APCELL: The Australian Physical Chemistry Enhanced Laboratory Learning Project

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Abstract

The Australian Physical Chemistry Enhanced Laboratory Learning project was established to address the problem of falling student enrolments and continuations in Australian physical chemistry courses. The Project has pooled the resources of over 30 Australian universities (and several New Zealand affiliates) to establish a protocol for developing and assuring the quality of laboratory teaching experiments. Using a 'research-led teaching' approach an "Educational Template" was developed which ensures that contributions to the project are strongly learner focussed. In this paper we introduce the APCELL project, describe some of the approaches that have been employed in developing the project, outline important progress achieved to date, and discuss the interaction between APCELL and *This Journal.*

I. Introduction and Motivation

In late 1999, the Committee for University Teaching and Staff Development (CUTSD)* funded the Australian Physical Chemistry Enhanced Laboratory Learning (APCELL) project. The APCELL project was established to use the context of laboratory learning to address the problem of low intake and poor retention of students in Australian physical chemistry courses. One of the primary objectives of the APCELL project is to disseminate widely the results, outcomes and practical developments in physical chemistry laboratory exercises that are based upon student-focused pedagogical tenets. The rejuvenation of the Australian Journal of Education in Chemistry *(This Journal)* offers an ideal opportunity for APCELL to disseminate key aspects of its work, and for *This Journal* to present innovations in university chemistry laboratory teaching and learning, including rigorously tested chemistry experiments, to a wide audience.

APCELL officially started in January 2000. The project's genesis, however, can be traced back several years earlier to discussions between academics attending research conferences around Australia, concerning anecdotal evidence that an increasing number of students were finding their physical chemistry laboratory courses to be uninteresting and unmotivating. These informal discussions highlighted a widespread recognition amongst academics that students studying physical chemistry were not learning in the laboratory as well as they should, or could. While academics at individual institutions routinely attempted to improve learning in the laboratory, it was apparent that no single institution had been successful at overcoming the multiple barriers to learning. These barriers are those imposed by limited physical resources, limited specialist expertise, limited pedagogical expertise and limited active student involvement in the learning process. It was agreed that a collective effort involving the resources of multiple institutions was required to overcome the problems and the idea of APCELL was born.

Such anecdotal evidence suggesting the existence of poor student perceptions of physical chemistry is born out by recent statistics published by the Australian Commonwealth Department of Education, Training and Youth Affairs (DETYA) [1] and the Australian Council of Deans of Science. [2, 3] The histogram in the upper panel of Figure 1 shows the total number of students enrolled in university degrees for the period 1983-2000 as reported by DETYA. [1] In this 18-year period total university student numbers have almost doubled from roughly 350,000 to approximately 650,000. The solid circles in the upper panel of Figure 1 report the total number of students enrolled in science-based subjects over the same 18-year period. The latter figures have been normalised to the total student enrolment numbers for 1983 in order to illustrate the relative increase in the proportion of students studying science, particularly since the mid-1990s. Over the 1983-2000 period the number of students studying science subjects has more than doubled, a rate of increase greater than that observed for overall student enrolments.

The lower panel of Figure 1 shows the percentage of students enrolled in four broad science disciplines,

* The activities of CUTSD are now assumed by the Australian University Teaching Committee (AUTC).

viz., the chemical, biological, mathematical and physical sciences for the years 1989, 1993 and 1997 (the years for which figures are available). [1, 2] For clarity, the percentage of students enrolled in the computing sciences (included in the upper panel of Figure 1) has been omitted. Over the 8-year period for which data are available, student enrolments in the biological sciences have increased from 30% to 40% of all students enrolled in science subjects. Conversely, enrolments in the mathematical sciences have decreased from 26% to 18% and enrolments in the physical sciences have decreased from 11% to 8% of all students enrolled in science subjects. The trend in the chemical sciences is less dramatic, with a decrease in fractional science enrolment from 17% to 15% over the 1989-1997 period. Chemistry is the "central science" and as such, it is not surprising that the chemistry trend is intermediate between the physical and biological data. In fact, "chemical science" not only falls between these two other categories, it includes them in sub-disciplines such as biological chemistry and physical chemistry. While data are not available at this level of detail, anecdotal evidence certainly supports the view that physical chemistry is under a greater threat from falling student numbers than is biological chemistry.

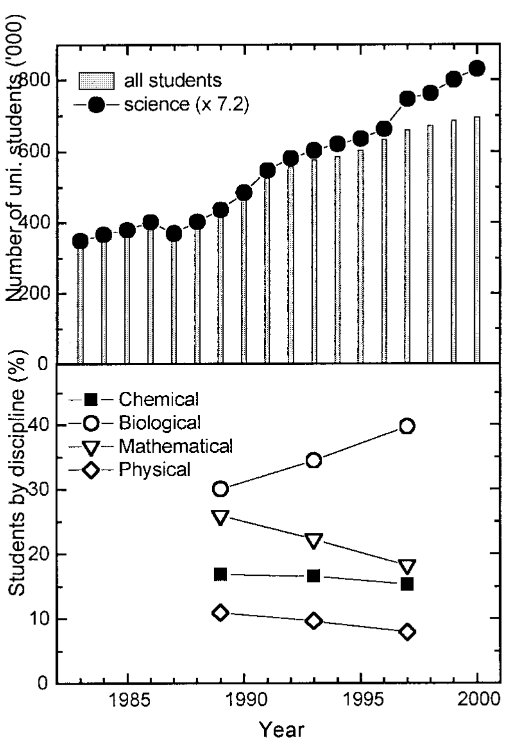

Figure 1. Total Australian university student numbers covering the period 1983 – 2001. The upper panel shows total student numbers and total students studying science (normalised to 1983 by multiplying by 7.2). Science numbers are increasing at a slightly faster rate than general numbers. The lower panel shows the breakdown of science students in four broad scientific areas. The data show the more "physical" and "mathematical" the science the greater the decrease in relative student numbers.

The motivations for students to move away from the mathematical and physical sciences towards the biological are complex and difficult to fully understand. There might be a perception by students at secondary school and university that jobs are more readily available and/or better remunerated in the life sciences. A recent analysis, however, does not bear this out. Employment rates are similar across all of these four science disciplines (mathematical sciences actually performing better), and salaries correlate in the other direction, favouring the more mathematical and physical sciences (Table 1).[3] These two trends, lower student numbers and higher salaries in physical science, might be related by supply-and-demand economic factors. Regardless, it seems clear that incoming students do not *perceive* curricula in the physical sciences as being relevant to them, nor is the wider relevance of such studies explained. It is therefore reasonable to contend that improved enrolment and retention numbers in physical chemistry can result from providing a better learning environment for students. The APCELL project has focused upon addressing one important aspect in improving student motivation and learning in physical chemistry – the student laboratory experience. Laboratory work is considered to be of great importance in the chemistry curriculum, yet research suggests that it may not achieve the desired learning objectives ([4, 5] and references therein). Students can often see the laboratory exercise as simply a task to be completed as quickly as possible, with the minimum possible effort [6], and this attitude can defeat any attempts to use the experience as a teaching and learning tool. Students may not see the relevance of the laboratory exercise to either the study they are undertaking or their experiences outside of the teaching institution. On the other hand, perhaps because the importance of laboratory work is taken for granted by academics, there are rarely any mechanisms in place to monitor the effectiveness of these courses. This is not to say that physical chemistry academics (including the authors) have been idle in rejuvenating and modernising physical chemistry laboratories. Such efforts, however, have met with limited success due to the constraints of limited time, and limited expertise or experience in pedagogy. The APCELL project is overcoming the resource constraints of individual chemistry departments by treating participating institutions as if they belong to one large department. The project has brought together, for the first time, diverse physical chemistry educational expertise and resources from across almost all Australian universities.

Table 1: Median gross annual incomes of full-time employed graduates within 10 years of graduating from a 3 year science degree. [3]

Major area of undergraduate Science degree	Median annual full-time salary (A$)
Mathematical Sciences	50,000
Physical Sciences	47,000
Life Sciences	45,000

During the course of the project to date the APCELL team (i.e. members from all participating universities, Appendix 1) has developed an "Educational Template", established a novel review process for submitted experiments and set-up an extensive database of experiments with full documentation. The purpose of this article is threefold:

i) to explain how and why these processes have evolved,
ii) to disseminate information about APCELL, and
iii) to explain the interaction between APCELL and this rejuvenated journal.

II. Research-Led Teaching and the Educational Template

'Research-led teaching' (RLT) and 'scholarship of teaching' are phrases that are being heard in discussions about teaching in Australian universities. [7, 8] The current focus on RLT exemplifies various trends and changes in Australian and international higher education. [9] The use of the term is, in part, a reflection of the increasing recognition of the scholarly and professional nature of university teaching as an added dimension to the disciplinary expertise of academics. The focus on RLT supports, and is supported by, a growing body of research literature on teaching and student learning. At a more pragmatic level the interest in RLT reflects a university strategy of building upon established research expertise and performance in the increasingly competitive teaching quality market. [10]

The term 'research-led teaching' has various meanings in different contexts. [11] Amongst other things RLT can refer to:

- **The use of disciplinary research in teaching -** for example, the use by a teacher of one of their current journal publications reporting a key piece of cutting edge research;
- **Teaching and curriculum that uses evidence derived from research and inquiry -** for example, designing a learning task on the basis of published education research or one's own inquiries into how students approach particular assessment tasks;
- **Research into teaching and learning -** for example, a research investigation into how students approach different learning tasks.

While the APCELL project can be described in terms of each of these aspects, it is primarily an example of the second category of RLT – a teaching and curriculum development initiative that is based on research. The methods employed in the APCELL project were selected on the basis of the research literature in the field of change management and academic development. [12] While there were numerous publications that espouse excellent practice in designing and teaching in laboratories, these do not appear to have had much influence on laboratory teaching practices. [13] The problem faced by physical chemists at the teaching coalface is that, in the main, they are discipline experts but not well read in educational research. Educational research, like any other field of inquiry, has its own language and methodologies that are not always transparent to those outside the field.

The project therefore planned to engage academics in reflecting on their own curriculum decisions about teaching and design of laboratory practice. [14] The project methodology identified the need to engage participating academics from the participating universities (see Appendix 1) at the level of their underlying ideas about teaching and learning, rather than at the level of teaching behaviours. The project aimed to use processes that would encourage academics to design their laboratory teaching from a learner-focused perspective rather than a teacher-focused perspective. This strategy required that the project start with the participants' own ideas and conceptions of teaching, even if these were teacher-focused, then reflect on, and challenge these ideas in developing the parameters for the laboratory curriculum design. The result is an "Educational Template" that bridges the gap between relevant educational research and practising teachers. The educational research that underpins the template and laboratory-based learning in particular has been described previously. [11]

Text box 1 shows the concise explanatory notes that now form the first part of the template. These explanatory notes (and indeed the whole template) are studded with concepts from the education research literature, but cast in a language and in a context that is more readily accessible for discipline-based teachers (physical chemists in particular). The full template is freely available at the APCELL web site. [15] It is not intended that the objectives or methods described in the template and accompanying documentation be prescriptive. In fact, users of the database are encouraged to adapt the APCELL experiments to suit particular teaching contexts and resources. Users should also be able to adopt the teaching approaches and strategies described in these templates to other experiments and other undergraduate laboratory teaching activities. Submitters of experiments are encouraged to take this into account and present options, alternatives and extensions wherever possible and appropriate.

The five sections of the Template, as summarised in the Text Box, present

(1) a general summary;

(2) an analysis of the educational objectives;

(3) student experiences;

(4) documentation and

(5) peer review criteria for acceptance to the database.

Section (1) provides a context for the experiment in terms of course objectives, student abilities, relevance to students' aims and interests, etc.

Sections (2) and (3) ensure that the experiments are focused on achieving high quality learning by students, by examining the experiments from the students' perspective. An important aspect of this process is documenting ways in which the outcomes of the students' learning experiences will be evaluated.

The intention of Section (4) is to make the implementation of the experiment as straightforward as possible by new users.

Section (5) encourages critical self-review prior to submission to the APCELL database.

Text Box 1:
Descriptive page from the APCELL "Educational Template". This page explains to the academic the rationale of the template to form a bridge between educational research and academic practice. See the APCELL web site for the full template. [15]

Structure of the Template

There are five sections to the template.
Sections (1) to (4) must be completed and peer reviewed prior to an experiment being included in the APCELL database.

Section (5) gives the criteria against which the assessment will be made.

Section 1: Summary:

This section provides general information that can be used as an overview of the experiment and to quickly determine how the experiment is relevant to a particular course.

Section 2: Educational Analysis:

The second section is a table that provides a clear description of the intended learning outcomes (i.e., what you anticipate that a student will learn by undertaking this experiment), a description of how this learning will be achieved and a description of how this learning can he monitored.

The *learning outcomes* might cover theoretical understanding, technical skills or generic skills and provide the basis for the learning outcomes that should be included in the student notes. The description of *how this learning will be achieved* contributes to both demonstrator notes and student notes. This section provides the basis for identifying what teachers and learners have to actually do in the laboratory in order for students to learn what is intended. The final section of the table describing *how the learning can be monitored* provides the basis for assessment criteria that could be used by demonstrators and students to monitor learning.

Intended learning outcomes and assessment criteria should be clearly given in both the student and demonstrator notes.

Section 3: The Student Learning Experience:

The third section presents evidence from students regarding the quality of their learning experiences in this laboratory. A summary should be given of the key issues identified through the student feedback questionnaires. As well as quality assurance evidence, the questionnaire used in this section provides a valuable tool for ongoing evaluation of teaching experiments in general.

Section 4: Documentation:

The fourth section contains the student, demonstrator and technical notes for the experiment.

Section 5: Peer Assessment:

The final section shows the criteria against which the submission will be peer assessed and should be used to self-assess your submission.

III. The Review Process

The review process for an experiment submitted to APCELL has also evolved with the project. This process is based rather heavily on the experience of the first Experiment Workshop held in Sydney in Feb, 2001. At this workshop 60 staff and students from participating institutions came together to engage in an inquiry into the student learning experience of the 30 submitted experiments. During the workshop both teachers and students participated as learners and both contributed 'learner' evaluation data to the inquiry into the experiments submitted. At all stages the methods of review were focused on overcoming the identified barriers to effective student learning in the laboratory. [16]

The experience from the workshop showed clearly to all participants the value and necessity of evaluating experiments in a hands-on, interactive environment. The workshop also reminded academics of what it is like to carry out an unfamiliar experiment, i.e. to adopt the role of a student. (Academics took their role as student very seriously and realistically duplicating the student learning experience - many did not read the practical notes beforehand!)

As a result of the experience of the first workshop, it was decided that experiments submitted to APCELL should be submitted to an extensive and rigorous review process. The first stage of this review involves the anonymous critical feedback of the submitted documentation from both an academic and student member of the APCELL team. The second stage involves the experiment being set-up (preferably in a different laboratory) and evaluated in the same hands-on, interactive, student-focused way as the experiments evaluated at the first workshop. This two-stage review process provides experiments that are a strong, student-focused, relevant learning experience, and that have been proven to be flexible enough to set up in more than one laboratory environment. It is an important part of the process that students are involved in the evaluation of the experiment. It is not always possible for academics, even with the best of intentions, to see an experiment from the perspective of a student, who does not bring with him or her the experience and preconceptions of an academic.

The experience of the first workshop has led us to investigate the possibility of holding more workshops, linked to existing conferences. This will allow submitters to have their experiments reviewed in bulk, and would reinforce the student-centred learning experience that was such a valuable outcome from the first workshop. To this end, a second experiment workshop will be held at the RACI Chemical Education Division Conference to be held in Melbourne in Dec, 2002.

A secondary, pragmatic, benefit of incorporating peer-review into the submission process is that it adds a degree of credibility to the process. This allows the submission of an experiment to the APCELL database to be recognised as valuable scholarly activity, thus providing a mechanism for acknowledging the important practice of reflecting on and contributing to teaching activities. This is further reinforced by the collaboration between APCELL and *This Journal*, discussed in section V.

IV. The APCELL Database

The most practical outcome of APCELL will be the database of reviewed and tested experiments. This database already exists and there are over 30 experiments somewhere in the process between submission and full review. Once an experiment is fully reviewed it is completely and freely available on the APCELL web site. [15] In addition to the Educational Template, supporting documentation for each fully reviewed experiment includes a set of student notes, demonstrator notes and technical notes to allow ready implementation into a new laboratory. Experiments that have not been completely reviewed are not freely available but the web site contains a complete list of all submitted experiments under review, including a brief description of each experiment, and the contact details of the submitter.

The APCELL project does not claim the copyright or intellectual property ownership rights to any experiment submitted for review and dissemination via the publicly accessible database. These rights remain with the experiment's originators and/or the submitters of the experiment to the database, as appropriate. The project requires that submissions for review and subsequent dissemination acknowledge the original sources of the experiment and any contributions that have been made in the experiment's development. If the origin of the experiment is, to the best of the submitter's knowledge, unknown, this should be clearly stated. The project requires that the submitter's Head of Department certify all submissions to the database to this effect, and acknowledge that all submitted material has been released to unrestricted public access.

V. Australian Journal of Education in Chemistry and APCELL

APCELL not only draws upon the results of previous teaching and learning research in terms of teaching and curriculum design, but the project methodology also uses the processes of scholarly inquiry into teaching and student learning. Moreover, the products of the APCELL project have the potential to generate and support further pedagogical research, which is the third category of research-led teaching described earlier. This third area of RLT falls outside the purview of the core business of the APCELL project as CUTSD funding specifically prohibits the use of funds to support educational research – the funds are intended to produce tangible products to assist better teaching and learning in universities. Because APCELL is naturally spawning educational research we have sought the proper vehicle for its dissemination and the cooperation between *This Journal* and APCELL was established to do this.

APCELL provides a very practical resource for physical chemists – the database of student-centred, validated experiments. These experiments are themselves not necessarily innovative or new. In many cases their heritage is completely unknown, and in others the experiment itself has been previously published. The innovation of APCELL is the RLT approach, as exemplified by the Education Template. Utilising RLT and student-centred approaches to an existing experiment can turn it from one where students are not motivated to learn (for a variety of reasons, e.g. lack of clear objectives, or lack of context), into one that provides a good learning experience. Publication is a peer-reviewed journal, such as *This Journal*, provides a mechanism for acknowledgment of such pedagogical activity.

This Journal will not therefore publish the experiments themselves (unless they have been created anew). However, the pedagogy of an experiment, as summarised by the Template, and aspects of the appraisal and review by academics and students, may be of significant interest to the chemical education community. In those cases, *This Journal* will consider publication of the educational research aspects of the experiment. Following this article is the first such publication. We hope it will be the first of many over the years.

VI. Other Areas of Chemistry

While this paper has been written in terms of the utility of the APCELL concept to physical chemistry, we believe that it is equally useful in all areas of chemistry, and perhaps more generally in any experimental science. It is the intention of the Directors of the APCELL project to, in the near future, widen its scope and accept submissions from across the full range of chemistry laboratory teaching programs. Further details of such expansions will be reported in *This Journal* as they occur.

VII. Conclusions

The APCELL project is bringing together academics from most Australian Universities to enhance the quality of laboratory teaching in physical chemistry. The project is built on sound educational research. Participants are asked to reflect upon the pedagogy of an experiment by being guided through an Educational Template. The practical outcome of APCELL will be a database of educationally sound and tested experiments available to all via the Web. New educational research spawned by the project will be published in *This Journal* and elsewhere.

VIII. Acknowledgements

The APCELL project is supported by a CUTSD grant and the contributions of the Chemistry Departments of the participating universities, in particular the Chemistry Department of Adelaide University and the School of Chemistry, and Institute for Teaching and Learning, of the University of Sydney.

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Appendix 1: APCELL Participants.

Staff and student participants in the APCELL project, together with institutional affiliations.

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