Why Should On-line Experiments Form Part of University Science Courses?

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Introduction

Just as in government, it seems that there are always "buzz words" in teaching. In many Western countries the present favourites include "Lifelong Learning" and "Distance Education", reflecting the view that education should be universally available to students, irrespective of age and location. The importance of Lifelong Learning and Distance Education is apparent in an increasing number of articles published on these issues, and a bias in European Union funding devoted to research into them. Much progress has been made in recent years; one might (perhaps cynically) suggest that an increase in the number of published papers is an inevitable consequence of increased funding, but the growing interest in these areas is also a consequence of a widespread recognition that they are areas of genuine importance.

The principle catalyst for the expansion of distance learning has been the evolution of the Internet. Internet-based learning can take place anywhere, provided that access is provided to a computer, telephone and modem, and such access is, of course, now common in the Western World. If learning is to be effective, there must be suitable teaching material available on-line, but most scientists are computer-literate, and many have been quick to develop web-based material. As a result, the quantity of on-line science tutorials, databases and auxiliary materials, such as interactive periodic tables, is now very considerable. Because of the ease with which subject matter can be "published" on the Web and the general lack of peer review, on-line material is not always of the highest quality. However, there is much which is accessible, authoritative and well-constructed, and the quantity of this in scientific areas is now such that one could study substantial portions of a chemistry degree course entirely on-line.

It is inevitable that distance learning will continue to grow in importance as access to the Web broadens. Web-based material offers advantages in speed of delivery, flexibility and cost, and schools and universities will increase their use of electronic information because of this. However, a crucial ingredient is missing from on-line science: there is almost no opportunity for students to carry out experiments - as opposed to interact with simulations - through the Internet. In subjects such as physics and chemistry, which are inherently experimental, this is a serious limitation.

To develop the broadest possible understanding of science, it is important that students can experience the practical side of the subject, even if they have no direct access to a laboratory. The Internet offers the chance for remote learners to study the principles of science on-line, but it can also provide the means by which they can carry out practical work. Similarly, the Internet will allow practical courses for those students who are taught in more traditional surroundings to

be enhanced. The potential and practicalities of experiments conducted over the Internet form the topic of this article.

The need for on-line experiments

We shall start from two assumptions:

- that carrying out real (as opposed to simulated) experiments can materially enhance understanding for students, so practical experiments should whenever possible be a component of science courses; and
- that the Internet provides a convenient and effective medium by which experiments can be made available to students.

Our view in this article is that Internet-based experiments are entirely feasible, and that they offer a range of significant advantages. A subsequent paper will discuss the software implementation of on-line experiments, and the details of how they may be integrated into a traditional practical course.

Of the two assumptions given above, we shall not try to justify the first - that experiments can enhance scientific understanding. Science is based upon experiment, and while it is entirely possible to study fundamental areas of science, such as quantum mechanics or nuclear physics, without ever completing an experiment, in even these areas theory is generally tested by comparing theoretical prediction with experimental results. Universities and colleges recognise implicitly the value of experiment by making practical courses an integral part of their degree courses. It is reasonable to suppose that experimental aspects of science do not somehow become of lesser importance if the course is delivered remotely. It follows that experiments are of as much educational value to distance learners as they are to traditional, university-based learners.

The second assumption, that the Internet might provide a suitable medium through which to conduct experiments, requires more justification. Although the Web was not designed to support interactive experiments, the rapid increases in speed of network communication now offer the possibility of carrying out sophisticated experiments, and a later article will show how effective the Internet can be as a medium for the delivery of on-line experiments.

We will not discuss individual experiments in detail here, but will present some of the reasons why, in the near future, universities, colleges and schools may find it desirable to use the Internet to enhance their practical courses.

Advantages of Internet-based experiments

Internet-based experiments offer advantages to both learner and institution; we consider here some of the more important benefits.

Access to experiments for remote learners

Many students study university or college level courses remotely, perhaps because they have a job and are unable to enrol as full-time students, because they lack the necessary qualifications, or because they find part-time study more attractive than a full-time course. The Open University in the United Kingdom, and equivalent institutions in other countries, have a very large constituency of students, illustrating how attractive such remote courses are.

At present, home-based students can carry out only a limited range of (generally unsophisticated) experiments at home, although these may be supplemented by an occasional residential stay at university, during which experiments which require more substantial equipment may be performed. The Open University recognises the value of experiment in many of its excellent science courses by both providing kits of experiments which science students can use at home, and by offering university-based summer schools at which students can undertake experiments which are not possible at home. If it were possible for these students to carry out experiments through the Internet, there could be a significant increase in the range of experiments which they could perform. In addition, experiments which require sophisticated equipment could be integrated into the course in a more timely manner, and performed by students when the relevant theory was being studied, rather than having to be carried out during a residential summer school, when theory and experiment might be separated by several months.

Expansion of university and college practical courses through the sharing of experiments

At most universities the practical courses in chemistry are, especially in physical chemistry, a compromise. There is an (often substantial) wish-list of experiments which those running the course would like to offer. A somewhat smaller number makes up the list of experiments which can actually be provided. Time, space, finance and available expertise may serve to limit the number of experiments which can be made available to students, and at almost every institution there are experiments which, while educationally valuable, cannot be offered. A small number of students may visit neighbouring universities to carry out experiments which are not available in their home institution, but this kind of sharing is difficult to organise, and is of benefit only if co-operating institutions have courses which do not overlap excessively.

If experiments are available through the Internet, instead of students going to the experiments, the experiments can come to the students. The range of experiments can be increased, and, if an experiment which a department is unable to provide themselves is available remotely, the practical course can be expanded at negligible cost.

Avoidance of duplication of equipment

In chemistry, and also in physics, identical or similar experiments are found in the undergraduate practical courses in many different universities. A glance at the contents of practical courses in physical chemistry in the United Kingdom suggests that most chemistry undergraduates have the chance to measure the high-resolution infrared spectrum of HCl and DCl, the visible spectrum of gas-phase iodine molecules, the enthalpy of combustion of an organic solid, the kinetics of an iodination reaction and so on. Every university has its own slant on the chemistry practical course, but there is much overlap between courses at different universities.

This is to be expected. The HCl/DCl spectrum is a valuable way of illustrating selection rules, the determination of molecular parameters from spectroscopy, the effect of temperature on spectra and more. Experiments which are effective at illustrating the lecture course at one institution are likely to be of similar value elsewhere. However, when so many institutions are running similar or identical experiments, a considerable duplication of equipment is inevitable. One might regard this duplication as an inefficient use of resources, made more difficult to justify by the fact that much equipment purchased for undergraduate chemistry courses is used moderately during term-time, but hardly at all out of term.

Sharing of resources amongst universities is - at least in chemistry in the United Kingdom - at a low level. This need not be so. If nearly identical experiments and equipment are used in two or more institutions, could not both experiment and equipment be shared through the Internet?

There are of course experiments for which this might be difficult or undesirable. For example, it might be important that students be present as measurements are made, so that they can learn how a spectrometer actually operates; students might need to perform some preliminary part of the experiment, such as the synthesis of DCl before a spectrum can be recorded; unwanted complexity might be introduced into experiments by the need to provide remote access; it may also be difficult for a student to modify the procedure for an experiment if he or she has no physical access to the equipment.

For these, and other, reasons, it is unlikely that departments would want to run all or even most of their experiments through the Internet, but a class of experiments, outlined below, are eminently suitable for on-line operation.

At a time when universities and colleges are under considerable financial pressure, the chance to maintain or expand the practical course, but at the same time to reduce its cost, should be attractive to many.

Access to equipment in remote or hazardous locations

Much fascinating science is observed only under extreme conditions. The interaction of subatomic particles in nuclear physics experiments is an obvious example, but there are also examples in chemistry, where studies of reactions at high temperature, under high pressure or under conditions of zero gravity tell us much about the way molecules behave. The conditions required for these experiments may be difficult, dangerous or expensive to create, but this in no way lessens the value of the experiment. Indeed, sometimes extreme conditions are most effective in testing and validating scientific theory.

If students can rarely visit other universities to carry out experiments, it is even more unusual for them to have access to the specialised facilities which would allow experiments under extreme conditions to be carried out. Remote access, however, brings with it none of the dangers which direct access might provide, and often the very nature of the extreme conditions makes this kind of experiment more interesting to the student. It can be challenging to get some students involved in the practical course, and the chance to perform experiments under exotic conditions may be just the sort of stimulus required to awaken the interest of such students.

Sharing of experiments between students

Group work is a valuable way of improving understanding and retention of information. In many universities, especially in the USA, group projects are a popular way to promote scientific learning, and in most universities a similar approach is taken in the practical course. Experiments are commonly performed by pairs or small groups of students, not only because this increases the number of students who can complete each experiment, but also because interpretation of data and the preparation of a report often benefits from students being able to discuss the experiment with their colleagues.

Such cooperation need not be limited to those working at a single site. Cooperation between students at different sites is becoming very much easier now that email is virtually instantaneous. If students have worked on the same experiment on-line, or have worked on different aspects of a single problem using an identical piece of on-line equipment, this kind of long-distance cooperation becomes a realistic option.

Ability to provide a more custom-built practical course for students

Laboratory space is limited, and so inevitably is the range of experiments which a given university can provide. In the lecture-based segment of courses many institutions offer a modular course which allows the student to design a course which (they believe!) best meets their own interests. It is more difficult to do this in the practical course, where the range of experiments may be smaller, and where typically the course may be strong in some areas of chemistry and weaker in others. There is not total agreement that modular chemistry courses are educationally preferable to courses designed along more traditional lines, but if a department believes that a wide menu of lecture courses is in the best interests of the student, they may feel that a broad spectrum of experiments is equally desirable. The augmentation of local experiments by the addition of a range of Internet-based experiments, widens the options available to students and allows a more personalised course to be built.

What kinds of experiments can be run through the Internet?

The advantages which Internet-based experiments offer are, I believe, substantial. The pressures to develop them, particularly financial pressures, are similarly strong, and it seems likely that there will be widespread access to web-based experiments within the next five to ten years. Indeed, considering the extraordinary rate at which the Internet has developed, it seems inevitable that such experiments will be pervasive within a few years. However, not every experiment is a candidate for on-line format, and we conclude with a brief consideration of the sort of experiment that could best be delivered over the Internet.

Some types of experiments are evidently poor candidates. It is possible to perform titrations remotely using an auto-titrator, but much of the educational value of performing a titration is learning the physical skills involved. Locating an end-point is easy if a machine does it for you. Furthermore, an on-line titration suffers from a potentially costly drawback, which will prevent many experiments from being made available on-line. Titrations consume chemicals, so on each occasion that an on-line titration is run there is an unavoidable cost to the hosting institution.

Furthermore, even if the cost of chemicals can be absorbed, a titration experiment cannot be run indefinitely without operator intervention - someone must ensure that stocks of chemicals are maintained. It is a simple matter to run an on-line experiment in such a fashion that only Internet connections from certain sites are allowed, but it seems likely that on-line experiments which consume significant quantities of reagent will not play an important part in practical courses for some time, and probably will always, when available, have restricted access.

Equally, universities may be reluctant to offer experiments in which mechanical equipment can be switched on and off by remote users. There is no difficulty in principle in arranging that a remote user should be able to turn on a vacuum pump, for example, but a pump may seize or overheat, and this clearly has safety implications.

Ideal experiments thus appear to be those in which chemicals are not consumed in any significant quantity, and which can safely be left running indefinitely at low or zero cost. Several types of spectroscopy experiments fall in this category, and are perhaps the most attractive candidates for on-line operation. IR or UV/visible spectra can be run on instruments equipped with sample changers, and MS (mass spectrometry) experiments on systems with auto-injectors. In addition, cyclic voltammetry experiments, some of which can be run repeatedly without a change in solution, can also readily be placed on-line at minimal running cost.

An on-line experiment at Oxford University, currently being upgraded by the installation of new software, is used to generate data for use in an experiment on error analysis[1]. The experiment, which is spectroscopy-based, has no moving parts, and can operate continuously without any operator intervention. The detailed implementation of this experiment is to be the subject of a later article.

On-line experiments are in their infancy. Like everything connected with the Internet, they are likely to become a routine part of teaching much earlier than one imagines. They may well also have a rather different form in five years from what one might at present envisage. In whatever form they appear, their widespread adoption seems inevitable, and close at hand. In view of the considerable advantages they offer, those of us who are involved in the teaching of practical physical chemistry should welcome their arrival.

Reference

1. Cartwright, H. M. (1998) Long-distance experiments: The use and control of scientific equipment through the Internet, in *New Network-based Media in Education*, University of Maribor, Slovenia, 102-106.

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