FINAL REPORT FOR A 1998 NATIONAL TEACHING DEVELOPMENT GRANT (INDIVIDUAL)

IDENTIFICATION

Name of Project Leader(s)

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Project Title

"Demonstration experiments in the lecture room environment"

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10 Key words or phrases that describe the project

Lecture room demonstrations, miniature spectrometer, fibre optic probe, computer simulation.

NTDG (Individual) 1998
Demonstration experiments in the lecture room environment Executive Summary

The major objective of this project was to improve the teaching of the advanced level subject of chemical spectroscopy at the University of Queensland. The project developed a way to use the existing lecture theatre projection facilities to show real, rather than "virtual", spectroscopic experiments during a lecture. This was based on a miniature spectrometer interfaced to a laptop computer. The specifications and performance of this instrument are detailed in the full report.

The project has developed;

a) A portable miniature spectrometer that is interfaced to a laptop computer.
b) The ability to display the spectrum on a lecture theatre projection screen.
c) A number of appropriate teaching demonstrations were developed, used and evaluated. These included 2 first year, 3 second year and 3 first year lecture demonstrations.
d) The resource will continue to be available and developed for many years.

Since the miniature spectrometer has only become commercially available in the year that this project was proposed (1997), it is possibly the first time that such a portable system has been evaluated for education purposes. It was quickly found during the project that it could easily be used in many other subjects, even those not directly involved with spectroscopy. The major strengths of the resource were found to be:

- Portability, especially for lecturers who already use a laptop to deliver their lectures. Demonstrations could be made with minimal additional preparation required. This contrasts with other multi-media displays which often require special trolleys, etc., and this encourages the resource to be used.

- Extreme sensitivity and speed of the detector enables both weak phenomena to be demonstrated and real time changes (<0.1secs) to be observed.

However, it was found that there were also drawbacks to the system, the main one being:

- The difficulty of making routine absorption measurements. At this stage this requires either a doubling of costs or a tedious use of light source attenuation and filters to prevent detector saturation.

As learning outcomes the students have:

- Seen the relevance and gain a deeper understanding of the lecture material by observing a concurrent experiment;
- Witnessed scientific method in progress;
- Seen "real" experiments, rather than virtual simulations or animations;
- Gained knowledge of the technologies and methodologies used.

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Demonstration experiments in the lecture room environment
Final Report

Justification and educational rationale

In the physical sciences, experiment plays a central role in the development of deep learning. Experiments are particularly effective in aiding students with a non-mathematical background to understand the concepts in subjects such as chemical spectroscopy. There are constraints of time and access to equipment, which prevent students from conducting historically and conceptually important experiments for themselves. Consequently, students;' exposure is limited to either superficial experiments, computer simulations or textbook descriptions (1, 2).
This project addressed this problem by developing an educational resource that allows critical experiments to be performed in the lecture theatre at the same time as the concepts are being introduced. Students can be guided through conceptually dense experiments in a step by step process. The lecture demonstration of important experiments removes the necessity of expensive equipment and costly infrastructure as well as reducing the pressure on practical sessions where students' time is better spent on experiments more appropriate to individual study. A by-product is that students are able to observe scientific method in progress. Such training is essential if they are to continue on to research-based careers in science.

Target student group

Chemical spectroscopy is traditionally taught within a framework that requires a high level of mathematical ability. This is contrary to the fact that the concepts do not require a high level of mathematical understanding. While the traditional mathematically-based methods of teaching this subject has merit to those students wishing to continue to postgraduate chemistry, these methods may not be appropriate for the average chemistry student. This has resulted in a decreasing number of students who are willing to tackle a subject that is perceived as difficult. Initially this project was directed tat these students. The target group was 18 third-year science students that are currently enrolled in CH304 (Spectroscopy: Molecules and Solids). However, during the course of the project it was realised that the spectrometer was also well suited for use in other first and second year courses for particular demonstrations outlined in the following sections. This included 14000 students in a first year course (CH140 Chemistry 1A) and 60 students in a second year course (CH231 Chemical Spectroscopy and Molecular Structure).

Technical soundness: (What worked and what didn't)

The project was built around implementing the miniature spectrometer. A brief description of its operation follows (3). Light enters an optical fiber and is transmitted into the spectrometer, collimated by a spherical mirror, diffracted by a plane grating and the resulting diffracted light focused by a second spherical mirror. An image of the spectrum is projected onto a linear CCD array detector with 2048 elements, and the data is transferred to a computer through an interface card. Exact specifications are given in appendix 1. Additional information, including an animation of this process can be found at : *http://www.oceanoptics.com/specanim.asp*

The following demonstrations have been tested.

First Year Demonstrations

1) Line spectra of the elements. A favourite demonstration is the "glowing pickle', where a high voltage is applied via electrodes to a pickle (4). The pickle glows bright yellow due to the emission of excited Na atoms. This demonstration illustrates that an atom can change electron configurations by the absorption or emission of light. As it stands the students are asked to accept that the yellow light corresponds to a very well defined wavelength corresponding to the energy different between excited and ground states. By using the spectrometer this can be clearly seen in the spectrum is a single spike. This can lead on to a discussion of how different elements are very wavelength specific and that this forms the basis of an extremely important analytical technique, atomic absorption spectroscopy.
2) The energy levels of the hydrogen atom (5). This particular demonstration needs a hydrogen discharge lamp. One was available at UQ from no longer used practical. Some 6 spectral lines of the Balmer series of the H atom are in the spectrometer's range. From the first 2 members the students are asked to derive a value for the Rydberg constant. From this they can predict higher members in the series. This is especially effective as the spectrum must be "zoomed" to see the higher members and students are quite excited to be able to accurately predict a spectral feature ("hey, the equation works!").

Second Year Demonstrations

1) *Line spectra of the elements 1*. The "glowing pickle" demonstration is repeated, but here are series of pickles that have been soaked in different alkali salts are used. (The same result can be obtained with by using lighted solutions of methanol with the different salts dissolved, but pickles tend to have a bigger impact with students). The shift in the main transition to longer wavelengths is observed on going from Na, K to Rb. This can be related to the increasing atomic number of the atoms. Also it can be explained that each of the intense lines observed is actually a pair of closely spaced lines split by "spin-orbit coupling". The individual lines of Na and K cannot be resolved on the spectrometer, but the two lines can just be resolved for Rb. This also demonstrates the increase in spin-orbit coupling with atomic number. It is noted that the resolution of the spectrometer can be increased by using a smaller diameter fibre optic (1nm for 25 um fibre is specified).
2) *Line spectra of the elements II*. Here the spectrum of the fluorescent lights can be measured which sows sharp lines. The spectrum can be compared with the spectrum generated from a mercury calibration lamp. The exact correspondence of spectral lines identifies these atomic transitions in fluorescent lighting. This illustrates the generation of the white fluorescent light from the lower pressure Hg in the fluorescence tubes.

3) *The spectrum of a laser*. When discussing the properties of lasers, nothing is effective as showing their special property of being light at a single wavelength as actually displaying it. This can be achieved with a simple red laser pointer. The width of the laser line can be compared with the Hg lines in the fluorescent light spectrum. One can discuss the limitations of measuring the spectrum of laser using a spectrometer, leading to a discussion of interferometers.

Third Year Demonstrations

1) *Frequency response of the human eye*. In this demonstration a silicon diode detector is attached to an oscilloscope and the results projected on to the lecture room screen. A light source is directed through a mechanical chopper wheel into a student volunteers' eye. The frequency of the chopper is varied until the perception of flashing disappears. There are two important sets of concepts addressed in this experiment. First, the frequency response and sensitivity of the human eye is compared with an electronic device. "Frequency response" and "quantum efficiencies" are abstract concepts which students grasp more readily when they are applied to something familiar. The second set of concepts relates to the chemical dynamics of the molecule "retinal" in the mechanism of vision. The students are introduced to terms like "potential energy surfaces" and "excited state conformational change". Again these are difficult concepts which are made easier when related to the relaxation of retinal which limits the speed in which the eye can detect changes in light intensity.
2) *Blackbody radiation:* Two blackbody radiation curves are measured. The solar spectrum can be measured one by pointing the fibre optic towards a window. Students can note deviations from a smooth curve caused by absorption of various atmospheric gases. A second black body curve can be obtained from turning off the fluorescent lights and detecting the spectrum of the down lights in the lecture theatre. (These are typically incandescent lights). Here students can note the very different spectra of fluorescent and incandescent lights. Students will compare the spectra with curves derived from classical and quantum mechanics. An estimate of the temperature of the sun and of the light filament can be easily obtained.
3) *Photochemical reactions:* A solution of methylene blue is photobleached with a red laser pointer (6). The bleaching can be monitored by measuring the absorption through the solution at the laser wavelength. The concepts of photochemical reactions and their technological importance are illustrated.

Administrative convenience

The principal reason for the success of the laptop spectrometer is that quite sophisticated experiments can be made with minimal pre-lecture preparation. The display projectors are in all major lecture theatres and in most other rooms used for lectures in the Chemistry Department. Typically a lecturer will already be using a laptop in lectures, so the demonstration can entail very little organizational overhead. In 1999 the department invested in a portable display projector so that the laptop spectrometer can now be used in any room.

Evaluation
Evaluation of the use of the laptop spectrometer has been both qualitative and quantitative involving both students and colleagues. Much of this is still on-going as the resource will continue to be used for many years. Student opinion has been solicited both informally and through evaluation questionnaires, designed with the assistance of the Tertiary Education Institute at the University of Queensland. The overwhelming response has been favourable.

Personally I can add these comments. The miniature spectrometer has only become commercially available in the year that this project was proposed (1997), the basic design had previously only been available as an internal board in a desktop computer. It has been a great learning experience for me. I found that many of the uses I originally envisioned were impractical. The measurement of simple absorption spectrum was actually quite complicated. This was due to the single beam nature of the measurement: a background spectrum of the light source had to be measured first, then the transmission spectrum through a sample was then converted into an absorption spectrum. This would have pedagogical value for an advanced class in illustrating the meaning of an absorption spectrum. However as a general technique it is impractical as the detector is too sensitive with a relatively limited dynamic range. This required filters and careful attenuation of the to light source to keep the detector from saturating. One solution would be to purchase two spectrometers to run as a double beam instrument, but this effectively doubles the price. I have concentrated on emission experiments where the instrument performs extremely well. As advice to others considering using such an instrument, I would see our instrument further developed to i. Include some demonstrations that take advantage of the ability to measure spectra in milliseconds i.e. the kinetics of a fast chemical reaction. ii. Higher resolution by using a smaller core fibre.

Means of dissemination
Besides general advertising within the department of its availability, the laptop spectrometer was also used in the recent Uni-Expo. Here it was used to display the spectra from chemi-luminescence reactions and generated interest in departments outside Chemistry. In late 1998 the project was discussed amongst attendees of the 2^{nd} Royal Australian Chemical Institute 9RACI) Physical Chemistry Conference.

Appendix 2 Laptop spectrometer specifications

There are many different options available for instruments of this kind. One can choose different gratings, detector and sampling optics depending on the region of the spectrum and resolution that is of most interest. A discussion of some possible options can be found at the site: **http://www.oceanoptics.com/**

The options used for this instrument is a compromise between price and educational objectives.

Spectrometer model:	Ocean Optics S2000-11-15
Spectral range:	250 – 850mm
Detector:	2000 pixel silicon CCD array, UV enhanced Well depth: 160,000 photons Sensitivity: 86 photons/count Integration time: 20 milliseconds to 60 seconds
Sample Optics:	High throughput collection lens, 200um, 2 metre collection fibre. Wavelength resolution: -10 nm
Interface card:	DAQ-700 (National instruments) 12 bit, 16 channel, 100 kHz PCMCIA card.
Light source:	Integrated tungsten lamp, coupling optics and cuvette holder.
Laptop:	Toshiba 300CDS, Pentium 133, 64M RAM, 2 x PCMCIA (type II) slots

Note: these specifications are subject to rapid change.\

Persons interested in purchasing a similar device should especially be aware of the availability of suitable software and upgrade paths.

Appendix 3 Willingness to be contacted for advice.

I am willing to share my experiences with anyone who wishes to implement a similar resource.

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Appendix 4 References

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