Extending the science curriculum: teaching instrumental science at a distance in a global laboratory using a collaborative electronic notebook

Final Report 2013

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http://altc.ourexperiment.org/

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List of acronyms used

ELN	Electronic laboratory notebook
Hg	Mercury
AA	Atomic absorption
HPLC	High performance liquid chromatography
URI	Uniform resource identifier
ACELL	Advancing chemistry by enhancing learning in the laboratory
Course	A unit of study in a program leading to the award of a degree
UNSW	The University of New South Wales, Sydney, Australia
USYD	The University of Sydney, Sydney, Australia
Curtin	Curtin University, Perth, Australia
Chiang Mai	Chiang Mai University, Chiang Mai, Thailand
S'o'ton	University of Southampton

Executive summary

The project demonstrates how a communal web-based ‘electronic hub’ facilitates teaching chemical laboratory experiments across universities.

All outcomes are contained in the web site: http://altc.ourexperiment.org/

The project addressed how, in the coming decades, we will be teaching instrument-based science and undertaking collaborative learning activities, and also addressed issues of delivering a curriculum over the web. Utilising virtual access to key equipment for remote students provided scope for them to connect with local students, thus allowing them to fully engage with the practice of modern science.

The goal of this project was to develop a framework for the incorporation of laboratory-based teaching into a global web-based undergraduate tertiary curriculum. The framework provides science educators with the tools necessary to implement an undergraduate course in the analytical sciences across two or more institutions, located within the same country or across international borders. The project brought together academics and students from five universities across three continents.

The successful implementation of an undergraduate laboratory course across institutions requires a suitable set of experiments. A centralised electronic hub (the ELN) to take the role of the traditional course manual, for the recording and dissemination of results, and posting of discussion and reports is also essential, as is a suitable assessment framework.

For some collaborations a full course may not be essential but rather the opportunity to “cherry pick” particularly well-crafted experiments to complement/supplement an existing course may be the desirable outcome.

An unexpected bonus of the experiment development for this project was the realisation that more traditional synthetic experiments may also be delivered via a collaborative web based laboratory course. This can be carried out either by having local and remote students prepare analogues of the same basic compound, and then provide a collaborative interpretation of the data obtained. Alternatively the various cohorts can develop different approaches to a specific synthesis which is then collaboratively analysed to develop the “best” guidelines for synthesis.

The ELN chosen for this project was LABTROVE which was developed by the group of Professor Frey at the University of Southampton, and supported by UK and European grants. The requirements for an electronic hub are that: it is easily accessible and easy to use by all students and mentors on a range of different platforms; that it is secure; that it is able to manage files in many formats and that it has a secure archival component. LABTROVE meets all these requirements as well as cross references of entries and tagging files/posts with metadata (date/time stamps/recorded or blog poster/maintains a history of changes or edits) to enable verification of the validity of any uploaded/posted material. An additional electronic requirement of the project is that any instruments that generate data for any experiments are able to "blog" their raw results directly to the ELN. The code to carry out this process has been developed as part of a data archiving project at UNSW funded by a grant to UNSW from the Australian National Data Service (ANDS).

The experiments need to be deliverable to a global cohort regardless of the location of the equipment, students and their mentors. This report contains several exemplar experiments that show how the traditional laboratory experiments can be adapted for global use as well as two exemplars of more open ended synthetic experiments/projects that could be used as the basis of collaborative undergraduate research. The experiments on the analysis of caffeine in drinks and mercury in fish are based on the more traditional laboratory experiments and provide examples of experiments that can be done at one location with the results loaded to the ELN and the results used by all. If several institutions that can measure mercury levels are involved in the course then the additional possibility of obtaining data for mercury levels in different parts of the world become possible, with comparisons of results and resulting cross-cultural discussions. The measurement of the extinction coefficient of an organic dye is an example of an experiment that can be done remotely by the entire cohort with results able to be discussed by all. The synthesis of substituted porphyrins and the resolution of chiral drugs are more open ended experiments and provide scope for each institutional group to work independently, or collaboratively, for the synthetic preparations and then come together via the ELN for a discussion of the outcomes.

As part of the project we have explored various options for the assessment of student outcomes. It was necessary to address this issue, as each academic institution involved in a course of this nature may have differing assessment criteria and differing cultural requirements for assessment. The more traditional experiments lend themselves to the traditional assessment schemes based on closeness to the "correct" answer and responses to interpretive questions based on the data/results obtained. The more open ended experiments posed more of a problem in that there is no "correct" answer but rather a set of data (yields, measurements of spectra etc.) that are then interpreted by the cohort. The assessment thus comes in two parts – an experimental competence component, to be assessed at the institutional level, and an interpretive component, to be assessed at the course level. Assessment at the local level based on an agreed template, with scope for variations due to local requirements appears to be the model. This spreads the assessment load and also involves the local staff in all the assessment process.

The project has not addressed the issue of cross institutional enrolments and costs. It has been assumed that the costs in materials for experiments are borne by the individual institutions and would not be additional costs, as the experiments would be operating under the normal course structure. Indeed material costs per institution would be expected to drop as the number of in-house experiments is reduced as a result of the cross-institutional sharing of results. The time cost associated with managing the course and in assessment is also not anticipated to alter significantly. Host institutions offering a greater share of experiments in a course might anticipate a greater share of academic mentor time in responding to student enquires and providing guidance for assessors, however this is expected to even out and be no greater that if a course was completely 'in house'.

Table of Contents

Figures

Chapter 1 The Project

Project Outcomes and Rationale

The project delivers a kit of instrument-based experiments in science (focused in chemistry) that can be undertaken collaboratively over the internet by undergraduates at a home and remote location. The project development team comprised staff from five universities on three continents. Outcomes are a peer-reviewed curriculum of collaborative science experiments, with associated instructional material for staff and students.

The project outcomes have been disseminated in the scholarly domain through conference presentations and peer-reviewed papers, in addition to face to face discussions with interested academics. Publication of the process of setting up collaborations to utilise the outcomes of the project will be forthcoming.

Rationale

The science graduate of the future will be expected to know not only the basic scientific principles of increasingly complex instrumental methods, but how to operate in the IT-enabled world, with laboratories sharing not only information but access to instruments across continents. This project set out to explore the ability of the Web 2.0 environment, specifically 'electronic laboratory notebooks' ELNs, to accommodate the way we will practice, and teach the practice, of science in the future. As well as the physical benefits of giving a student access to a wider range of current scientific practice, the project offers a solution to: a) needed improvements of how we introduce students of science to our professional community, and b) how to better align student practices with those within the science discipline, particularly with respect to how information is made available and how information and communication technology (ICT) frameworks within institutions of higher education are structured.

Modern science relies greatly on complex instrumentation for its data. The use of instruments, such as mass spectrometers, astronomical telescopes and synchrotrons, must be taught, and this activity is a major part of a modern university science curriculum. The lack of access to instruments is not just a problem for institutions in developing countries; no university has every possible instrument. For example there is just one synchrotron in Australia. All modern instruments have the potential to communicate via the internet, but as many are restricted to a local intranet we are yet to realise the full use of instruments remotely. We believe that this kind of internet delivery is a positive force for collaborative curriculum development.

Team members (S'oton, UNSW) developed and trialled an ELN with postgraduate research students. From our experience we know that ELN technology can be used as:

1) repositories of experiments and associated data at the level of an individual researcher (a science blog),
2) a means for groups to share and discuss inferences drawn from experiments (e.g. members of a research group can be connected to each other).
3) a data repository with instruments 'pushing' data into the ELN so that data is accessible regardless of location.

The Project harnesses recent advances in ELNs to deliver a curriculum to benefit undergraduate students from different locations and backgrounds.

Background to e-learning in science

We are rapidly leaving paper-based research behind, with collaborative technologies, the online environment, and electronic laboratory notebooks replacing their non-electronic counterparts. Some areas of science were 'early adopters' of collaborative technologies, and were first seen in the early 1990s (Olson et al., 2002). From the late 1990s, research into global problems like climate change and epidemics such as HIV/AIDS exploited collaborative technologies out of necessity. Olson et al (2002) explained that by the start of the 21st century not all communities were ready for these technologies and that for a successful collaboration there needed to be: a) collaboration readiness (where participants are willing to share information), b) collaboration infrastructure readiness and c) collaboration technology readiness (including adequate technical support). Like any valuable discussion, a level of momentum within the collaboration, derived from the willingness of the participants, is essential for success. This particularly true for the academics involved in the collaboration as a change in staffing of a course can often lead to significant changes to the course with not all changes being for the better.

Given that much of the instrumental data generated in science is in digital format, it would seem that moving to operating in the electronic collaborative environment is a relatively easy step. There are a number of factors that are delaying the natural progression of such collaborations (Quinnell et al., 2009): 1) despite changes to legislation to allow electronic records, organisations often dictate that researchers log their experiments in a paper laboratory note book; 2) the scientific community and the instruments they use are diverse so there is no single solution for all research and 3) because tertiary science education is usually conducted in a highly modular fashion, we are not providing our students with sufficient training and opportunities to participate in collaborations.

Electronic laboratory notebooks

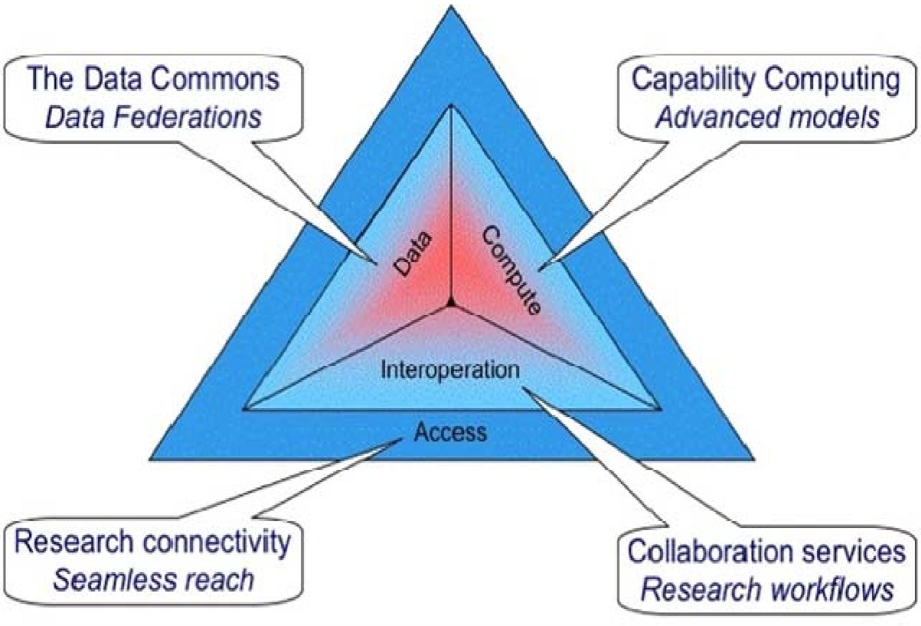
The project is fortunate to have had access to the ELN developed for research in chemistry from the University of Southampton. The Southampton Blog ELN was developed by working research scientists to be as flexible and simple as possible. Blogs are seen as a good analogy of the traditional laboratory book. The user is presented with a blank sheet, which is not really different from a fresh page in their laboratory book. Unlike the ELNs that have been specifically designed for a single type of research (e.g. myTea, (Gibson et al., 2005)), the S'o'ton ELN has been designed with great flexibility to accommodate a range of

experimental approaches and instruments, by adding tools such as cross-post linking, templates and attachment of data. Current research user groups at Southampton University and UNSW include crystallography, analytical chemistry and biotechnology. A blog platform for the ELN has a bonus in that the ELN enables those who wish to partake in open science, to publish their research at source (Neylon, 2007).
The drivers to support implementation of ELNs are:

- The ELN acts as a digital repository to archive digital and digitised experimental data with the data having a life beyond that of the researcher.
- All data and annotated experimental details are security time and date stamped (through a unique URI), and can be linked to related blog posts through meta data tags. Annotations are searchable for easy retrieval.
- Because the ELN is web based it is straightforward for the institution to be responsible for the host server. A wider rollout of the ELN to allow shared access by different teams of researchers is simply a matter of creating accounts that can be accessed by the user's university credentials. Obtaining access for staff and students outside the lead institution could be a problem if accounts are restricted by the University administration to official members of the institution .

How the project supports ALTC, institutional and national priorities

This project primarily addresses ALTC **Priority Three**: "Innovation in learning and teaching, particularly in relation to the role of new technologies". The use of an electronic laboratory notebook is an innovation in learning and teaching, as will be the curriculum developments that follow from the proposed methodology. The problem here is not just creating and using new technology, but how it can be integrated into a new approach for teaching tertiary science. The traditional teaching style of 'one experiment' 'one laboratory' 'one or two students' on 'one afternoon', no longer mirrors or prepares future researchers who will work in teams that may be distributed around a building, country, or even the world. Using scientific instruments is arguably becoming easier and more automated (this is not without its risks), but the increasing amounts of data create their own challenges, along with how to communicate results and formulate the understanding that comes from those results. The 'new technology' in this proposal is an electronic laboratory notebook that is accessed from the internet and is coupled with instrument computers. The innovation comes from our realisation that students need to be taught how to use this technology, and how to collaborate with colleagues via the web.



Scheme 1: Basic functionality of eResearch Infrastructure in Australia (see http://www.pfc.org.au/bin/view/Main)

The project has addressed institutional priorities, for example, the UNSW Graduate Attributes: “a capacity to contribute to, and work within, the international community”, “the skills involved in scholarly enquiry”, and “the skills required for collaborative and multidisciplinary work” (Director of Learning and Teaching, 2008). In addressing these attributes it contributes to two of the three ‘Key priorities’ for enhancing the student learning experience, namely: “Embedding graduate attributes into programs” and “Improving the quality of both informal and formal learning spaces and the virtual learning environment” (Marshall, 2008).

Australia, like most nations with a scientific capability, is considering how best to promote research at a national and international scale and how to enable this through modern technologies. The scheme (Scheme 1) is from the National Collaborative Research Infrastructure Strategy (http://www.pfc.org.au/bin/view/Main) which shows the need for services that support collaboration and connectivity among research groups. There must be educational initiatives to back up these priorities.

Relation to other studies

The project is a direct descendent of Kennedy’s seminal study “Educating the Net Generation” (Kennedy et al., 2009).

In the Australian chemical community a long-running project ACELL: Advancing Chemistry by Enhancing Learning in the Laboratory (Jamie et al., 2007) has developed a number of undergraduate experimental projects first in physical chemistry, and now across all of the chemistry sub-disciplines. It has been sponsored by the Royal Australian Chemical Institute, and requires new experiments to be peer reviewed to meet specified educational objectives. Experiments developed in this project meet the guidelines for submission to ACELL.

There are several projects around the world that offer virtual experiments. In particular, The Center for Authentic Science Practice in Education based at Purdue University allows such access to a number of measurement instruments (The Center for Authentic Science Practice in Education, 2004), and MIT has operated a microelectronics *Web lab* since 1998 (Ableson, 2005). With regard to the MIT project, the iLab project at The University of Queensland (see http://icampus.uq.edu.au/projects/ilab/) was an initiative centred on engineering and physics to allow its own students access to experiments over the web via Web 1.0 technology. The aim is primarily to provide access to equipment, through essentially 'learning modules'. This was a useful first step and addressed technical issues of accessing equipment remotely.

The present project, which relates to modern analytical instrumentation, is a carefully constructed pedagogical exercise to quantify the benefits of remote experimentation through collaborations of students (and staff), across selected Australian and international campuses. We have realised that the aspects of student interaction through the electronic laboratory notebook, and staff understanding of the power of collaboration, are as important as the hardware. The ALTC project is fully Web 2.0 compliant with the ability for instruments to blog into the electronic lab notebook, and users to share ownership of data.

Driving change in the curriculum

The project outcomes will stimulate changes in the science curriculum by

1. Making instrumental data available to a group of students through the internet addressing the perennial problem of the apparent disconnect between theory (given in lectures) and the practice of science (done in the laboratory). The data and the collaborative discussion are made the focus of the teaching, from which supporting theory naturally arises.
2. The approach allows teachers to put in context the needs for secrecy and protection of IP, and openness and the sharing of data and ideas. Neylon writes "At its logical extreme Open Science includes making all the science we do freely available *as it happens*. Many people find this scary. Some, perhaps a growing number, find it tremendously exciting." (Neylon, 2007)
3. In documenting the ELN implementation process we have been able to ascertain that the ELN can enhance student-teacher (and student-supervisor) communication. As we are moving more and more to *open access* for all information, it is critical to document and disseminate how our practice as educators changes, so that we do not become lost in the new technology.

Dissemination

Dissemination is an integral aspect of the project both to publicise the product and to publish the scholarly outputs. Since the beginning, the ELN has been open to public discussion and scrutiny.

A product of the project has been a network of instruments that can blog their results (yes – instruments can have their own blogs) to be available for appropriate cohorts of researchers (students and their teachers). Now established in the partner universities, they can continue and be added to, and the guides for participants will be available to other groups that wish to adopt the curriculum. We have allowed observers, anyone with web access to have access to the blog, in keeping with the approach of 'open science'. There is a public forum for discussion, and the project team are providing resources for sister networks to be set up. Evaluators – the project team, the reference group and other selected interested people – have access to all the blogs.

Uptake of the approach outlined in this report by so-called "second generation innovators" (Southwell et al., 2005) will include other traditional laboratory based sciences such as physics and biology. Because there are few sciences that do not teach how to use measuring instruments, and do not rely heavily on global collaboration, we expect that, for example, medicine (pathology), psychology and the social sciences to follow.
Global dissemination has been facilitated via a world-wide forum, namely the International Year of Chemistry (IYC) which was held in 2011. Two project leaders (DBH, JF) are involved with the International Union of Pure and Applied Chemistry (IUPAC), and the Chair of the Chemistry Education Committee (Professor Peter Mahaffy, King's University, Edmonton, Canada) is a member of our international reference group.

Scholarly aspects of the project will be published in the peer reviewed literature and have been presented at national and international conferences in both the education and science sectors.

Approach

Description of the program

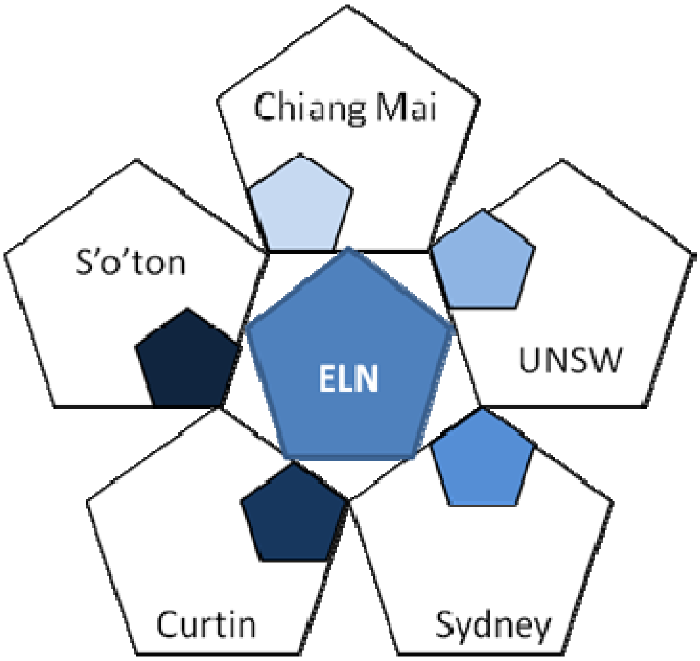
Five undergraduate science experiments have been set up that are based on instrumental measurements and collaborative research practices. The instruments have been configured and operated locally, or (where possible) over the internet, and deliver results into the electronic laboratory notebook. Cohorts of students at each site were recruited.

As well as performing the experiment in a local group (whether physically or virtually, synchronously or asynchronously) the students were asked to then collaborate over the internet (via the ELN) to arrive at a whole group consensus of the results. Scheme 2 shows the original concept of the ELN as the electronic hub linking each of the five sites. As the project developed, practicalities of time zones and university sessions led the experiments to operate in a bipartisan mode between pairs of universities.

The aims of the project were addressed by:

1. The electronic laboratory notebook as home for the experiments (communicate with the instruments and receive data, host the individual student notebooks, allow access for appropriate groups)
2. An infrastructure of a network of instruments that communicate over the internet that can be accessed by different cohorts (students and staff, staff, evaluators, public).

3. Undergraduate students who were recruited for the project.
4. Protocols for carrying out rounds of experiments



Scheme 2: Five universities offering an experiment for local students and over the internet

Electronic laboratory notebook (ELN)

The project used the ELN blog developed by team member Frey at Southampton University (Frey, 2004), where it is being used by a number of research groups (Coles et al., 2006). It is presently also being used in UNSW by a group of chemistry honours and postgraduate students. Installation of the ELN site requires a suitably configured, secure server. Institutional IT departments maintain such servers for enterprise wide services such as e-mail, academic administrative functions, institutional web sites and so on. The software is written in php and java using a blog scripting language and the IP is owned by Southampton University. UNSW has an agreement with J Frey who offered a Creative Commons-style licence for University use of the ELN. The ELN is very easy to deploy and use. Most students are aware of blogs, and the site follows popular conventions for posting and commenting on posts, with the addition of meta-tags and some facility to preview uploaded files (picture formats, pdf etc). Posts can be edited but not deleted and all use is audited. Each post is time stamped and a unique URI is generated with information about the post. An associated QR code and barcode is also generated from which the post can be retrieved. Although not used in the present project, the barcode can be pasted into a report and then scanned by a marker with tablet or smart phone to retrieve the full electronic record. The system is flexible and a new user can be instructed in its use in less than an hour. In fact students simply used the ELN, with the greatest problem being to set up an Open Access ID and login. Instruments can have their own blog. In this mode, whenever an instrument generates data that is stored in a designated folder on its computer, a copy is automatically sent to the ELN, together with relevant metadata. This can be accessed remotely by a group of suitably designated users like any other blog.

The ELN used for this project was hosted by the University of Southampton. Each institution had access to the ELN, and experiments were given their own blogs. A company (Labtrove) has been established to provide set up help and support for the ELN and is linked to the Frey group at Southampton. Future sustainability and transition to new forms of collaborative technologies will be facilitated by this.

Network of instruments

The choice of instruments was finalised in the first stage of the project. Modern instruments are almost all connected to a computer, and laboratories are usually connected to the internet. To interface an instrument computer to the ELN is a matter of installing a small piece of code that causes new data arriving into a folder to be pushed to the ELN. At present a potentiostat at UNSW, and several spectrometers and X-ray diffraction instruments at Southampton are connected to their respective blogs.

As well as instrument data, it is also possible to download environment data (temperature, humidity) from the instrument room. Already at Southampton, anomalous data has been attributed to failures in air conditioning, recorded during the experiment.

Undergraduate students

Each university established a plan to recruit students to the project. The ELN experiment can be incorporated as part of an existing undergraduate course, or as an elective summer program. At UNSW a third year analytical chemistry course “Advanced Instrumental Analysis” (CHEM6041) has instrumental experiments (HPLC, Cold vapour atomic absorption spectrometry) that have been identified as project experiments. Where the experiment was done outside a course, students were recruited from the appropriate cohort (e.g. 3rd year chemistry students) and suitably remunerated (included in the budget).

Assessment of student reports of experiments

The team developed an assessment approach that addresses issues raised in the James et al paper (James et al., 2002), particularly ‘assessing group work’. We developed assessment tasks that are common across the institutions while allowing for local assessments that address specifics of the local courses. Teachers from each institution graded the whole cohort, allowing cross cultural information about expectations and assessment policy to be obtained.

Protocol

1. Questionnaires were constructed and manuals and protocols written for the students.
2. The ELN was established, connections made to the institutional instruments and generic accounts created – usually via OpenID accounts. (Note – as of 2014 OpenID will no longer operate, being replaced by generic Facebook and Google ID’s)
3. The international reference group were consulted and signed off on the experiments.

Steps in conducting a round of experiments:

1. Set up internet connections and ELN for all participants (including reference group, evaluators and public access)
2. Test experimental protocols.
3. Perform experiments. (Note this was usually asynchronous. One experiment was performed in one location and data analysed over a two week period.)
4. Assess practical reports, survey students and staff.
5. Analyse results. Discuss changes in experiments. Prepare for next round

Dissemination

The dissemination strategy is outlined above. Here follows a list of dissemination activities.

- A resource kit for new groups to use the technology, including code, manual and information on trialled experiments. There will also be resources for the administration of courses using the technology.
- A resource for training teachers who are planning collaborative activities via the ELN.
- Publications in the peer reviewed literature covering the education sector and the scientific domain (e.g. in chemistry: Journal of Chemical Education, Chemistry in Australia).
- Conference presentations: including ALTC, RACI, IUPAC.

Deliverables and Outcomes

1. The documentation for students who perform each experiment. This includes manuals, electronic templates for results, and explanations of expected data analysis.
2. Resources in the form of kits (mostly electronic) for teachers, and course organisers who will adopt the technology, web pages, and publications.
3. Expensive scientific resources will have been effectively shared providing an example of good practice for future collaborations.

Scalability

In principle the collaborative on-line experiment can be participated in by any number of universities and students. Institutional servers are upgraded to accommodate the likely traffic and data storage requirements. Because the experiments are known in advance, the size of the ultimate database for the ELN (which would be mostly the instrumental data; text posts take up little space), can be calculated and allowed for when setting up the ELN server. For example at UNSW where we have solid institutional support, 250 GB was set aside for the ELN trial underway currently, with provision for future expansion.

There is no limit to the number of different institutional consortia that can be set up using the ELN technology, although in the project experiments were only conducted between pairs of universities. Each experiment needed one partner institution to host the ELN blog and provide infrastructure support, and others in the project group would provide experiment(s) and/or would be connected to the ELN. This approach favours helping smaller institutions and those in developing countries. Even if an institution did not have a suitable instrument to join the cluster, its students could still participate with only an internet connection. This was the case with Chiang Mai University.

Sustainability

Recent developments in nations' approaches to coordinating investments in science indicate that the outcomes of this project will be sustained.

The program developed in this project will be maintained by institutional input as universities develop institutional data repositories, supported by funding from Government (for example in Australia by the Australian National Data Service (ANDS) and the Australian Research Collaboration Service (ARCS) which operate under the National Research Infrastructure Committee (NRIC)). It is important that the project maintains alignment with national developments in this area (see Scheme 1 above). A dialogue has been maintained with institutional resources such as the library.

Chapter 2 The Experiments

Any experiment chosen for a course must pass certain criteria to be a 'good' experiment. It must meet the curriculum requirement of the course, it must provide the appropriate learning outcomes for the students and it must be technically accessible to the students given their skill set on entering the course. It must also be robust in that it does not require any idiosyncratic fixes to be able to run. They must also provide a known outcome. Open ended laboratory experiments must also meet these requirements although the 'known outcome' test is relaxed.

The following set of experiments meets the criteria.

Exemplar Experiments

UNSW has adapted two experiments for use in the global classroom. Experiment one involves the measurement of caffeine in drinks using High Performance Liquid Chromatography (http://altc.ourexperiment.org/caffeine). The caffeine experiment is one that is carried out at one institution with all students then collaborating to prepare a report(s). Experiment two involves the measurement of mercury levels in fish using Cold Vapour Atomic Absorption Spectrophotometry (http://altc.ourexperiment.org/Hgfish). The measurement of Hg in Fish could be run at one institution or several with local fish being used as the "unknowns". None of the three distant universities (Curtin, Chiang Mai and Southampton) have the facilities to measure Hg levels within their Chemistry sections.

The University of Sydney experiment is a non–instrumental experiment. Dr Todd is involved in a WHO project to prepare the chiral drug praziquantel for the treatment of the parasitic disease schistosomiasis. This is an Open Science project that is readily adaptable for undergraduates and gives them exposure to modern collaborative research practices (http://altc.ourexperiment.org/drugres). This experiment is non-traditional in that it does not fit into a fixed time period (3/4 hours). It would be ideal as a collaborative project for senior undergraduate students in a project lab environment. This experiment provides the framework for any "simple" research problem that mentors might like to use as a vehicle for the development of collaborative learning skills across institutional boundaries.

The Curtin experiment involves the synthesis of a number of substituted porphyrins and a comparison of the properties of these porphyrins (http://altc.ourexperiment.org/porphyrins). This experiment fits the traditional model of laboratory experiments in that it is done in a fixed period(s). The attraction of this experiment is that it allows for teams at each institution to prepare differently substituted examples and then draw conclusions about the effect of differing substituents. Again other classes of compounds, other than porphyrins can be used as the vehicle for the learning process.

The University of Southampton experiment is based an alternative method of measuring the molar absorption coefficient of an organic dye using laser spectroscopy (http://altc.ourexperiment.org/beer_lambert). Rather than the standard absorbance vs concentration measurement, the experiment measures absorbance vs path length. This experiment is an “on-line” experiment that can be performed remotely by all of the student cohorts. The experiment requires a solution cell, laser and camera as well as a computer to control the experiment. The instrument “blogs” the result of the experiment to the ELN. The student then downloads the data and analyses it to extract the absorption coefficient. While the remote ‘hands on’ experiment was not contemplated in the proposal we are very pleased to see this development. Extensions to this experiment could include use of different laser sources.

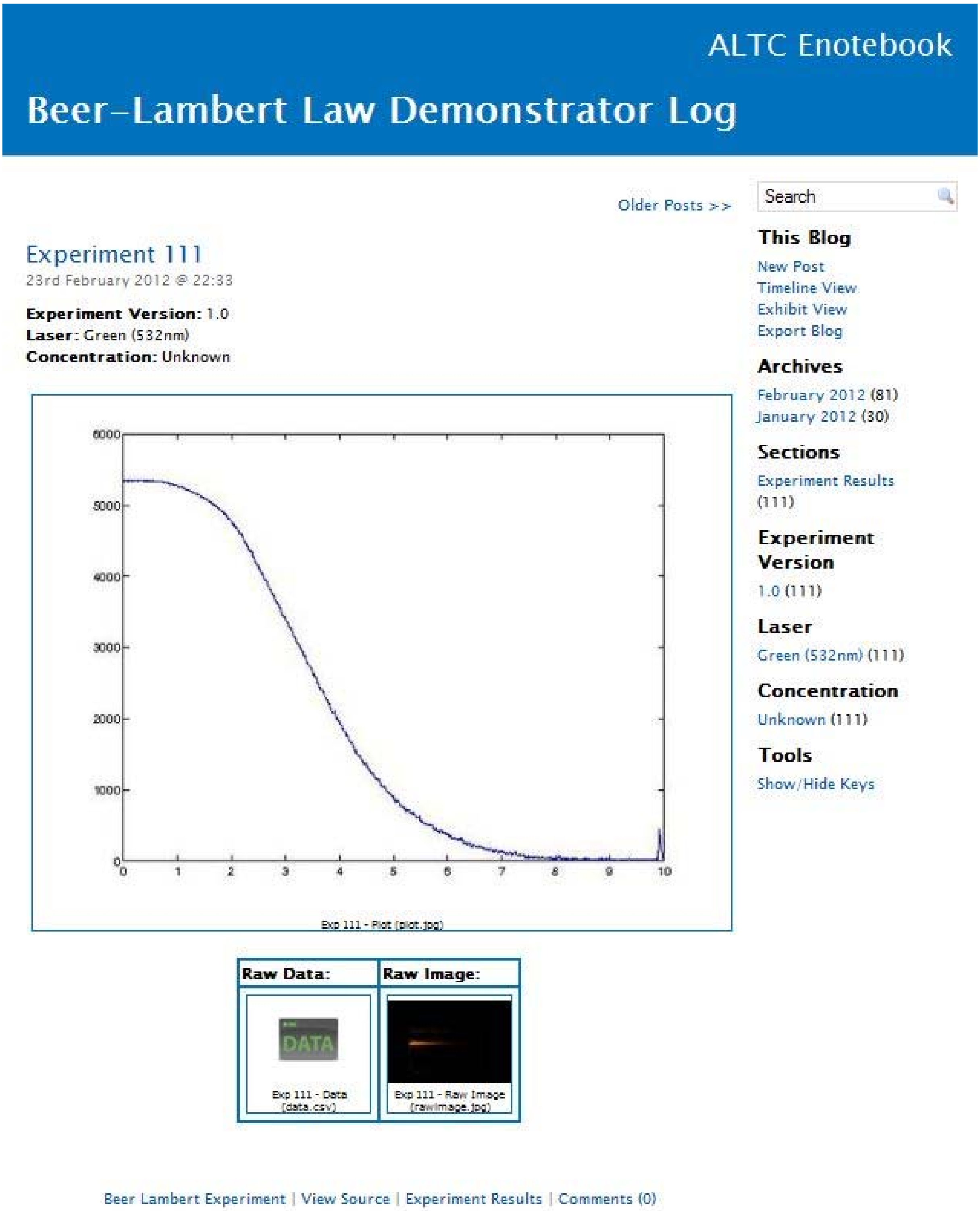


Figure 1: Screen shot of the Southampton experiment after running from UNSW. (24th February 2012)

Due to the serious ill health of the staff member from the University of Chiang Mai the anticipated experiment was not forthcoming.

Ancillary Student Documentation

The UNSW, Curtin and Southampton experiments are extracted or adapted from current undergraduate experiments. The documentation of these experiments has been modified to change site specific instructions to more general instructions with regard to the mechanics of the report preparation and any pre laboratory preparation required bearing in mind that the Electronic Laboratory Notebook (ELN) will be the repository for results and final reporting.

Site specific instructions that need to be altered are generally those that involve a face-to-face interaction between student(s) and mentor. As the students and mentors may be on different continents such interactions are not possible. We have modified the instructions to utilise the electronic hub as the 'clearing house' for these interactions. Students and staff can upload data, reports, questions etc which can then be commented on by both staff and students. The interactions can be almost simultaneous or may be delayed depending on the degree of physical and temporal separation.

The use of the ELN enables both raw and modified experimental data to be 'blogged'. This facility allows for review of all that experimental data by an assessor, in cases where misinterpretation of the raw data may have occurred.

The ancillary forms such as Risk Assessment/Safe Work Practices that are used at UNSW have also been made available to the team. These have been modified to again take into account the global nature of the experimenters. For example the normal practice for a risk assessment is that the laboratory supervisor must sign off prior to the students undertaking the experiment. In the global environment the student team will submit their risk assessment to the ELN and the experiment supervisor will be required to comment on the assessment prior to the students undertaking the practical work. Rather than students at remote sites preparing their own risk assessments, they will be asked to review the risk assessment and comment on it, indicating acceptance or highlighting any deficiencies noted. The meta data tags enable all such interactions via the blog to be appropriately attributed.

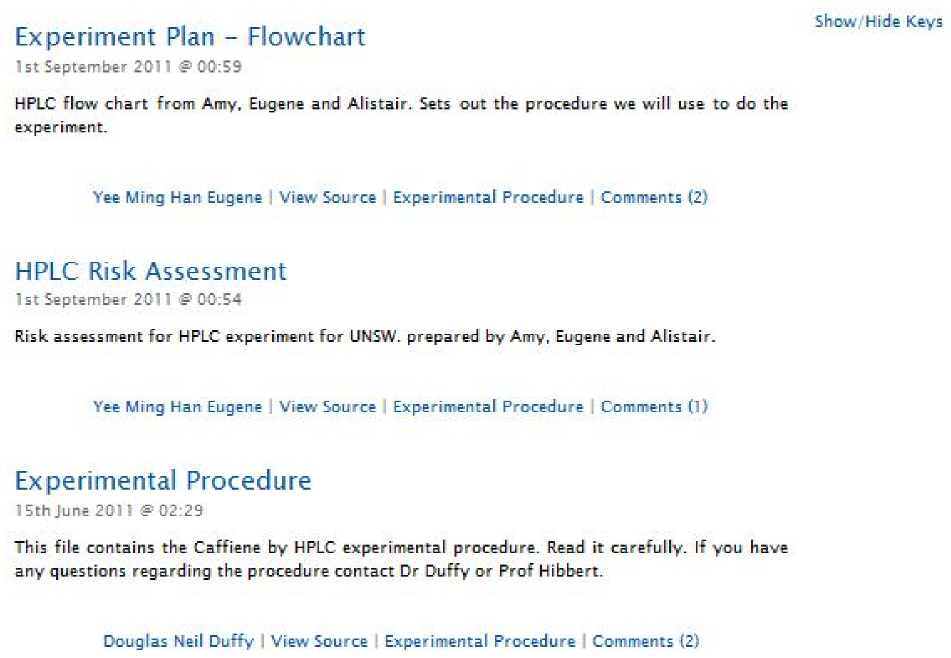


Figure 2: Part of the UNSW HPLC experiment page showing links to instructions and health and safety components. (Screen shot 24th February, 2012)

The University of Sydney experiment is somewhat different in that it is a research based synthetic experiment. This experiment requires the students to read current chiral resolution strategies and prepare an experimental plan for approval prior to carrying out an practical work. A process that is appropriate for any such 'research based' undergraduate experiment.

Ancillary materials such as notes on background theory and data analysis are being identified and uploaded to the ELN. For example the Southampton site has uploaded background theory (or links to the theory) for the measurement of the extinction coefficient of the dye making the experiment essentially self-contained within the ELN.

Ancillary Documentation for Teachers/Course Organisers

Potential resources for teachers and course organisers include; background theory notes, marking guidelines, templates for report preparation, pre laboratory quizzes (as appropriate) and templates for student feedback.

The marking guidelines for UNSW experiments have also been posted (http://altc.ourexperiment.org/) as a starting point for discussion as to how it is best to assess students in a global collaborative approach. Are the standard criteria appropriate or do we need to include other assessment tools/criteria. This aspect of the project is still under discussion and will be refined over the two rounds of experiments.

The experiment offered by The University of Sydney differs from the traditional synthetic undergraduate experiment in that the outcome is uncertain. The goal is to improve the selectivity of isolating one isomer of the chiral drug by utilising a matrix of resolving agents and solvent combinations. Thus all results will add to the body of knowledge and may point to the optimum conditions for the resolution. This will require a different set of marking criteria than an experiment which is expected to get a known result. The team is currently addressing criteria that may be used to judge student performance in such an experiment. Similarly the experiment being offered by Curtin falls into the "no correct answer" category. Marking of this report will allocate the bulk of the marks to the analysis and conclusions as to the influence of the substituted withdrawing/donating groups on the absorption spectra of the various porphyrins synthesised.

One other resource for teachers/course coordinators that has been identified as necessary is a course management tool. Most institutions currently use Blackboard, although Moodle is gaining some popularity. These are institution specific, in that some sort of ID specific to that institution (staff/student number plus password) is needed to access the system. Such a global course as proposed by this project will require a tool as part of the ELN or running in parallel to the ELN. As other tools are developed, cross institutional capabilities may be included. Until such time a 'manual' system needs to be utilised, or alternatively courses need to be created at each institution and they 'manage' their own students.

Assessing the Efficacy of the Course

Any such course is only as good as the perception of it by both staff and students. Statistical data on the student learning outcomes when performing collaborative science experiments at a distance as part of an undergraduate curriculum can be readily assessed. Specific questions that can be answered are

- Given an experiment that can be performed by local students or over the internet, what are the relative outcomes of each cohort in terms of marks and perceived learning experiences?
- What are the staff perceptions of experiments conducted by remote groups?
- What kinds of experiments give the best learning outcomes?
- How useful is the web-based electronic laboratory notebook in creating a collaborative environment for learning?
- Have the desired graduate attributes been addressed by this new technology? Is critical thinking and a rigorous approach to science supported by this technology?
- Is curriculum development enhanced?

Survey/questionnaire instruments to probe these questions have been developed <http://altc.ourexperiment.org/surveys>. In addition a survey has been developed for members of the broader scientific community to probe their thoughts on the use of a global approach to teaching science at a distance using an ELN. This survey was released to participating academics.

Chapter 3 The ELN

Electronic laboratory notebook (ELN)

The ELN has been set up at the University of Southampton and is the repository of documents, discussions and potential experiments. It is available at <http://altc.ourexperiment.org/ >

The ELN has several blogs. Several are for communicating and reporting amongst the research team and IAG. Each undergraduate experiment has been assigned its own Blog, with an additional blog acting as a centralised repository for more general documentation and instructions. The screen shot below shows the ELN as of 24th February, 2012.

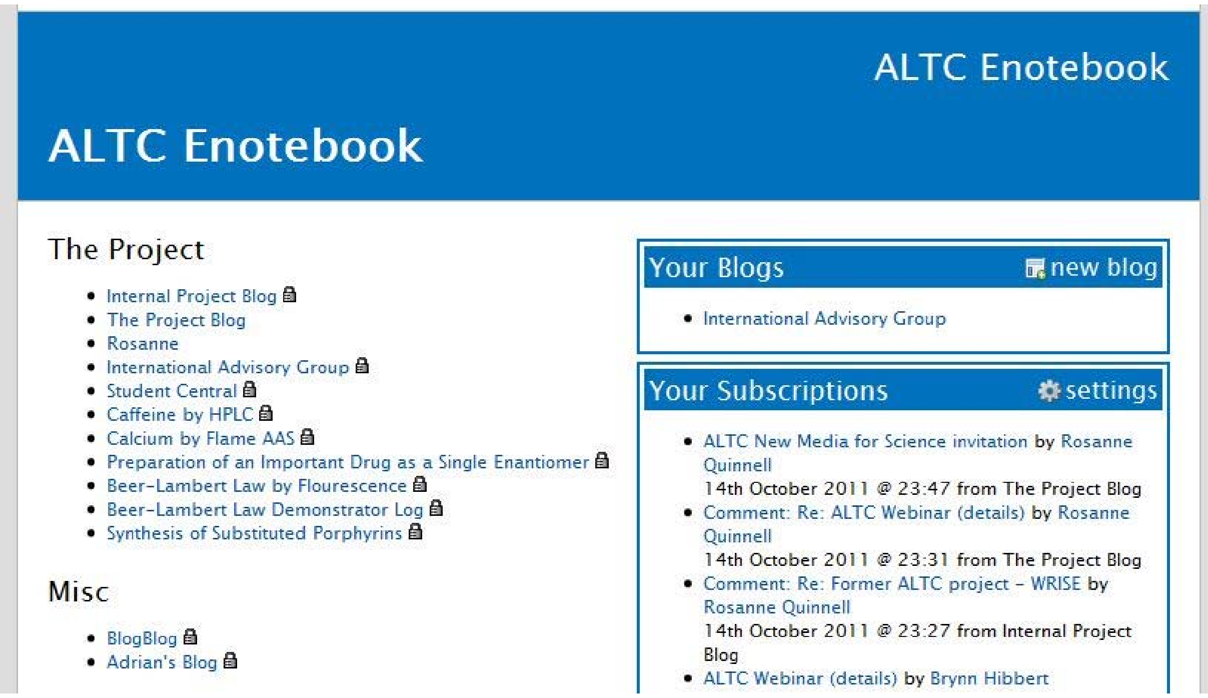


Figure 3. Screen shot of the front page of the ELN on 24 February 2012.

The blog entries with a lock have restricted access. This may be the project leaders, or students and academics, or personal entries. The others are fully accessible via the web.

The 'Student Central' blog takes on the role of course manual with general course management information, templates etc being located in this entry. Each experiment then has its own blog. Experimental instructions, theory notes, reside here. It is also the blog that students will interact with their mentors through for that particular experiment. Results, reports, risk assessments etc being uploaded to this page.

The 'BlogBlog' is an entry for reporting blog problems to the administrator of the ELN.

In the collaborative approach to these experiments we are requiring the student teams to submit a group report rather than the traditional individual report based on collaboratively obtained data. This raises the challenge of plagiarism and how we ensure that all students receive due credit. We have prepared statements as part of the general documentation which we hope will tackle this issue. In addition the meta data tags which will accompany each entry to the blog and also each modification allows for the tracking of 'who did what' for use in assessing the student contribution to the report.

As part of this project it became necessary to develop code to allow data to be sent from an instrument to the blog. Funds were secured from the Australian National Data Service (ANDS) to develop this code. The following outlines the outcomes of the development. More details of the data capture and integration project are available at <https://projects.ands.org.au/id/DC5H> .

ANDS is transforming Australia's research data environment to:

1. make Australian research data collections more valuable by managing, connecting, enabling discovery and supporting the reuse of this data
2. enable richer research, more accountable research; more efficient use of research data; and improved provision of data to support policy development

ANDS project DC5H: Data capture and integration across multiple platforms (UNSW)

Development of a web application (**ACData** application)
The specific objectives this project aims to achieve are;

- A data store and management system that will provide secure access to research data by one or many users.
- An application that will enable the ingestion of raw and processed data, including the capture of metadata, from a range of commercial instruments.
- Provide a structured, hierarchical framework for sorting and storing research data that is aligned with current research workflows
- Provide a set of tools for the import both metadata and data from a range of analytical instruments including, but not restricted to NMR, IR, Raman spectrometers, capillary porometers and digital slide scanners.
- A harvestable OAI-PMH feed that will automatically link with existing e-Research infrastructure such as the ARDC, MemRE and ELN.
- Methods for establishing enduring links between research data and publications.
- A service that allows the export of data from ACData to the ELN storage facility.
- A range of scripts that will allow the automated generation of meta-data and export of data from specific instruments to the ELN storage facility.
- Methods for comparing source data, exported from the equipment, with existing data in MemRE to encourage researchers to make data available to the research community

It is envisaged that the ELN will be able to accept data for which the metadata is sent to ANDS, and the results stored in the university repository (ACData). Undergraduates performing experiments with results being captured by the ELN will have the opportunity to participate in this scheme to store all the experimental data of the University in a single store. They will understand how data can be archived and used for future projects (tracking results over time), and will become part of the research nexus. One long-term example is the measurement of mercury in fish and hair. Over the years we have noticed that the levels of mercury have fallen as this element is withdrawn from industrial use (discontinued use in batteries, electrical switches, etc.). Having the data in a secure repository will allow future generations to revisit the experiments and chart the improvement of the environment with time.

Chapter 4 Integration into the Curriculum

A "How-to" guide for the administration of a global undergraduate course in the experimental sciences

For any program of study to remain current and useful, to those graduating from the program, it must be reviewed against sector standards and technological advances on a regular basis. Any decision to change must be for sound educational reasons and also within the resources of the institution.

The drivers for a global ELN based course may be financial or educational or both. Peer to peer academic collaborations may lead to the desire to implement change which might not otherwise be available. Increasingly academic institutions are partnering (eg Universitas 21, http://www.universitas21.com/) and utilising a global ELN based approach to teaching may be a way of cementing these partnerships at a department level and also enhancing the student outcomes of both institutions.

The following steps are a 'broad brush' approach to implementing a global course into an undergraduate curriculum via an ELN.

Step 0:
Review your current curriculum, to decide if there are any deficiencies or enhancements that need to be addressed. This would mostly be answering the question 'Are there additional areas that would strengthen the degree offerings?'. A positive response then requires additional questions to be asked – 'Within current budgetary restraints can these additional offerings be developed in house?'. If no then it may be possible to implement change by using cost effective collaborations.

Some deficiencies/enhancements that may be considered include - the development of collaborative learning opportunities, or the involvement of students in undergraduate research projects or it may be your course no longer meets the requirements of advancing technologies and you cannot foresee the development/deployment of adequate resources to incorporate the new technologies. Specific examples may be in the area of new analytical methods, which would require the purchase of expensive equipment and/or staff to teach in the area.

Step 1:
Once it is decided that your students and your institution would benefit from participation in a cross institutional undergraduate course, a suitable, and willing, partner needs to be found. From our experience the best partnerships develop where the partners are all committed to the goals of the shared experience. That is they all need to get something out of the relationship whether it be a new valid learning experience for students, a validation of the way that a technique is taught or simply satisfying altruistic needs in providing the best possible outcomes for all students, not just those of your own institution.

It is important that any interactions be two way. You will need to have something to offer to the collaboration and not rely on only receiving benefits. This may take the form of offering experiments from your own suite of undergraduate experiments or taking a mentoring role for experiments offered by the partner institution that you are not formally incorporating into your curriculum.

Again our experience is that initially these collaborations are best carried out on a two institution basis, usually managed by academics that already know and respect each other. A good working relationship between the participating staff is paramount to the success of any cross institutional course.

Step 2:
Once it is decided to undertake a global collaboration ensure that sufficient lead time is allowed to prepare for 'going live'. This will minimise any problems that may arise. The lead time will vary depending on what each institution has available already, and how much if any new material is required – hopefully this is minimal.

Agree on what you want to do, which experiments you want to incorporate, who will host the ELN, how many students will be involved, group sizes within the cohort.

Having decided which experiments you want to incorporate, it will be necessary to prepare ELN friendly versions. These may be complete files that mimic the traditional paper manuals or may be a series of on-line instructions. Instructions on how the data is to be managed, submission of reports, risk assessments, other assessment related tasks also need to be incorporated into the ELN. It is also essential that decisions on who is responsible for feedback and assessment be made, as well as a clear schedule of when the feedback will be made.

For experiments that take place at each institution such as the measurement of the distribution of an element/substance globally it is appropriate to have technical staff carry out a trail run of the experiment to ensure the results and procedures are as you expect.

For synthetic experiments that prepare a range of molecules whose properties are than measured, it must be agreed which properties are to be measured and discussed by students and also what methodologies are to be used for the synthesis prior to undertaking the experiment.

Step 3:
Implement the course and enjoy.

References

ABLESON, H. (2005) MIT Microelectronics i-Lab. M.I.T.

COLES, S. J., FREY, J. G., HURSTHOUSE, M. B., LIGHT, M. E., MILSTED, A. J., CARR, L. A., DEROURE, D., GUTTERIDGE, C. J., MILLS, H. R., MEACHAM, K. E., SURRIDGE, M., LYON, E., HEERY, R., DUKE, M. & DAY, M. (2006) An e-science environment for Service Crystallography - from submission to dissemination. *Journal of Chemical Information and Modeling,* 46**,** 1006-1016.

DIRECTOR OF LEARNING AND TEACHING (2008) UNSW Attributes. Sydney, UNSW.

FREY, J. G. (2004) Dark lab or smart lab: The challenges for 21st century laboratory software. *Organic Process Research & Development,* 8**,** 1024-1035.

GIBSON, A., STEVENS, R., COOKE, C. & BROSTOFF, S. (2005) myTea: Connecting the Web to Digital Science on the Desktop.

JAMES, R., MCINNIS, C. & DEVLIN, M. (2002) Assessing learning in Australian Universities.

JAMIE, I. M., READ, J. R., BARRIE S. C., BUCAT, R. B., BUNTINE M. A., CRISP, G. T., GEORGE, A. V. & KABLE, S. H. (2007) From APCELL to ACELL and beyond – Expanding a multi-institution project for laboratory-based teaching and learning. *Australian Journal of Education in Chemistry,* 67**,** 7 - 13.

KENNEDY, G., DALGARNO, B., BENNETT, S., GRAY, K., JUDD, T., WAYCOTT, J., CHANG, R., BISHOP, A., MATON, K. & KRAUSE, K.-L. (2009) Educating the Net Generation. Australian Learning and Teaching Council.

MARSHALL, S. (2008) Learning and Teaching enhancement plan, 2008-2012. Sydney, UNSW.

NEYLON, C. (2007) Science in the open.

OLSON, G., TEASLEY, S., BIETZ, M. & COGBURN, D. (2002) Collaboratories to support distributed science: the example of international HIV/AIDS research. *Proceedings of the 2002 annual research conference of the South African institute of computer scientists and information technologists on enablement through technology***,** 44–51.

QUINNELL, R., HIBBERT, D. B. & MILSTED, A. J. (2009) eScience: evaluating electronic laboratory notebooks in chemistry research. *24th Annual conference of ascilite.* Auckland.

SOUTHWELL, D., GANNAWAY, D., ORRELL, J., CHALMERS, D. & ABRAHAM, C. (2005) *Strategies for effective dissemination of project outcomes*. The University of Queensland and Flinders University

THE CENTER FOR AUTHENTIC SCIENCE PRACTICE IN EDUCATION (2004) Instrument Network. Purdue University