calculation into its steps guides a student through the calculation and promotes identification and remediation of errors. The program's interface requires the student to enter all data and answers to one group of calculations into a single data entry screen. In this way any inconsistencies in the calculations can be easily identified by the student with the aid of the program. Data entry screens facilitate editing so that any errors can easily be corrected. If errors are made, the student can make the appropriate corrections and have the work marked again. Enabling students to correct their work in this way encourages them to work at their own pace and strive for competency with the material.

On-line help is available, with textual and diagrammatic outlines of concepts required to solve a problem. Wherever possible, graphic images are used to illustrate textural explanations. Providing help in this way allows detailed explanations to be presented to the student without showing exactly how calculations are performed. If this assistance is not sufficient then students have recourse to tutors.

Advantages to the assessor

There are considerable savings in personnel costs associated with marking laboratory calculations using computer programs. The student record file can be retrieved directly into a spreadsheet program with minimal effort. The assessor is liberated from much of the tedium of marking laboratory notebooks and the quality of marking is made much more consistent and thorough.

The computer program has been written so that the assessor has access to the results generated by the program. This has two benefits: it allows rapid identification of the source of a student's error and it allows for quick and efficient spot checks of submitted laboratory notebooks. Being able to see the answers generated by the computer program when a student is having problems with a calculation enables rapid isolation of the source of the student's problem and to confirm whether the student has problems with other parts of the work.

Results

Although the approach outlined above has been successfully applied to several laboratory exercises at second year, the one we have most complete data is the exercise that explores the induction of β-galactosidase in *Escherichia coli*. Computer based assessment was first introduced for this exercise in 1993 but was not compulsory. The results (Table 2) show that students using the computer program scored much higher grades (81 %) than those assessed by tutors (66 %). In 1994 computer based assessment was compulsory for all students and the mark due to computer assessment was 94.6 % while the overall mark was 82.3 % (Table 2). The overall mark for the exercise was weighted equally between computer assessment and data analysis in 1994. The mark due to computer assessment for 1993 and 1994 was 76 and 94.6 % respectively. An analysis of the data was performed to determine if the results were biased towards males or females. In 1994, there were 63 female and 68 male students in the class and there does not appear to be any difference in the mark obtained by males and females either by computer assessment or overall (Table 2). The results also show that students spend about 5 hours using the computer marking program (Table 2). We estimate that they spend about an equal amount of time working on their calculations away from the program. If this estimate is correct students spend about 2.5 hours working on their calculations for every 3 hours practical session. Finally, about 84 % of student achieve grades of 91—100 % for their calculations (Table 3).

Parameters	1993 A	1993 B	1994 M	1994 F	1994	1995
Class size	128	33	68	63	131	169
Time spent (min)	—	—	—	—	—	209
Program usage range	—	1—18	1—16	1—14	1—16	1—16
Program usage	—	4.85	6.18	6.60	6.38	7.44
Program mark range (%)	—	16—100	39—100	24—100	0—100	0—100
Program mean mark (%)	—	76	94.4	94.9	94.6	94.8
Final mean mark (%)	66	81	81.4	83.3	82.3	83.0

Table 2. Grades achieved in the "Enzyme Induction in *Escherichia coli*" exercise in 1993-1995. In 1993 the use of the marking program was optional so the results are separated into hand marked (1993A) and computer marked (1993B). The final mark consists of the results from computer marking (if any) and the analysis of experimental data (from the laboratory note book). The columns 1994M and 1994F represent the 1994 data separated into male and female students, respectively. In 1994 the results also show the mean time students spent using the computer program.

Mark range (%)	Number of Students	%	Mark range (%)	Number of Students	%
0 — 10	0	0.0	51 — 60	3	2.3
11 — 20	0	0.0	61 — 70	3	2.3
21 — 30	2	1.5	71 — 80	3	2.3
31 — 40	1	0.8	81 — 90	9	6.9
41 — 50	0	0.0	91 — 100	110	84.0

Table 3. Frequency distribution of student marks in 1994 achieved in the computer assessed component of the exercise. The number of students and percentage of the class are given next to each mark range.

Tutorial Exercises Assessment

To gain proficiency in statistics it is necessary to apply the knowledge learnt in lectures to real problems. This has traditionally been done during tutorials but it has become more and more difficult to cope with large classes and the lack of motivation of students. To force student to work through the tutorials it was decided to grade them and these grades counted to the final assessment. In order to assess tutorial papers it was necessary to automate the assessment. To this end the preparation of unique tutorial questions and assessment was taken over by computer programs.

Program design

There are four components to the design. (i) generate test and sample data sets (ii) printing and distribution (iii) answer entry and (iv) assessment and posting of results. These points will be discussed in more detail below.

- A sample data set, questions and answers is prepared and distributed to students.
- A test data set which must be unique for each student, a common set of question is also distributed to each student.
- When students have completed their work they enter their answers into a program that records their answers. This program must place a time limit on data entry to discourage students from using valuable computer time in calculating their answers and prevent students trying to re-enter their work.
- After the deadline, the results file must be collected and processed and student results posted.

Results

Grades have improved since the introduction of graded tutorial exercises (Table 4) even though grades for the tutorial exercise represent a small part of the years work

Year	Enrolled	Passing	Pass rate (%)
1991	120	82	68
1992	191	106	55
1993	187	169	90
1994	137	118	86

Table 4. Final grades since 1991 in teaching statistics in biology. In 1993 computer assessment of tutorial work was introduced.

Summary

I have presented three strategies that have been developed to improve student learning outcomes in teaching undergraduate biology: computer simulations, laboratory and tutorial marking programs. Computer simulations that assess student work are used specifically in first year biology. Laboratory and tutorial marking programs are used exclusively in second year. In third year the use of software is more limited because we find it is not always economical to write the programs ourselves.

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Escuela Practica: an introduction to vegetation sampling using computer simulation

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Introduction

The fact that vegetation varies from location to location and with time is common knowledge. The description of this spatial and temporal variation, or pattern, is a prelude to seeking an ecological explanation for the observed variation. It is essential, therefore, that students in ecology receive a grounding in the methods used to describe vegetation.

The elements of vegetation description are outlined in any of the large number of available standard texts (*e.g.,* Greig-Smith 1983; Causton 1988). These elements include sampling design, measures of plant abundance, type of distribution, identification of association between species, and the scale of any observed pattern.

Prior to 1987 third year plant ecology students at The University of Western Australia were given their introduction to the methods of vegetation description in the field. A set of four artificial populations were occasionally used in the laboratory, principally when the weather was too wet for field work, to illustrate the effects of plant distribution and quadrat size on estimates of frequency and density. It was found that these exercises offered several advantages over conventional field work. Compared with the field work they could be completed relatively quickly; the students did not have to cope with problems of species identification; and, because they were able to compare their sample estimates with the known parameters of the artificial populations they had greater confidence in the methods being demonstrated.

In 1987 the four artificial populations were designated as separate species and combined into a single map. To introduce more variation additional species exhibiting a range of distributions (random, clumped and regular) and associations (positive, independent, and negative) were added. In an attempt at further realism separate overlays were generated containing information representing soil type and topography. Students were now able to investigate not only aspects of vegetation description but the next ecological step of how the discovered species patterns might be related to abiotic factors of the environment. An Apple University Development Fund award in 1990 of $3000 enabled the transfer of the map information to the Macintosh microcomputer format.

EcoMap Software

The vegetation and environmental information is represented in the computer as a mythical reserve, *Escuela Practica* (from the Spanish *Escuela* = School and *Practica* = Practical). Four files make up this data representing, respectively, the species symbols, their coordinates, the soil type and topographical elevations.

The application to run *Escuela Practica* is EcoMap, a software package written in Pascal† . EcoMap is believed to run on all Macintosh microcomputers from the MacPlus upwards using System 6.0.3 or later and Finder 6.1.3 or later. It can be run from a floppy disk, is faster from a hard disk but once loaded no further use of the disk is required. Memory requirements are less than 200K of RAM. Currently the software has to be installed on individual machines. At present the software will not run on PC-compatibles.

Once the data files have been loaded the main Map window appears showing a portion of the *Escuela Practica* Reserve. Location of the observer (the cursor) is indicated by coordinates on the top and left screen margins. Two other optional windows are available. The Key window provides a legend of the species symbols while a floating Measure window allows distances between points to be measured on the screen.

Laboratory Use

Escuela Practica currently comprises 12 species (max is 20). The 10 species forming the understorey are represented by small geometric shapes, the two tree species and their respective canopies by circles. Students are encouraged to begin their investigation as they would in the field, by carrying out a simple reconnaissance. In this phase they are expected to 'stroll' through the Reserve using the scrolling controls and note any obvious patterns in species distributions, the relative abundances of the species and their association with environmental features. This scrolling feature offers a major improvement over the original paper version as it is no longer possible for students to see all the Reserve at once, just as would apply in the normal field situation. Impressions gained during the reconnaissance can be checked against results obtained during the later detailed sampling.

The reconnaissance phase is followed by a series of exercises aimed at developing a more complete description of *Escuela Practica's* vegetation and environment. Vegetation sampling is possible using plot or plotless methods. Plot methods involve placement of sampling units (quadrats or transects) of some specified size and shape. In the *Escuela Practica* simulation, the quadrats (max 20) can be square (the default option), rectangular, circular or oval. Quadrat shape and size are selected from dialogue boxes under the Sampling menu. Belt transects are located and sized using the rectangular quadrat command. A separate option is available for locating line transects. Apart from the line transects all plot samples are positioned with their sides parallel to the Reserve boundaries. Quadrats that happen to be inadvertently positioned too close to the Reserve boundaries will be 'flipped' over so as to fit within the Reserve.

Plotless methods involve selection of one or more individuals from, usually, a series of randomly selected points. Distances between the selected individuals and sampling points will also be measured using the Measure device. In practice the easiest way to set up the sampling points is to position a series of line transects across the Reserve and position the sampling points randomly along these lines.

The Instructor's Manual which accompanies the *Escuela Practica* simulation presents a series of basic exercises for students to complete. These include the relationship between plot size and species richness (for species-area curves); estimating the density and frequency of each species and the effect of quadrat size on these estimates; and determination of plant distribution type.

A second group of exercises explore possible relationships, for example, whether there is any association between the tree species and understorey species; the relationship of tree biomass and distance between nearest neighbours; and between tree diameter and canopy cover.

Two of the included plant genera have simulated mosaic distributions. The scale of these mosaics is estimated using the block-size analysis of variance approach of Greig-Smith (1952).

While some of the statistical implications of the various sampling procedures are covered in the Instructor's Manual, supplementary exercises are given to the students to develop their experience in the use of basic univariate and bivariate statistical methods, both parametric and non-parametric. The same exercises are also used to introduce students to graphing procedures, spreadsheets and word processing. Selected exercises are written up as a formal assignment for marking.

Current Use and further Development

Consideration was given during the writing of EcoMap to having the exercise data recorded automatically but costs precluded this option. At present all data are recorded manually by the students and then entered into the appropriate software application. While there would be savings in time with automatic recording it is believed that, despite availability of hand held microcomputers, the manual system is still more like the field situation in which most students will find themselves later working.

The availability of present day colour monitors offers potential for some further innovations, for example, subjective estimations of plant abundances in the field can be influenced by whether or not particular species are flowering.

Student response to *Escuela Practica* over the six years it has been used at The University of Western Australia has been positive. Students with little familiarity of microcomputers seem especially to benefit because of the multiplicity of ancillary software applications they are introduced to as part of the overall exercise. However, it has been found important to match students based on their familiarity with microcomputers otherwise the more experienced tend to take over.

In 1995 the Department of Geography at The University of Melbourne introduced *Escuela Practica* into its first year teaching program. Exercises successfully used were the introductory ones on species area curves and quadrat sampling. Further extension of the use of *Escuela Practica* is likely to be dependent upon producing a PC version of the EcoMap software and plans are in hand to do this over the next 12 months.

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† EcoMap was written by Dr M Wheatley, currently at the UWA Development Unit for Instructional Technology. The concept and data for *Escuela Practica* were developed by Associate Professor David T. Bell and the author.

Dry labs in biochemistry departments

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A number of issues in the use of computer-based 'dry' labs were raised and discussed in the plenary session. In this session the focus was moved to discussion of examples and how they have been integrated into laboratory courses. Examples of applications of 'dry' labs were outlined in the areas of pre-practical preparation, data handling and calculations, and combined 'wet' practical and computer simulation. Categorising examples proved to be difficult, given that many examples cover more than one of these areas, or may be applied in different ways either before, during or after practical sessions.. A simulation of protein purification (Booth 1987) was demonstrated, and its use in classes and assessment of outcomes and educational value were discussed. The session concluded with general discussion about appropriateness of various activities and issues involved in implementation.

Assistance with pre-practical preparation

Lack of preparedness of students is a common problem in laboratory courses. Computer-based simulations of experiments have been applied to assist students to prepare for practical work by helping them become familiar with conceptual and numerical aspects of practicals, before coming to the laboratory. In this context I have used a simulation of protein purification (Booth 1987) as outlined below. Another example of this approach may be found in a practical involving estimation of the K_m of b galactosidase (Jones *et al.* 1985). Programs that simulate the operation of equipment such as spectrophotometers, HPLC or NMR instrumentation may be used prior to practical classes for training in equipment use.

Assistance with calculations and data manipulation

Computer programs have been devised to assist in laboratory calculations including general laboratory calculations, buffers, radioactivity and spectrophotometry (Carrington 1993, Pamula 1994, Wiseman *et al.* 1995). Other programs have been used to aid students with calculations integral to manipulation and analysis of data obtained at the bench. Examples include an experiment on induction of b galactosidase in *E. coli* (Pamula 1995) and estimation of the K_m of b galactosidase (Jones *et al.* 1985). These programs emphasise the correct processing and analysis of data, which enhances understanding and interpretation and assists students to draw valid conclusions from their data. In my second year science biochemistry practical classes, I have adopted a combined wet bench practical and computer program package investigating glycolysis and fermentation of grape juice (Pamula and Wheldrake 1994). I found that this exercise provides my students with a useful guide to completing calculations in the context of a real practical situation. Helping students break down calculations into their constituent steps and providing immediate feedback helps address a common problem in biochemistry practical work.

Simulated data acquisition and experiments

Experiments are often simulated because they are too dangerous, prohibitively expensive, too complex or lengthy to carry out in limited practical timetables, or involve procedures that are extremely difficult or impossible for students to perform using available equipment (*e.g.,* rapid reaction kinetics to monitor changes in the concentrations of reaction intermediates). More recently, experiments have been simulated for educational reasons, for example separately addressing the differing objectives of acquisition and analysis of data. The most common approach is to simulate entire experiments or biological processes, for example oxidative phosphorylation (Day *et al.* 1996), investigation of osmosis using red blood cells (Fyfe and Fyfe 1996) and investigation of metabolic pathways in microorganisms (Jenkins and Cartledge 1995). I have participated in development and use of programs that simulate experimental data including effects of environment on enzyme activity, analysis of enzymic reaction intermediates, and binding of oxygen to haemoglobin (Learmonth *et al.* 1988; Sawyer 1972). There are many examples of programs that deal with enzyme kinetics, available either commercially or in the public domain, although many address theoretical rather than practical aspects. Another approach is to combine a 'wet' practical with computer based data simulation, to extend analysis to areas that cannot be covered in a practical session. An example of this approach is investigation of flux through metabolic pathways in a practical on synthesis of urea in isolated hepatocytes (Bender 1986).

Computer-based data acquisition

There has much activity interfacing computers with laboratory equipment, with many research instruments now computer-controlled. There are relatively few examples specifically designed with teaching in mind, however (Learmonth 1995). Examples include experimental data acquisition from oxygen-sensitive electrodes (Learmonth 1987) and spectrophotometers (Titheridge *et al.* 1995).

Simulation of preparative and analytical procedures

The logic, organisation and problem solving aspects of preparative and analytical procedures may be treated separately from the technical aspects by use of computer simulation. Combined with separate training in the actual techniques, these programs may be used as "dry runs" to prepare students for the real work, or to extend instruction to procedures not possible for students to perform. Examples of programs in this category include subcellular fractionation and centrifugation (Smith 1988), protein purification (Booth 1987), protein sequencing (Havlicek and Towns 1979; Place and Schmidt 1988; Vuento and Vihinen-Ranta 1994), gene cloning and sequencing (Smith and Hames 1989) and chromatography (Dramer and Kaars 1987).

A case study — how 'dry' laboratory activities have been integrated into a 'wet' laboratory course

In my third year science biochemistry course, about half of the semester's practical sessions are devoted to purification and analysis of proteins. The practical course begins with a tutorial on protein purification and analysis, based largely on chapter 5 of the text by Voet and Voet (1995). The theory behind the techniques as well as practical aspects are discussed in the tutorial. In the second session, students explore schemes to purify proteins using a computer simulation (Booth 1987). Students had prior exposure to a number of the techniques simulated (*e.g.,* gel filtration, ion exchange chromatography, electrophoresis) in practical sessions in first and second year. In the third session, students revise and practise the estimation of protein concentration and enzyme activity, so that they are better prepared to analyse the fractions produced by various preparative procedures. The final four sessions are devoted to purification and analysis of an enzyme from plant leaves.

I have found this to be a most effective approach to prepare students for a reasonably complicated preparative procedure. I developed this approach in response to problems caused by students being ill prepared for the work at hand. Using the computer simulation, students can make mistakes without costing them days of work. In addition, when they come to the real laboratory work, they have a better idea of what they are trying to do and don't blindly follow recipes given in the practical notes. The whole exercise becomes much more successful and rewarding for the students. It has certainly reduced the number of blunders and conceptual errors that have resulted in the loss of proteins that took weeks to prepare. In future I intend to improve the exercise by condensing sessions devoted to purification and analysis of the enzyme into a two day workshop, to reflect the way it would be done in a professional laboratory.

Conclusions

In conclusion I consider that computer-based exercises can be, and are being successfully used to make our teaching more effective by supplementation and limited replacement of 'wet' laboratory activities. I have found that this works for material developed in-house, and also for material developed elsewhere. Getting over the "not invented here" syndrome can be a major obstacle to the widespread use of computer programs. My view is similar to that about adopting textbooks. Generally we are prepared to accommodate some faults or things we don't like, communicating changes to students. I believe we need to treat computer software in the same way. Most progress will be made in addressing common introductory courses, where local variations can be minimised. It would likely be beneficial to produce materials by consortia of Universities/groups, leading to advantages such as expansion of the feeling of ownership. This does not necessarily imply a high overhead, but can work with collaboration among a network of interested groups or individuals which may extend internationally (Learmonth 1994). A number of biochemistry departments in Australasia are already producing materials, and in 1991, a booklet compiling software use was compiled by the Biochemical Education SIG of the ASBMB (Towns *et al.* 1991). The issues surrounding the use of computers in biochemical education have been given a high profile at annual meetings, and computer-based practicals have been specifically addressed (*e.g.,* Dawson 1992).

Finally, discussions during the workshop identified laboratory courses with up to 50% 'dry' lab sessions. This seems to me to provide an acceptable balance, if the activities are well integrated. There is also great potential to combine 'dry' and 'wet' activities in the same session. Implementation of computer based 'dry' labs has come under much scrutiny, which traditional 'wet' courses seem to have evaded. Reassessment of our practical courses seems to be in order, and 'dry' activities may be applied to address some of the problems we have with current courses.

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From overhead projection to effective interactive learning software for science students

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Summary

Small, simple, highly interactive software modules have been developed to help science students surmount some of the main barriers for effective learning (as experienced in traditional lecture-based teaching): lack of motivation, lack of rapid and specific feedback, lack of interaction with the learning material, and lack of the opportunity to apply newly acquired knowledge.

These modules are different to other multimedia materials currently available in that:

- they will allow students to progressively test their assumptions and further their understanding of scientific concepts. Students will develop not only conceptual understanding but also problem-solving skills;
- the use of academics as software developers means that the modules can be easily changed in response to student needs and feedback;
- students' progress and difficulties can be tracked and students will be able to record comments while using the modules. Tracking and students' comments will allow teachers to discover areas of difficulty which can be addressed through small group work and also provide for a continuous cycle of development, use and evaluation;
- the modular construction makes sections of the program interchangeable between disciplines and allows academic staff to build courses by drawing on small modules of relevant content instead of large blocks of content comprising significant amounts of irrelevant material.

Current learning situation

In many universities, science teaching is based on traditional lecturing with end of semester examinations. Usually this results in students being preoccupied with note taking in lectures rather than reflecting on the content. Proper interaction with the material and intensive studying often does not occur until the examination period. Typically students study a large quantity of material at the end of semester resulting in shallow learning with low retention, poor problem solving skills, and unsatisfactory conceptual understanding.

Changes initiated with the use of interactive software modules

Use of software modules

Science courses at Murdoch University have also generally followed this traditional pattern, but in 1995 an attempt to change this was begun in third year Biotechnology with the transformation of about 10 lectures into highly interactive software modules. In the initial phases of this pilot project students downloaded the modules onto floppy disks and worked through the material as a supplement to the lectures, either at home (80%) or in the university's computer laboratory (20%). Student feedback indicated that they found the material more exciting than lecture presentations and more effective for their learning as they had "time to think about the material and understand it". Following this positive feedback it was decided to replace three lectures completely with the interactive software modules. Built-in progress tracking indicated that 48 out of 50 students worked through these lecture-replacement modules, successfully completing the randomly-generated problems which had been designed to help them progressively develop and apply the concepts on which the lecture would have focussed. Again, students reported perceptions of having learnt more effectively than they did as a result of lectures.

Expected outcomes of including teacher-designed highly interactive software modules in science teaching

Typically, in lectures students are passive, they are not provided with the opportunity to apply concepts as they are being developed or receive feedback on these, and are not well catered for as individual learners. By contrast, as indicated through student response to the modules produced thus far, it is expected that the use of the interactive software modules described will achieve the following learning outcomes:

- *Immediate feedback leading to enhanced learning*: Each module is capable of providing students with immediate feedback in much the same manner as that provided by one-on-one tutoring. Although feedback itself is not sufficient for the development of understanding, feedback that relates to the testing out of assumptions or application of knowledge to a problem is critical to deep learning and is the objective of many good laboratory classes.
- *Problem-solving skills*: The software modules specifically require students to adopt a problem-solving approach when dealing with scientific concepts. In line with adult learning principles students will have to construct their own understandings by referring to both their existing knowledge and the new information presented at each stage of a module. Individual differences in understanding and progress can be catered for because students will be able to work through the modules at their own pace and choose their own learning pathway.
- *Increased motivation and retention*: The modules actively engage students in the exploration of scientific concepts in a way that student involved in the pilot project have described as stimulating and motivating. In progressing through each module they test and become aware of their developing conceptual knowledge and feel rewarded through the visible indication of their progress towards understanding. Motivation is a key factor in learning and retention.

Other possible benefits of teacher designed software modules

- It will reduce the time that teachers need to spent on assessment tasks because of the automated tracking of students' advancements in the modules. This time can be used more effectively in additional student/teacher interactions (*e.g.,* small group teaching). The use of problem solving program modules has been found to result in students being eager to obtain information needed to complete the modules.
- Program can effectively prepare all students for laboratory classes (if attending the lab is subject to having reached a certain level of skill or understanding in the program).
- Fast upgrading, trouble shooting, debugging and accommodating students input. As the teacher is also the developer, the program can be modified instantly upon students' requirements. This is more difficult with traditional multimedia projects (CD-ROM, developer team , *etc.*).

• The authoring of program modules engages the teacher in educational theory and stimulates the teacher to think of students possible misconceptions (*e.g.,* in the design of feedback to incorrect answers) which can be more intellectually rewarding than repeating lectures year after year.

Steps from overhead projections to developing interactive teaching software

Use of computer presentation software

To prevent students from being preoccupied with copying notes, computer generated presentations (*e.g.,* PowerPoint) were used in lectures and copies of all slides provided in the study guide. While this helped students to focus on the content of the lecture, it did not cater for a number of additional students needs such as: individual pacing, building up simple slides to complex graphical diagrams and minimising interference (distraction).

Use of self-paced presentations

It was decided to convert some of the conceptually more challenging presentations onto a platform that allowed the students to view the material at their own pace, either at home or at university computer facilities. *Authorware Professional* was chosen as one of the most user friendly authoring tools for "non programmers". The first attempts with this software resulted in linear paging programs (electronic book) that were clearly analog to the lecture presentations. Students could move from screen to screen by clicking a "Continue" button. This clearly offered students a self-paced approach and the possibility to view the material at the time of their choice. However, after preliminary tests with students, this material was found to be unsuccessful in enhancing students' learning as many students viewed the material relatively superficially, and "skipped from screen to screen in the hope to come across something exciting". It was perceived that this way of passively viewing information had no benefit over the use of lectures or books as the medium. The inclusion of branched pathways and "jumping" to other parts of the program (hypertext links) did not appear to address this problem.

Omitting continue button

In order to force students to take full notice of what is presented on each screen the standard "Continue" button was omitted and replaced by a hidden "Hot spot" on the screen. In the development of graphical representations of biochemical chain reactions the explanatory text on the screen (equivalent to the lecturer's comments) asks students (by using coloured text) to point to a particular part of the diagram. Correct pointing (hitting the hidden hot spot) results in the further development of the diagram while incorrect pointing can trigger a specific explanatory feedback. This relatively small change improved the effect of the program as it allowed only those students that read the comment, reflected about its meaning, and could relate it to the diagram to advance at a reasonable pace. The completion of sentences, the calculation of simple numerical problems and the positioning of items to specific locations were used in much the same way. In comparison with lectures, students can only advance further in this presentation, when they "follow" the train of thought of the author. This could be particularly useful as a replacement of pre-laboratory talks.

Students assisting in the development of the "presentation"

While the approach described above asks the students to follow and to act during the presentation of material, it did not necessarily require them to reflect in more depth and detail on the material. In more recent program modules it was attempted to use the computer program analog to a one-on-one tutoring situation.

After providing students with a little information pertaining to the target concept, the program requires them to test their assumptions about the next logical step by suggesting what this step would be by either keying in a word or numerical answer, plotting a point on a graph, moving an object to a correct position, making a sequence of choices or adjusting parameters in a process simulation. Following a student's response, the student is given different feedback by the program, depending upon whether the response was appropriate or not. If students choose an answer within the range of possible correct answers, they are presented with a new problem that tests their assumptions and challenges them to work out the next logical step in the argument. If the answer chosen is incorrect they are provided with further information that hints at other aspects they need to consider in order to solve the problem or directs them to additional resources within (different module or level) or outside (tutor, textbook, *etc.*) the program. Students learn from the instant feedback to their actions similar to a laboratory situation. It is hoped (but not evaluated yet) that this way of helping to construct knowledge gives the student the feeling of owning some of the knowledge rather than "being filled with knowledge". One of the aims behind using this approach is to include a constructivist approach of student centred learning. Future programs are planned to include further aspects of the constructivist theory (*e.g.,* students decide on which modules they use to obtain tools needed to solve particular problems).

Advancing by problem solving

A simple (in terms of authoring skills needed) but very effective way (judged from students feedback) to develop particular skills in students turned out to be the use quizzes. For example, students learn about the oxidation states of carbon in organic compounds. The students are asked for example "What is the oxidation state of carbon in methanol?". A correct answer results in the increase of a visible numerical counter and in a the display of a new compound structure to be analysed. If the wrong answer is given, the student is asked to "Please consider the oxidation state of oxygen (-2) and hydrogen (+1) and the fact that the total oxidation state of this uncharged molecule must be 0". Again the main learning effect is by learning from feedback to mistakes, quite similar to laboratory experiments. It was observed that students are more interested in pieces of information when they first have experienced the need for it. After having achieved say 10 correct answers students obtain a "token" (bonus point) that certifies mastering of a certain set of skills. After developing and fostering different skills in this way, students obtain the tools to solve more comprehensive problems (for example establishing the mass balance of bacterial fermentation processes).

Including a Game Component

The use of tokens or similar rewards was demanded by students after working through a program module without a visible reward at the end. However, it was observed that some students still preferred to guess the correct answers and were not fully focused on "getting it right". By contrast the same persons could be seen very concentrated, focused and aroused when playing commercial computer games. It was attempted to somehow draw on some of the obvious energy that computer games manage to mobilise from within the user. Realising that the obvious fascination with many computer games is not exclusively to win bonus points but also the exposure to the stress of failing (*e.g.,* death, or dropping to a lower level as a punishment), a stress component was included in some parts of the program by requesting students to get 10 correct consecutive answers before a "token" is given. Mistakes result in the loss of all credit points (counter is set to zero). This inclusion of this educationally doubtful "negative conditioning" resulted in markedly higher levels of tension and arousal when students had reached 8 or 9 correct answers and did not want to lose these points by a careless answer. In computer labs they reflected more carefully about the answer and also consulted each other before keying in their answer. Compared to the situation in many lectures, this small change seemed to have students' internal energies focused on the learning objective.

Experiencing scientific laws and processes - relation to dry labs

With some experience (*e.g.,* three months) in developing simple program modules as described above, more complex modules could be developed that make use of some mathematical principles behind scientific laws and processes. For example in a module about the sedimentation velocity of particles, students manipulate the parameters of Stokes' Law and observe the effect of the manipulation on the outcome of a simulated process (*e.g.*, sinking velocity of a particle, Figure 1).

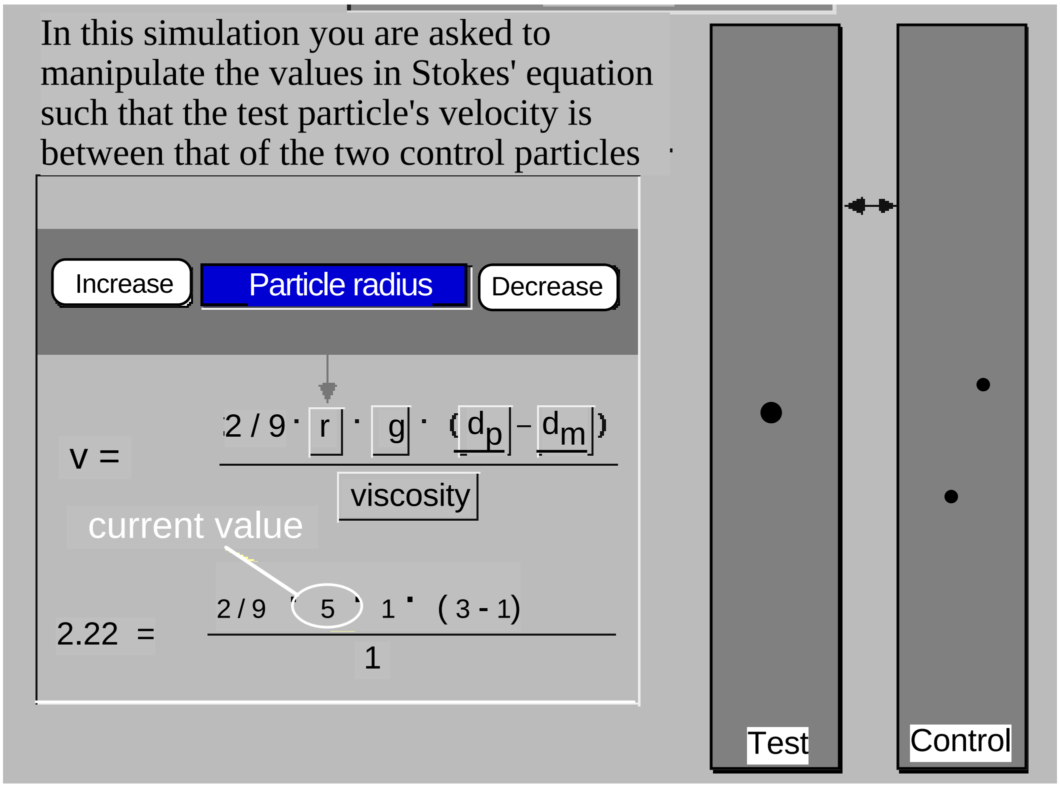

Figure 1. Part of the screen allowing students to interact with Stokes law (modifying variables in the law to adjust the sedimentation velocity of a particle to a certain level).

It was perceived that students should not only be given room to freely explore this principle but also be required to solve problems of significance in their subject area. Here, for example, the velocity of a particle had to be changed such that the movement of the particle on the screen fits certain criteria; for example:

the particle velocity reaching a certain value;

determination of viscosity from monitoring the settling velocity in different media;

adjustment of buoyancy and velocity of a planktonic alga by changing the algal floc size, lipid content *etc.*).

This approach encourages the understanding of the law by applying it. This is similar to the intent of typical laboratory classes. Although it is recognised that such simulations cannot replace the real world experience of experiments they offer a number of benefits in addition to lectures, tutorials and laboratory classes:

- active learning at their own pace;
- learning from feedback;
- effective tool to make sure students have achieved a certain level of experience or skill prior to laboratory classes (no more unprepared students?);

• possibility to allow students to interact with simulated processes that would be too time consuming, expensive or dangerous to run in the lab.

Student real time interaction with simulated industrial or laboratory processes

Other simulations developed engage the students in real time simulation of processes that are too difficult or expensive to run in laboratory classes. An example is the simulation of microbial oxygen uptake kinetics in a chemostat culture as a function of different variables such as the oxygen mass transfer coefficient of the aeration equipment, the air flow rate, the substrate concentration, the microbial kinetic parameters (k_M value, v_{max} value, endogenous respiration rate, oxygen half saturation constant , Figure 2).

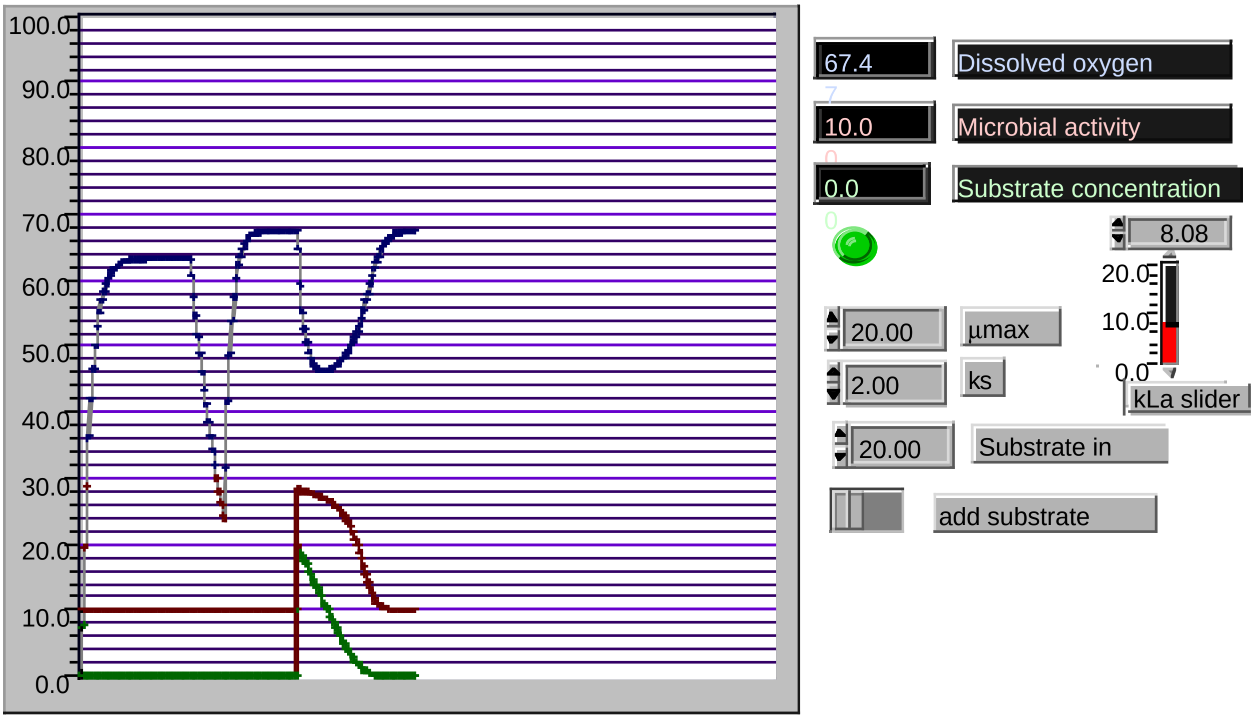

Figure 2. Part of the Screen (here shown in black and white only) of students process simulation (addition of substrate to a starving microbial culture, monitoring of oxygen and substrate concentration, and microbial activity).

For some of those simulations that display the current state of a process via a running graph other, faster authoring tools such as LabView had to be used†. A comprehensive simulation of such a bioprocess is given to students for investigation, analysis and evaluation. Students produce an assignment (each student works with a simulation that uses different sets of parameters) that can be easily marked by comparing with values in a programmed computer spreadsheet.

The simulation of a sophisticated bioprocess was used in combination with laboratory project work where students were exposed to the “nuts and bolts” of the bioprocess such as calibrating flow pumps, adjusting oxygen flow, aseptic sampling *etc.* As the simulation always guarantees a set of useful data for analysis and interpretation there is no necessity for the laboratory component to produce “good data” hence students can be allowed to work somewhat more freely and learn from their own mistakes.

† Example modules of such processes can be provided to interested teachers.

Multimedia preparation for first year chemistry and physics laboratories

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Introduction

'Wet' labs are used because chemistry and physics are experimental sciences. It is vital that students experience real laboratory situations and techniques. It is also important that they learn to work through a whole experimental problem — from aim to conclusion. It is also important, in view of their future employment tasks, that they learn to conduct practical work safely: that they deal with potentially hazardous situations such as handling hot containers, pouring real acid, mopping up spills, and coping with broken glass. It is found that much learning occurs in the laboratory — students comment that a particular point was not understood until they met it "hands-on" in the laboratory.

'Wet' labs are high cost facilities. A large cost is incurred in staff time — academic (including co-ordinators and demonstrators) and technical support staff. The laboratory building itself is usually specialised and represents a large capital expenditure. Equipment, including balances, glassware, and instruments, is another cost and the cost of consumables and waste disposal, especially in a chemistry laboratory, is high.

The 'wet' labs are only available to students for a short time each week (typically 2-3 hours), so it is vital that students make best use of them. To do this, the student needs to come to the lab prepared.

Many approaches to laboratory pre-instruction have been tried. In the absence of any formal pre-instruction program, it is found some students do prepare thoroughly (by reading the laboratory manual) while others do not (to the extent of not even knowing which experiment is scheduled). Written exercises are frequently used for laboratory preparation. These may be done hurriedly and in consultation with other students. Demonstrators may give an introduction during the laboratory class, but these have been found to be of variable quality and quantity. In attempting to address these issues we have developed audio-visual based laboratory pre-instruction material — a set of videotapes (physics) and an interactive multimedia CD-ROM (chemistry).

One advantage of centrally prepared material is that it gives a uniform starting point for all students undertaking the laboratory. It also may be prepared by experienced teachers, whereas the laboratory staff is often of variable experience and quality (experienced academics; new academics; post-docs; PhD, Masters and Honours students).

Physics videos

Videos were considered to be an appropriate technology for delivery of the physics pre-lab material, as video players are widely available (in the laboratory, in the library, at home) and most students are familiar with using videos. Unlike the laboratory manual, videos employ colour, sound and motion to give a more realistic presentation of the experimental methods and techniques. The video material produced also serves as a resource for future use, for example as digital video, on CD-ROM, or on the World-Wide Web.

Chemistry CD-ROMs

In chemistry, we have developed 'dry' labs pre-instruction using interactive multimedia, packaged on a CD ROM. These 'dry' labs provide practice in a safe environment by using simulated experiments and instruction in and demonstration of good techniques by video. The use of random data allows each student to do his or her "own" experiment. Successful completion of the 'dry' lab is necessary before lab entry.

It should be recognised that the time and cost in producing interactive multimedia materials are considerable. In our case, the design and production took 18 months. Many types of expertise are required: academic staff writing, materials, actors for video clips, camera persons, film editors, graphic artists, instructional designers, programmers, student reviewers (pre-cutting of CD), technical staff to prepare materials, voice-over persons for videos and simulations. An initial CAUT grant (Awarded 1992) of $39,000 covered some of the costs, but many additional costs were borne by the University: academic staff time, computer site expansion, computer supplement and upgrade, CD cutting-trial and final, evaluation and modifications, filming staff and filming materials, printing costs, software purchase, technical staff time. It is estimated that the total cost is about $100,000.

Evaluation of physics videos

Student surveys held in each of the first two years of the use of the videos yielded positive responses. Concerning production values, the videos were rated of appropriate length, good technical quality, relevant to the experiment, and helpful. The students thought the videos would increase their understanding of and performance in the experiment. As an overall appraisal, the students recommended the future use of the videos.

The performance of the student in an experiment in which s/he saw a video, relative to one in which s/he did not, was examined. The book mark, class mark and total mark were considered. The marks gained after viewing the videos were not statistically different to those gained without watching the videos.

Evaluation of chemistry CD-ROMs

Extensive evaluation of the CD-ROMs was undertaken, including an initial test/control trial, the completion of an evaluation instrument by each student for each pre-lab, observation of students in action, keeping a log book of problems, comparison of student performance on labs with and without interactive multimedia pre-labs, post-graduate student research, leading to enhanced awareness among Departmental staff of teaching /learning quality.

In response to an evaluation instrument, students indicated the CD-ROMs were easy to follow, adequate in covering all important points, good lab preparation, easy to understand, clear in explanation, user friendly, easy to get started, successful in making one confident about the lab, better than written pre-labs, better than demonstrator talk, easy to use, convenient to access.

Some comments from students are:

" I really feel I now know what to expect when I come to the lab"
"That was great — a wonderful use of modern technology"

“The CDs take a bit longer than the written pre-labs but are worth it!”
“ We want more!”
“I am going to blow up the computer lab and destroy the CDs so no unsuspecting first years can ever use them and go through the mental strain. Many of my closest friends are now in therapy”.

Comments from demonstrator:

“Group B asked more meaningful questions and generally seemed to have a better understanding of the experiment”.
(Unknown to the demonstrator Group B was the group that had completed the CD pre-lab.)

Conclusion

The production of videos interactive multimedia materials is costly and time consuming, but can provide a quality teaching/learning tool that can be shared with other educators and institutions. The use of the CDs in particular requires availability of sufficient computing hardware, which many students have problems with.

Many students find the video and CD prelabs stimulating and feel better prepared and more confident after using them. Student scores on labs with video or CD prelabs are slightly better are not statistically significantly different to those without. However, the measures used to test for effects may not be sensitive to the changes. Finally, our aim has not been to replace the traditional ‘wet’ lab, but to facilitate our students making the best use of it.

Further Reading

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Photograph of workshop participants

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